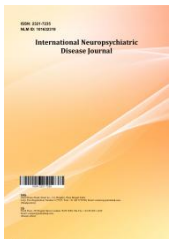

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Neurobiopsychological Foundations of Inspirational Teaching: A Critical Narrative Review of Empowerment, Meaningfulness, Agility and Sustainability

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Author's contribution

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Review Article

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Abstract

Descriptions of the "great teacher" as an inspiring figure are abundant in professional discourse, yet the biological and psychological processes that might underpin inspirational teaching, and sustain it across a working life, remain loosely specified. Interest in educational neuroscience has grown quickly, and claims about brain-based explanations of teaching quality now circulate well ahead of the evidence that would justify them. This review examines what is currently defensible about the neurobiopsychology of inspirational teaching, organised around four constructs that recur in the professional and empirical literature: empowerment, meaningfulness, agility and sustainability. Literature was identified through structured searching of open scholarly databases and indexes covering January 1995 to 12 July 2026, supplemented by backward and forward citation tracking and by targeted searches of institutional sources. Evidence was appraised for design adequacy, measurement validity, replication status and translational distance rather than aggregated quantitatively. Four conclusions emerge. Controllability and choice have well-characterised neural substrates, and the animal and human work on stressor controllability provides the strongest mechanistic anchor for teacher empowerment, although almost no study has measured empowerment and its putative neural mediators in the same teachers. Self-relevance and value affirmation engage ventromedial prefrontal and ventral striatal circuitry, giving meaningfulness a plausible reward-related basis, but the peripheral biological signature of eudaimonic well-being remains contested after a documented failure to replicate. Agility, as used in educational and organisational writing,

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conflates a measurable neurocognitive capacity for set-shifting with an aspirational professional disposition whose measures show weak discriminant validity. Sustainability is the best-evidenced pillar at the level of occupational outcomes and the least secure at the level of biomarkers, since burnout lacks a reproducible endocrine signature and overlaps substantially with depression. Interpersonal neural synchrony is an informative marker of joint attentional engagement in classrooms but has not been shown to cause learning. Priorities for future work include longitudinal designs linking instructional experience to allostatic indices in the same individuals, adequately powered classroom hyperscanning with preregistered analyses, and intervention trials that report physiological and occupational outcomes together.

Keywords: Educational neuroscience; teacher well-being; psychological empowerment; meaningful work; cognitive flexibility; interpersonal neural synchrony; occupational stress.

1. Introduction

Few professional judgements are made as confidently, or defended as loosely, as the judgement that a particular teacher is inspiring. The attribute is treated as self-evident by students and administrators alike, and it carries considerable weight in appointment, promotion and public commentary about educational quality. Its empirical status is far less settled. Quantitative work on teacher effects establishes that teachers differ substantially and durably in their influence on pupils, with value-added estimates predicting later educational attainment and adult earnings (Chetty *et al*., 2014), and with teacher effects extending to complex reasoning and social-emotional competencies that standardised achievement tests do not capture (Kraft, 2019). What that work does not establish is which attributes of the teacher generate the effect, and the tempting inference that the effective teacher is the inspiring teacher has not been tested directly.

Psychology has supplied a more precise vocabulary. Inspiration has been characterised as a discrete motivational state with three defining features: evocation, in that it arises unbidden rather than through deliberate effort; transcendence, in that it orients attention beyond ordinary self-interest; and approach motivation, in that it impels the person towards expression or transmission of the evoking quality (Thrash & Elliot, 2003, 2004). This tripartite specification separates inspiration from adjacent constructs such as enthusiasm, engagement and charisma, and it makes clear that inspiration is a state that is transmitted rather than a stable trait that is possessed. Educational research has developed the transmission side of the problem independently. Teacher enthusiasm has been unpicked into an experienced affective component and a displayed behavioural component that are only moderately related (Keller *et al*., 2016), and teacher enjoyment has been shown to covary with student enjoyment within lessons, with instructional behaviour mediating the relation (Frenzel *et al*., 2009). Affective teacher-student relationships predict engagement and achievement across the school years, with the strongest associations for negative relational quality (Roorda *et al*., 2011). More recent classroom evidence also indicates reciprocal transmission of same-valence emotions between students' perceptions of teachers' emotions and students' own emotions, supporting a bidirectional rather than exclusively teacher-to-student account of classroom affect (Li *et al*., 2025). A recent systematic review further indicates that the association between teacher motivation and teaching behaviour operates through heterogeneous intrapersonal processes, reinforcing the need to distinguish motivational states from their instructional expression (Lazarides *et al*., 2025).

Alongside these psychological accounts, neuroscience has been recruited into educational discussion with increasing frequency. The recruitment has not been uniformly disciplined. Neuromyths remain widespread among practising teachers, and exposure to general neuroscience content does not reliably reduce them (Torrijos-Muelas *et al*., 2021). Sceptical analyses have argued that neuroscientific data have not y*et al*tered any educational decision that could not have been reached from behavioural evidence alone, and that the field's translational claims routinely outrun its findings (Bowers, 2016; Howard-Jones, 2014). Others have defended a more modest role, arguing that neuroscience literacy changes how teachers conceptualise learning and their own professional agency even when it does not dictate specific classroom techniques (Dubinsky *et al*., 2013, 2022; Jolles & Jolles, 2021). A scoping review of translational work over the past decade found that classroom-facing studies cluster in a small number of domains, chiefly literacy and numeracy, and that studies of the teacher as a biological agent are comparatively rare (Fante & Manganello, 2026). Critical educational scholarship has gone further, describing the recent turn towards teacher well-being as a governance strategy that individualises structurally produced strain and dresses it in neuroscientific language (Wilkins *et al*., 2025). That critique deserves engagement rather than dismissal, and it frames much of what follows. Recent scoping work in interpersonal educational neuroscience likewise documents growing use of interaction-level neural measures in teaching-learning research while identifying continuing methodological challenges for their educational interpretation (Zhang *et al*., 2024).

Four constructs recur wherever inspirational teaching is discussed in policy documents, professional development frameworks and empirical literature: empowerment, meaningfulness, agility and sustainability. Each has an established research tradition. Psychological empowerment has been operationalised as a four-dimensional motivational state comprising meaning, competence, self-determination and impact (Spreitzer, 1995), with meta-analytic evidence linking it to job satisfaction, commitment and performance (Seibert *et al*., 2011). Meaningful work has been theorised as arising from several distinct sources rather than a single mechanism (Rosso *et al*., 2010), and orientation towards work as a calling rather than a job has long been distinguished empirically (Wrzesniewski *et al*., 1997). Learning agility has been proposed as a capacity to extract and apply lessons from unfamiliar experience (DeRue *et al*., 2012). Occupational sustainability has been examined principally through burnout research and its correlates in teaching populations (Maslach & Leiter, 2016). What is missing is a treatment that asks whether these four constructs share biological substrates, whether the evidence supporting each is of comparable quality, and where the resulting picture is coherent rather than merely convergent in vocabulary.

Existing reviews do not fill this space. Reviews of teacher well-being are numerous and increasingly systematic, but they are conducted almost entirely at the level of self-report and occupational outcome (Hascher & Waber, 2021; Ozturk *et al*., 2024;

Zhou *et al*., 2024). Reviews of educational neuroscience concentrate on pupil learning rather than teacher functioning (Fante & Manganello, 2026). Reviews of interpersonal neural synchrony treat the classroom as a setting for studying joint attention rather than as a workplace with allostatic consequences for one participant (Lu, 2025; Zhang *et al*., 2022). Organisational neuroscience has examined inspirational leadership directly (Boyatzis *et al*., 2012; Jack *et al*., 2013), but its methodological foundations have been criticised sharply and its findings have not been integrated with educational evidence (Lindebaum & Zundel, 2013). The four constructs are therefore reviewed in separate literatures that rarely cite one another, using measures that are rarely commensurable, and with levels of evidential support that are rarely compared. A subsequent systematic review also characterises recent teacher well-being research as conceptually and methodologically fragmented, reinforcing the value of integrative appraisal across levels of explanation (Gámez-Genovart *et al*., 2025).

1.1 Scope, Research Gap and Objectives

This review examines the neurobiological and psychological processes that plausibly underpin inspirational teaching and its maintenance across a career, organised around the constructs of empowerment, meaningfulness, agility and sustainability. The unit of analysis is the teacher as a biological and psychological agent operating within an instructional relationship, in compulsory and higher education settings. The review covers work-psychological, educational, affective-neuroscientific, psychophysiological and interpersonal-neuroscientific literatures, and it treats the teacher-student dyad and group as the relevant interactional context.

Several matters lie outside the scope of this review. Education for sustainable development, and the curricular treatment of environmental sustainability, are distinct subjects and are not considered; sustainability here denotes the maintenance of a teacher's capacity to teach well over time. Pupil-level neuroscience of reading, mathematics and developmental disorders is excluded except where it bears directly on instructional interaction. Pharmacological and clinical treatment of occupational illness is excluded. Leadership neuroscience is considered only where its methods and findings inform the interpretation of inspirational influence in instructional settings.

The specific gap addressed is the absence of an integrated critical appraisal that places the four constructs on a common evidential footing and states, for each, what is mechanistically established, what is plausible but untested in teaching populations, and what is currently unsupported. Reviews to date have either surveyed teacher well-being without biological measurement or surveyed classroom neuroscience without reference to occupational psychology. Neither approach permits a judgement about whether a neurobiopsychological account of inspirational teaching is presently defensible.

Four objectives follow. The first is to specify what inspiration denotes when treated as a transmissible motivational state rather than a professional accolade, and to distinguish it from adjacent constructs. The second is to appraise, for each of the four constructs, the strength and translational distance of the mechanistic evidence. The third is to evaluate interpersonal neural coupling as a candidate mechanism for the transmission of inspirational states in classrooms. The fourth is to derive an integrated account that separates established from hypothesised relations and to set out prioritised research directions.

2. Methods for Literature Selection

2.1 Review Design and Rationale

A critical narrative design was selected because the review question spans literatures with incompatible designs, measures and units of analysis. Occupational psychology contributes cross-sectional and longitudinal survey evidence with latent-variable measurement; affective neuroscience contributes small-sample task-based imaging; psychophysiology contributes laboratory and field studies of endocrine and autonomic indices; educational research contributes cluster-randomised trials and large observational datasets. No defensible common effect metric exists across these bodies of work, and a quantitative synthesis would impose a spurious commensurability. Narrative synthesis is appropriate where the analytic task is conceptual integration and adjudication among competing explanations rather than estimation of a pooled parameter (Greenhalgh *et al*., 2018; Sukhera, 2022).

Adopting a narrative design does not relax the requirement for transparency or appraisal. The review followed the quality domains specified for narrative review articles, including explicit justification of importance, statement of aims, description of the literature search, referencing of claims to appropriate evidence, and evidence-calibrated presentation of data (Baethge *et al*., 2019). Search concepts, sources, eligibility rules and appraisal criteria are reported below so that the coverage of the review can be assessed and extended.

2.2 Information Sources

Structured searching was conducted in PubMed, Europe PMC, the Education Resources Information Center, Crossref, the Directory of Open Access Journals, OpenAIRE and Google Scholar. Searching was supplemented by backward citation tracking from included reviews and empirical reports, by forward citation tracking to locate replications, critiques and corrections, and by related-article searching within the biomedical indexes. Institutional sources were searched directly for policy and workforce evidence, including the United Nations Educational, Scientific and Cultural Organization. Records were checked for corrections, expressions of concern and retraction notices before inclusion.

2.3 Search Strategy and Search Period

Search concepts were constructed for five domains: the instructional agent and setting; the four focal constructs; candidate biological mechanisms; interactional and interpersonal-neuroscientific methods; and outcomes at the level of the teacher and the

learner. Within each concept, controlled vocabulary and free-text synonyms were combined with the Boolean operator OR, and concepts were combined with AND. Truncation and phrase searching were used where the index supported them. Representative strings are given in Table 1.

Table 1. Search concept blocks, representative Boolean strings and the sections of the review they support

Concept block	Representative search string (generic form)	Purpose within the review	Supporting references
Instructional agent and setting	("teacher" OR "instructor" OR "educator" OR "lecturer") AND ("classroom" OR "instruction" OR "pedagogy" OR "teaching quality")	Bounds the population and setting; retrieves teacher-effect and instructional-quality evidence	Chetty *et al*. (2014); Kraft (2019)
Inspiration and adjacent affective constructs	("inspiration" OR "enthusiasm" OR "awe" OR "elevation" OR "charisma") AND ("motivation" OR "transmission" OR "contagion")	Specifies the focal state and separates it from adjacent constructs	Algoe & Haidt (2009); Keller *et al*. (2016); Thrash & Elliot (2003)
Empowerment, control and agency	("psychological empowerment" OR "teacher autonomy" OR "sense of agency" OR "stressor controllability" OR "self-determination") AND ("neural" OR "prefrontal" OR "striatum" OR "well-being")	Links the empowerment construct to controllability and choice mechanisms	Haggard (2017); Maier & Seligman (2016); Spreitzer (1995)
Meaningfulness and purpose	("meaningful work" OR "meaning in life" OR "purpose in life" OR "calling" OR "self-transcendent purpose") AND ("reward" OR "ventromedial prefrontal" OR "inflammation" OR "mortality")	Retrieves construct, mechanism and outcome evidence for meaningfulness	Cascio *et al*. (2016); Rosso *et al*. (2010); Yeager *et al*. (2014)
Agility, flexibility and adaptive expertise	("learning agility" OR "cognitive flexibility" OR "set shifting" OR "psychological flexibility" OR "adaptive expertise" OR "teacher adaptability")	Distinguishes neurocognitive flexibility from professional agility constructs	Bohle Carbonell *et al*. (2014); Smith & Watkins (2024); Uddin (2021)
Sustainability, strain and recovery	("burnout" OR "emotional exhaustion" OR "occupational stress" OR "allostatic load" OR "recovery" OR "turnover") AND ("cortisol" OR "heart rate variability" OR "brain" OR "intervention")	Retrieves strain mechanisms, biomarkers and intervention trials	Bakker & Demerouti (2017); Danhof-Pont *et al*. (2011); Savic (2015)
Interactional and interpersonal-neuroscientific methods	("hyperscanning" OR "interpersonal neural synchrony" OR "brain-to-brain coupling" OR "second-person neuroscience") AND ("teaching" OR "learning" OR "classroom" OR "dyad")	Retrieves the candidate transmission mechanism and its methodological critiques	Dikker *et al*. (2017); Novembre & Iannetti (2021); Redcay & Schilbach (2019)

Note. Strings are presented in generic form; field tags, truncation symbols and phrase-matching syntax were adapted to each index. Concept blocks were combined with AND to produce the working searches, and single blocks were also run alone to retrieve construct-defining and methodological literature

The search period ran from 1 January 1995 to 12 July 2026. The starting year was selected because it marks the point at which psychological empowerment was operationalised as a measurable multidimensional state for workplace research (Spreitzer, 1995), immediately preceding the formalisation of dopaminergic prediction-error accounts of reward learning that reframed the motivational neuroscience on which later work depends (Schultz *et al*., 1997). Both developments are prerequisites for the questions this review addresses, and earlier literature does not support the constructs in their current form. The final search date was 12 July 2026.

2.4 Eligibility Criteria

Records were eligible if they were peer-reviewed journal articles, or authoritative reports from recognised intergovernmental or governmental bodies, published in English between 1 January 1995 and 12 July 2026, and if they addressed at least one of the following: the psychological structure or measurement of inspiration, empowerment, meaningfulness, agility or occupational sustainability; neural, endocrine or autonomic mechanisms plausibly implicated in these constructs; instructional interaction studied with interpersonal-neuroscientific methods; or interventions targeting teacher well-being, adaptability or occupational persistence with measured outcomes. Empirical studies, quantitative syntheses, methodological critiques and theoretical papers of demonstrable influence were all eligible.

Records were excluded if they were commercial or promotional material, non-scholarly opinion pieces, conference abstracts without full methodological reporting, or publications whose bibliographic identity could not be confirmed. Preprints were excluded where peer-reviewed evidence on the same question existed. Studies of pupil-level academic neuroscience without instructional or teacher relevance were excluded, as were studies of education for sustainable development. Sources whose Digital Object Identifier or stable official location could not be resolved were excluded regardless of apparent relevance.

2.5 Screening, Duplicate Handling and Study Selection

Titles and abstracts were screened against the eligibility criteria, and records passing this stage were assessed in full text where the full text was accessible. Where full text was not accessible, the record was retained only if abstract-level information was sufficient to support a narrowly specified descriptive claim, and it was excluded if the intended use required methodological detail. Duplicates arising from overlapping index coverage were identified by Digital Object Identifier, and where a Digital Object Identifier was absent, by matched author, title and year; the version of record was retained in preference to preprint or repository copies. Searching was restricted to English-language records, which is a limitation acknowledged in Section 12. Consistent with narrative review practice, no screening counts are reported, because the selection process was iterative and purposive rather than exhaustive and sequential, and reporting counts would misrepresent it as systematic.

2.6 Critical Appraisal and Evidence Synthesis

Included sources were appraised against criteria appropriate to their design. For survey-based occupational research, appraisal considered sample size and representativeness, common-method variance, the temporal ordering of measurement, and whether mediation claims rested on cross-sectional data. For neuroimaging and psychophysiological studies, appraisal considered sample size in relation to expected effect magnitude, the specificity of the inference drawn from regional activation, correction for multiple comparisons, and whether findings had been independently replicated. For intervention studies, appraisal considered randomisation and allocation concealment, the adequacy of control conditions, attrition, outcome-measure independence from the intervention rationale, and duration of follow-up. For quantitative syntheses, appraisal considered heterogeneity, the treatment of publication bias, and the comparability of pooled measures.

Themes were developed inductively from the appraised evidence and then tested against the four focal constructs, retaining a theme where it was supported by more than one independent research group and where the supporting evidence survived appraisal. Where studies disagreed, the disagreement was retained and its likely sources examined, including differences in measurement, population, analytic specification and statistical power. Confidence statements attached to each theme distinguish relations demonstrated in teaching populations from relations demonstrated in other populations and extrapolated to teaching. Table 1 summarises the search architecture and shows how each concept block maps onto the sections that follow; the strings are given in a condensed generic form because index-specific syntax varied, and they were adapted to the field tags available in each source.

3. Conceptual Architecture: What Inspiration Denotes in a Neurobiopsychological Frame

3.1 Inspiration as a Transmissible Motivational State

Treating inspiration as an attribute of a person invites circular reasoning, because the evidence usually offered for the attribute is the reaction it is invoked to explain. The construct becomes tractable when it is defined as a state with specified features, an identifiable trigger and a measurable consequence. Thrash and Elliot (2003) established that self-reported inspiration is distinguishable from positive affect, and that it possesses discriminant validity against openness and intrinsic motivation. Their subsequent work refined the construct into a two-part process in which the person is first inspired by an evoking object and then inspired to act, with the second phase carrying the motivational force (Thrash & Elliot, 2004). The distinction matters educationally, because instructional practices might plausibly influence either phase, and interventions aimed at the first would look quite different from interventions aimed at the second.

Attempts to identify neural correlates of inspiration itself remain preliminary. A review of the methodological problem noted that inspiration is difficult to elicit on demand, that its onset is not under experimental control, and that existing paradigms rely on proxies such as creative insight or aesthetic response (Oleynick *et al*., 2014). Closely related states have been studied more successfully. Awe, elicited by stimuli that exceed existing conceptual frames, has been associated with reduced activity in default mode network regions, consistent with the phenomenological report of diminished self-salience (van Elk *et al*., 2019). Behavioural work links awe to a diminished sense of the self's importance and to increased prosocial behaviour across several experimental elicitation methods (Piff *et al*., 2015). Moral elevation, elicited by witnessing another person's excellence, has been distinguished from gratitude and admiration by its characteristic action tendency towards emulation and affiliation (Algoe & Haidt, 2009). The correspondence between these states and inspiration is partial and has not been tested directly, which places an important limit on how far affective-neuroscientific findings can be imported.

3.2 Distinguishing Inspiration from Enthusiasm, Engagement and Charisma

Educational literature has often used enthusiasm as a proxy for inspirational quality. Careful conceptual work shows that this is imprecise. Teacher enthusiasm comprises an experienced dispositional-affective component and a displayed behavioural component, and the two correlate only moderately; students respond principally to the displayed component, whereas teacher well-being tracks the experienced component (Keller *et al*., 2016). Frenzel *et al*. (2009) showed that teacher enjoyment predicted student enjoyment across lessons, with teacher enthusiasm as displayed behaviour mediating the association, on data from more than 1,500 students and their mathematics teachers. That study, being observational and reliant on student report of teacher behaviour, cannot rule out reciprocal influence, and the authors were appropriately cautious about direction.

Engagement and flow describe absorbed task states rather than transmissible ones. Proposed neurochemical accounts of flow describe a configuration in which dopaminergic reward signalling and noradrenergic arousal support sustained effortless attention,

with reduced prefrontal self-monitoring (van der Linden *et al*., 2021). The account is coherent and integrates several literatures, but it is a synthesis of indirect evidence rather than a demonstration, and it has not been tested in teachers during instruction.

Charisma and inspirational leadership have been examined in organisational neuroscience. Recalling experiences with resonant compared with dissonant leaders produced differential activation in regions associated with social cognition and reward, and reduced activation in regions associated with analytic processing (Boyatzis *et al*., 2012). An experimental study contrasting coaching to the ideal self with coaching to problem-focused remediation reported activation differences in visual processing and default mode regions during the ideal-self condition, interpreted as engagement of imagination and openness (Jack *et al*., 2013). Both studies used small samples characteristic of task-based imaging at that period, and neither has been independently replicated. Sceptical analysis of this literature argues that organisational neuroscience has frequently proceeded by reverse inference, attributing psychological function to regional activation without the conditional probabilities that would license the attribution, and that its normative conclusions about leadership development are not warranted by its data (Lindebaum & Zundel, 2013). The concern is general rather than confined to leadership research, since inferring a mental process from activation in a region requires knowledge of how selectively that region is engaged across tasks (Poldrack, 2006).

3.3 The Transmission Problem

If inspiration is a state that passes between people, then a neurobiopsychological account must specify a transmission pathway. Three candidate pathways appear in the literature, and they differ in evidential status. The first is behavioural: the teacher's displayed conduct alters the learner's affective and motivational state through ordinary perceptual and appraisal processes, as in the enjoyment-transmission findings (Frenzel *et al*., 2009; Keller *et al*., 2016). The second is social-learning: the teacher functions as a source of value information, and the learner's valuation system updates in the direction of the model, a process for which the neural signature of conformity-driven updating in the ventral striatum and mediofrontal cortex provides an analogue (Klucharev *et al*., 2009). The third is interactional: teacher and learner brains become temporally coupled during communication, and coupling indexes or supports shared understanding (Hasson *et al*., 2012). These pathways are not mutually exclusive, and the evidence for them is graded, with the behavioural pathway best supported and the interactional pathway most heavily promoted relative to its evidential base. Section 8 examines the third pathway in detail.

Table 2 sets out the conceptual distinctions that organise the remainder of the review. Its purpose is to prevent the slippage that occurs when the same evidence is offered in support of different constructs. Reading across the rows shows that the constructs differ in whether they are states or capacities, in whether they are defined by phenomenology or by behavioural output, and in whether any physiological index has been validated for them in teaching populations. The final column indicates that the evidential anchors are drawn largely from outside education, which is a recurrent feature of this field and a constraint on the strength of any integrated account.

Table 2. Conceptual distinctions among inspiration and adjacent constructs, with their defining features and evidential anchors

Construct	Defining features	State or capacity	Candidate physiological or neural index	Validated in teaching populations	Supporting references
Inspiration	Evocation, transcendence, approach motivation; two-phase structure of being inspired by and inspired to	State	None established; proxies used	No	Oleynick *et al*. (2014); Thrash & Elliot (2003, 2004)
Awe	Perceived vastness requiring accommodation of existing frames; diminished self-salience	State	Reduced default mode network activity	No	Piff *et al*. (2015); van Elk *et al*. (2019)
Moral elevation	Witnessing another's moral excellence; action tendency towards emulation and affiliation	State	Not established	No	Algoe & Haidt (2009)
Teacher enthusiasm	Separable experienced affective and displayed behavioural components	Both	Not established	Partially, at behavioural level	Frenzel *et al*. (2009); Keller *et al*. (2016)
Flow and engagement	Absorbed, effortless task involvement with reduced self-monitoring	State	Proposed dopaminergic and noradrenergic configuration	No	van der Linden *et al*. (2021)
Inspirational or resonant leadership	Attributed influence eliciting affiliation and openness in followers	Attributed quality	Differential activation in social-cognitive and reward regions	No	Boyatzis *et al*. (2012); Jack *et al*. (2013); Lindebaum & Zundel (2013)

Note. Default mode network denotes the set of regions showing correlated activity during rest and internally directed cognition. "Validated in teaching populations" indicates whether the physiological or neural index in the preceding column has been measured in teachers or instructional interaction, not whether the construct itself has been studied in education

4. Empowerment: Control, Agency and the Neurobiology of Instructional Autonomy

4.1 The Work-psychological Construct

Psychological empowerment refers to an individual's cognitive orientation towards a work role, and Spreitzer (1995) established a four-dimensional structure comprising meaning, competence, self-determination and impact, with acceptable measurement properties in two industrial samples. The construct is deliberately intrapsychic. It is not a description of formal authority, and structural devolution of decision rights does not guarantee it. Meta-analytic synthesis across a large body of organisational research associates psychological empowerment with job satisfaction, organisational commitment, task performance and reduced strain, with high-performance managerial practices and socio-political support among its consistent antecedents (Seibert *et al*., 2011). The estimates are drawn overwhelmingly from cross-sectional self-report designs, so common-method variance inflates them to an unknown degree and reverse causation cannot be excluded.

Educational applications reproduce both the pattern and the limitation. Lee and Nie (2014) found that teachers' perceptions of empowering behaviour by principals and immediate supervisors predicted psychological empowerment, which in turn predicted work-related outcomes, in a single-source cross-sectional design. Tsang *et al*. (2022) reported that enabling rather than coercive school bureaucracy was associated with lower teacher burnout, with psychological empowerment mediating the association. Skaalvik and Skaalvik (2014) found that perceived autonomy and teacher self-efficacy jointly predicted engagement, job satisfaction and emotional exhaustion. These studies converge, but they converge within a single methodological tradition, and their convergence is therefore weaker evidence than it appears.

4.2 Controllability, the Medial Prefrontal Cortex and Stress Buffering

The strongest mechanistic evidence relevant to empowerment concerns behavioural control over aversive events. Work in the laboratory rat (*Rattus norvegicus*) established that the behavioural and neurochemical consequences of an identical stressor depend on whether the animal can control it. Amat *et al*. (2005) showed that the ventral medial prefrontal cortex detects the presence of control and, when control is present, inhibits stress-induced activation of the dorsal raphe nucleus; inactivating that prefrontal region abolished the protective effect of control, and activating it conferred protection even when the stressor was uncontrollable. Maier and Seligman (2016) reinterpreted five decades of learned-helplessness research in the light of this and related findings, arguing that passivity and heightened anxiety are the default response to prolonged aversive stimulation, and that what is learned is the presence of control rather than its absence. The reinterpretation reverses the original theory's polarity and has substantial implications for how workplace control is conceptualised.

The translational distance here should be stated plainly. The rodent paradigm involves escapable and inescapable tailshock; the teaching analogue involves discretion over curriculum sequencing, assessment design and classroom management under accountability pressure. The two share the abstract property of instrumental controllability and little else. No study has measured prefrontal engagement during controllable and uncontrollable professional demands in teachers, and the inference from rodent circuitry to teacher empowerment is therefore an analogy with mechanistic plausibility rather than a demonstrated pathway. It is a productive analogy nonetheless, because it generates the testable prediction that the protective value of perceived control should be greater for teachers whose prefrontal regulatory capacity is less compromised by prior chronic strain, which is a prediction that current occupational research does not address.

4.3 Choice, Agency and Reward Valuation in Humans

Human evidence supplies converging support at a shorter translational distance. Leotti *et al*. (2010) reviewed evidence that the opportunity to exercise choice is intrinsically rewarding, engaging striatal circuitry independently of the value of the outcome obtained, and argued that perceived control is a biologically prepared need rather than a preference. Murayama *et al*. (2015) provided a direct test, showing that self-determined choice enhanced subsequent performance on a stop-watch task and that the ventromedial prefrontal cortex responded to feedback differently under self-determined and externally imposed conditions, with striatal responsiveness to failure preserved under self-determined choice. The sample was small, as is typical of the paradigm, and the task bears no surface resemblance to teaching, but the finding aligns with the theoretical position that autonomy support alters the motivational significance of outcomes rather than merely increasing liking (Ryan & Deci, 2000).

The sense of agency, meaning the experience of being the author of one's actions and their effects, has been characterised as depending on both predictive comparison between intended and actual outcomes and retrospective inference, with contributions from parietal, premotor and prefrontal regions (Haggard, 2017). Teaching is an occupation in which the link between action and outcome is long-delayed, probabilistic and confounded by factors outside the teacher's control, which is precisely the configuration that weakens agentic experience. This offers an account of why teachers may report low empowerment even where formal autonomy is substantial, and it identifies a target for intervention that differs from devolving further decision rights.

4.4 Empowerment in Instructional Practice

The competence dimension of empowerment corresponds closely to teacher self-efficacy, which has been synthesised across four decades of research and shown to relate to classroom processes, student academic adjustment and teacher well-being, with the caveat that most of the evidence is correlational and that measurement has been inconsistent across studies (Zee & Koomen, 2016). Meta-analytic work reports a modest association between teacher self-efficacy and teaching effectiveness once personality is

accounted for, indicating that self-efficacy is not interchangeable with capability (Klassen & Tze, 2014). The classroom-facing counterpart of empowerment is autonomy-supportive teaching, which has been reviewed as a malleable instructional style with reliable benefits for student motivation, engagement and achievement, and with intervention studies demonstrating that teachers can be trained to adopt it (Reeve & Cheon, 2021). The relevant point for the present argument is bidirectional: teachers who experience autonomy support are more likely to extend it, and the trials that train autonomy-supportive teaching typically report improvements in teacher motivation as well as in student outcomes. Psychological safety in the work group is a plausible enabling condition, given evidence that shared belief in the safety of interpersonal risk-taking predicts learning behaviour in teams (Edmondson, 1999), although this has been examined far more extensively in organisational than in school settings.

4.5 Critical Appraisal

Three problems limit confidence. First, the empowerment literature in education and the controllability literature in neuroscience have no shared measurement. Empowerment is assessed by Likert-scaled self-report referring to a work role over an unspecified period; controllability is manipulated within trials and indexed by neural and behavioural response. No published study measures both in the same participants, so the mechanistic claim remains an inference across levels of analysis. Second, the direction of the empowerment-outcome association is not established. Teachers who are not exhausted may report greater empowerment because exhaustion narrows perceived options, an interpretation as consistent with the cross-sectional data as the reverse. Third, the construct's four dimensions are not equally distinct in practice; the meaning dimension overlaps substantially with the meaningfulness literature reviewed next, which raises the possibility that some of the apparent independence of the two constructs is an artefact of separate research traditions rather than a genuine psychological separation.

5. Meaningfulness: Value, Self-relevance and Reward

5.1 The Construct and Its Measurement

Meaningfulness in work has been theorised as arising from several distinct sources, including the self, other persons, the work context and spiritual life, with mechanisms that include authenticity, self-efficacy, self-esteem, purpose, belongingness, transcendence and cultural sensemaking (Rosso *et al*., 2010). The theoretical integration is valuable precisely because it resists reduction to a single mechanism, and it implies that interventions targeting one source may leave others untouched. Orientation towards work as a calling rather than as a job or career was shown by Wrzesniewski *et al*. (1997) to distribute roughly evenly within occupations rather than tracking occupational prestige, with calling orientation predicting satisfaction and reduced absence. In the general meaning literature, the Meaning in Life Questionnaire established that the presence of meaning and the search for meaning are separable dimensions with different correlates, the presence dimension associating with well-being and the search dimension associating with distress in some samples (Steger *et al*., 2006). Teaching is frequently characterised as a calling occupation, and the distinction between presence and search is directly relevant: a teacher actively searching for professional meaning is in a psychologically different position from one who reports having found it, and treating both as "high meaning" would obscure the difference.

5.2 Self-relevance, Values and Reward Circuitry

Neural evidence bearing on meaningfulness comes principally from research on self-relevance and value affirmation. Cascio *et al*. (2016) found that reflecting on personally important values engaged the ventromedial prefrontal cortex and ventral striatum, that this response was amplified when participants were oriented towards future benefit, and that the neural response predicted subsequent behaviour change in a health-behaviour context. The finding matters because it identifies a shared substrate for self-relevant valuation and reward, which is the minimum requirement for any account in which meaningfulness functions motivationally rather than merely evaluatively. Cohen and Sherman (2014) reviewed the broader intervention literature on values affirmation, arguing that brief affirmation procedures produce effects that can persist and compound in educational settings through recursive processes, while noting that effects are heterogeneous and conditional on context.

The general reward-learning framework supplies the mechanism by which valued outcomes shape behaviour. Phasic dopaminergic signalling encodes a prediction error, the difference between obtained and expected value, and functions as a teaching signal for associative learning (Schultz *et al*., 1997; Schultz, 2015). Berridge and Kringelbach (2015) distinguished the hedonic component of reward from the motivational component that drives pursuit, showing that these are dissociable at the neural level, and Salamone *et al*. (2007) established that nucleus accumbens dopamine is implicated in effort-related decision-making rather than in pleasure as such. The distinction has an obvious educational corollary. A teacher who finds the work meaningful is not necessarily one who enjoys each day of it, and interventions that increase enjoyment need not increase the willingness to expend effort that meaningfulness is presumed to support.

Curiosity provides the clearest demonstration that motivational state modulates learning at a physiological level. Gruber *et al*. (2014) showed that states of high curiosity enhanced memory for the material that provoked the curiosity and, incidentally, for unrelated material encountered during the curious state, with activity in the midbrain and nucleus accumbens and functional coupling between midbrain and hippocampus predicting the effect. The subsequent theoretical framework specifies how prediction, appraisal and exploration interact to produce this enhancement (Gruber & Ranganath, 2019). This is the most direct neural evidence available that an instructionally manipulable motivational state alters what is learned, and it is one of very few findings in this review with an unambiguous classroom implication.

5.3 Self-transcendent Purpose in Learners

Yeager *et al*. (2014) tested whether a self-transcendent purpose for learning, framed as contributing to something beyond the self, would support academic self-regulation. Across several studies including a randomised field experiment, the purpose manipulation increased persistence on tedious tasks and improved grades in mathematics and science among students at risk of poor performance. The work is important because it operationalises meaningfulness as a manipulable instructional variable rather than a dispositional attribute, and because its effects were obtained on behavioural and archival outcomes rather than self-report alone. Effects were moderate and moderated by baseline risk, and the studies do not identify the mediating psychological process with precision.

5.4 The Physiological Signature of Eudaimonia: An Instructive Controversy

The most heavily cited claim linking meaningfulness to biology asserted that eudaimonic well-being, defined by purpose and self-realisation, is associated with a favourable pattern of leukocyte gene expression, with reduced pro-inflammatory transcription, whereas hedonic well-being showed the opposite pattern despite similar affective correlates (Fredrickson *et al*., 2013). Brown *et al*. (2014) reanalysed the data and reported that the reported dissociation did not survive correction of statistical and analytic problems, including the treatment of collinear predictors and the specification of the multivariate model, and that the original conclusions were not supported. Related work extended the critique across subsequent studies from the same programme. The exchange is instructive for the present review in three respects. It demonstrates that a plausible and widely publicised biological account of meaningfulness can fail on reanalysis; it illustrates the vulnerability of small-sample multivariate biological research to analytic flexibility; and it counsels against citing peripheral biomarkers as evidence for psychological constructs without checking the replication record.

Epidemiological evidence for purpose is more robust, though it is observational. Hill and Turiano (2014) reported that greater purpose in life predicted lower mortality risk over a fourteen-year follow-up in a national sample, with the association holding across adulthood and independent of other well-being indices. Alimujiang *et al*. (2019) reported a similar association in a large sample of adults over 50 years, with the strongest association for all-cause and cardiovascular mortality. Both studies adjusted extensively for confounders, and neither can exclude reverse causation, since incipient illness lowers reported purpose. Ryff (2014) situated these findings within a broader account of eudaimonic well-being and its correlates, noting that the biological findings across this literature are of uneven quality.

Table 3 summarises the mechanistic position for empowerment and meaningfulness. The pattern it displays is consistent for both constructs: the psychological construct is well measured and reliably associated with occupational outcomes, the candidate mechanism is characterised in non-teaching populations, and the connection between the two is an inference rather than a finding. The table also records where a mechanistic claim has been contested, because a contested claim carries different weight from an untested one, and conflating the two would overstate the coherence of the field.

6. Agility: Flexibility, Adaptive Expertise and Instructional Responsiveness

6.1 A construct in Search of Discipline

Agility entered educational discourse from organisational practice, where learning agility was proposed as a capacity to learn from experience and apply that learning under novel conditions, with the implication that it predicts leadership potential. DeRue *et al*. (2012) argued that the construct as used commercially lacked conceptual clarity and theoretical grounding, and proposed narrowing it to speed and flexibility of experiential learning. De Meuse (2017) traced its subsequent development and reported associations with leader success, while acknowledging that much of the supporting evidence came from proprietary instruments and unpublished technical reports. Smith and Watkins (2024) reviewed the available measures and found substantial heterogeneity in what they operationalise, limited evidence of discriminant validity against general mental ability, openness and goal orientation, and a scarcity of independent validation. The construct therefore occupies an uncomfortable position: it is widely used, intuitively appealing and weakly specified.

The consequence for a neurobiopsychological account is direct. Where a construct's measures do not discriminate it from established constructs, any biological correlate identified for it is unlikely to be specific. Claims that agility is a brain-based capacity should therefore be treated as claims about whichever established capacity the measure is actually indexing.

6.2 Flexibility as a Neurocognitive Capacity

Cognitive flexibility, by contrast, is well specified. Diamond (2013) situated it as one of three core executive functions alongside inhibitory control and working memory, dependent on prefrontal circuitry, measurable with established paradigms, and improvable through training with the important qualification that transfer is narrow. Uddin (2021) reviewed the neural mechanisms in detail, distinguishing switching, reversal learning and task-set reconfiguration, and locating them in interacting frontoparietal, cingulo-opercular and striatal systems. The review also emphasises that flexibility is not uniformly advantageous, since excessive switching impairs performance where stability is required, and that the optimal balance between stability and flexibility is task-dependent.

That qualification is important for education, because the professional rhetoric of agility usually treats flexibility as an unqualified good. A teacher who abandons an instructional plan whenever a difficulty appears is not exhibiting adaptive capacity but distractibility. The neurocognitive literature is clear that flexibility and stability trade off, and that the trade-off is regulated rather than fixed.

Table 3. Empowerment and meaningfulness: constructs, candidate mechanisms, strongest supporting evidence and residual uncertainty

Construct or sub-construct	Candidate mechanism	Strongest supporting evidence	Population in which mechanism was demonstrated	Principal uncertainty	Supporting references
Psychological empowerment (meaning, competence, self-determination, impact)	Perceived instrumental control buffers stress responding via ventral medial prefrontal inhibition of brainstem stress circuitry	Controllable stressors produce different neurochemical and behavioural outcomes from identical uncontrollable stressors; prefrontal inactivation abolishes the difference	Laboratory rodents; reinterpretation extended to humans conceptually	No study measures empowerment and prefrontal control detection in the same individuals	Amat *et al*. (2005); Maier & Seligman (2016); Spreitzer (1995)
Self-determination and choice	Opportunity for choice is intrinsically rewarding and alters feedback processing	Striatal engagement by choice opportunity independent of outcome value; altered ventromedial prefrontal feedback response under self-determined choice	Healthy adults in laboratory tasks	Small samples; tasks distant from professional discretion	Leotti *et al*. (2010); Murayama *et al*. (2015); Ryan & Deci (2000)
Sense of agency	Predictive comparison of intended and actual outcomes plus retrospective inference	Convergent evidence from timing, action-effect and clinical paradigms	Healthy adults and clinical groups	Delayed and probabilistic outcomes in teaching are outside the paradigms used	Haggard (2017)
Meaningfulness of work	Self-relevant valuation engages ventromedial prefrontal and ventral striatal reward circuitry	Values affirmation engages these regions and predicts subsequent behaviour change	Healthy adults and community samples	Work meaningfulness has not been used as the affirmation content	Cascio *et al*. (2016); Cohen & Sherman (2014); Rosso *et al*. (2010)
Purpose and self-transcendence	Purpose framing supports effortful self-regulation and long-term health	Randomised purpose manipulation improved persistence and grades; purpose predicts lower mortality in cohort studies	School and college students; general adult cohorts	Mediating process not isolated; cohort findings vulnerable to reverse causation	Alimujiang *et al*. (2019); Hill & Turiano (2014); Yeager *et al*. (2014)
Eudaimonic well-being and inflammation	Differential leukocyte transcriptional profile associated with eudaimonic well-being	Original report contested; reanalysis did not support the dissociation	Small community samples	Claim not currently supportable	Brown *et al*. (2014); Fredrickson *et al*. (2013); Ryff (2014)

Note. "Population in which mechanism was demonstrated" refers to the study population supplying the mechanistic evidence, not the population in which the psychological construct has been measured. Ventromedial prefrontal cortex and ventral striatum are abbreviated in the main text after first use

Psychological flexibility describes a related but distinct capacity, defined as the ability to contact the present moment and to persist in or change behaviour in the service of chosen values (Kashdan & Rottenberg, 2010). It is a clinically derived construct with substantial evidence linking it to mental health outcomes, and it aligns more closely with the meaningfulness literature than with the executive-function literature, since it is defined by value-directedness rather than by set-shifting efficiency. Reviews of these two literatures rarely cite one another, and the shared use of the word "flexibility" has probably obscured their independence.

Adult neuroplasticity supplies the developmental premise for any claim that professional adaptability can be cultivated. Lövdén *et al*. (2013) reviewed structural plasticity in adult learning and argued that structural change occurs when there is a sustained mismatch between functional supply and environmental demand, that it is time-limited and often partially reversible, and that reported volumetric changes are frequently small and variably replicated. The framework licenses cautious optimism about professional development while explicitly warning against the assumption that any training produces durable structural adaptation.

6.3 Adaptive Expertise and Instructional Responsiveness

The educational construct that most closely captures what "agility" is intended to mean is adaptive expertise. Bohle Carbonell *et al*. (2014) reviewed how experts handle novel situations and distinguished routine expertise, which delivers efficient performance on familiar problems, from adaptive expertise, which delivers effective performance on unfamiliar ones. The review identifies the cognitive and contextual conditions that favour adaptive expertise, including variability of prior experience, opportunities for deliberate reflection and a work environment tolerant of temporary inefficiency. It also notes that measurement remains a difficulty, since adaptive expertise is defined by response to novelty and novelty is hard to standardise.

Teacher adaptability has been studied more directly. Collie and Martin (2017) reported that teachers' sense of adaptability was associated with perceived autonomy support, with their own psychological functioning, and with students' numeracy achievement, in a design combining teacher report with administrative achievement data. Collie *et al*. (2018) subsequently examined adaptability within a job demands-resources framework, finding it associated with lower exhaustion and disengagement and higher commitment. These studies use appropriate multilevel modelling and, in the former case, an outcome not derived from teacher report, which strengthens them relative to the single-source designs common in this area. They remain observational, and adaptability was measured with a short scale whose relation to performance under genuine novelty has not been established.

6.4 Why Agility Claims Outrun their Evidence

The educational literature on malleable capacities offers a cautionary precedent. Growth-mindset interventions, which propose that beliefs about the malleability of ability shape achievement, were adopted rapidly and at scale. A national randomised trial reported small average effects concentrated among lower-achieving students in schools with supportive peer norms (Yeager *et al*., 2019), while a systematic review and meta-analysis reported that average effects across the literature were very small, that apparent effects were associated with lower-quality designs, and that few studies met best-practice criteria (Macnamara & Burgoyne, 2023). The two are not straightforwardly contradictory, since the trial's own estimates were small and conditional, but the episode illustrates how a plausible malleability claim can generate large-scale implementation ahead of the evidence, and how heterogeneity is obscured when average effects are reported without moderators.

Agility discourse in education is currently at the stage that mindset discourse occupied a decade ago. It has an appealing theoretical rationale, a proliferating set of proprietary measures, and almost no independent trial evidence. The neurocognitive literature on flexibility is genuinely informative, but it does not support the specific proposition that a general professional agility can be trained and will transfer across the varied demands of teaching. Diamond's (2013) observation that executive-function training transfers narrowly is directly relevant, and it has not been assimilated into the professional literature on teacher agility.

A further problem concerns the relationship between agility and sustainability. Flexibility is metabolically and attentionally expensive. Sustained task-switching and continual reconfiguration draw on the same control resources whose depletion is examined in Section 7. Treating agility as an unqualified professional virtue therefore risks recommending a pattern of work that undermines the fourth pillar, and the literatures are sufficiently separate that this tension has not been examined empirically.

7. Sustainability: Allostatic Cost, Recovery and the Career-Long Viability of Inspirational Teaching

7.1 The Scale and Shape of the Problem

Sustainability is the pillar with the clearest occupational evidence and the least secure biology. The workforce context is not disputed: the United Nations Educational, Scientific and Cultural Organization (2024) estimated that 44 million additional primary and secondary teachers are required globally by 2030 to meet universal basic education commitments, with attrition among early-career teachers a substantial contributor in many systems. Meta-analytic work on teacher turnover identifies working conditions, administrative support and student composition among the most consistent correlates, with compensation less influential than commonly assumed (Nguyen, Pham, *et al*., 2020). Burnout predicts turnover intention in teachers, with the exhaustion dimension carrying most of the association (Rajendran *et al*., 2020).

Burnout itself is defined as a syndrome comprising emotional exhaustion, depersonalisation or cynicism, and reduced personal accomplishment, arising from chronic unresolved workplace stress (Maslach & Leiter, 2016). Teacher-specific reviews find that well-being is associated with a wide range of individual and contextual factors, with autonomy, relational quality and workload prominent (Hascher & Waber, 2021; Ozturk *et al*., 2024). A meta-analysis of factors associated with teacher well-being reported

that job resources showed stronger associations with well-being than job demands showed with ill-being, though with substantial heterogeneity across studies and outcome definitions (Zhou *et al*., 2024). Personality accounts for a non-trivial share of variance, with emotional stability and conscientiousness the most consistent predictors of both effectiveness and burnout resistance (Kim *et al*., 2019).

7.2 Construct Contest and Biomarker Inconsistency

Two problems complicate any biological account. The first is that burnout's status as a distinct condition is contested. Bianchi *et al*. (2015) reviewed the overlap between burnout and depressive symptomatology and reported that the constructs share substantial variance, that burnout measures correlate highly with depression measures, and that the discriminant evidence is weaker than the field's separate literatures imply. If a proportion of what is measured as burnout is depression, then biological correlates attributed to occupational strain may in part be correlates of mood disorder, and the two are rarely distinguished in teacher samples.

The second problem is that burnout has no reproducible endocrine signature. Danhof-Pont *et al*. (2011) systematically reviewed biomarker studies of burnout, covering cortisol and other hypothalamic-pituitary-adrenal indices, immune and metabolic markers, and autonomic measures, and concluded that no biomarker had been consistently associated with burnout across studies. Findings for the cortisol awakening response in particular pointed in opposite directions across samples. Subsequent work has not overturned that conclusion. The implication is uncomfortable but should be stated: assertions that teacher burnout is characterised by a specific pattern of cortisol dysregulation are not supported by the cumulative evidence, and the appearance of support arises from selective citation of individual positive studies.

7.3 Chronic Occupational Stress and the Brain

Structural and functional imaging work in occupationally exhausted adults is more consistent, though based on modest samples from a small number of research groups. Blix *et al*. (2013) reported reduced grey matter volume in prefrontal and anterior cingulate regions and enlarged amygdalae in employees with long-term occupational stress compared with controls. Savic (2015) reported thinning of the mediofrontal and anterior cingulate cortex and enlargement of the amygdala and caudate in patients with occupational exhaustion disorder, with the extent of change related to reported stress duration. Golkar *et al*. (2014) found that the same population showed impaired down-regulation of negative affect and reduced functional connectivity between the amygdala and prefrontal regulatory regions, alongside reduced connectivity between the amygdala and the anterior cingulate. A follow-up study reported that several of these changes were partially reversible following clinical intervention and reduced occupational load (Savic *et al*., 2018).

These findings sit within an established framework. McEwen (1998) formalised allostatic load as the cumulative physiological cost of repeated or inefficiently terminated stress responses, distinguishing adaptive short-term mobilisation from long-term damage. Lupien *et al*. (2009) reviewed lifespan evidence that hippocampal, amygdalar and prefrontal structures show differential vulnerability to glucocorticoid exposure. Arnsten (2009) detailed the mechanism by which acute and chronic stress exposure impairs prefrontal function through catecholamine signalling and dendritic remodelling, with the important consequence that the regions supporting cognitive control and emotion regulation are among the first to be compromised.

The implication for inspirational teaching is specific rather than general. The capacities that make instruction responsive and emotionally attuned, including cognitive flexibility, working memory, reappraisal and inhibitory control, depend on the prefrontal systems that chronic occupational strain preferentially degrades. Cognitive reappraisal, in particular, has been shown meta-analytically to depend on dorsolateral and ventrolateral prefrontal engagement with modulation of amygdala response (Buhle *et al*., 2014). A teacher operating under sustained allostatic load is therefore not merely tired but is likely to have diminished access to precisely the regulatory capacities that the professional literature identifies with excellence. Causality remains to be demonstrated. The imaging studies are cross-sectional and cannot exclude the possibility that pre-existing structural differences confer vulnerability to exhaustion, and none was conducted in teachers.

7.4 Daily Effort, Fatigue and Metabolic Cost

Evidence at a shorter timescale addresses the daily cost of sustained cognitive control. Wiehler *et al*. (2022) found that a full day of demanding cognitive work was accompanied by accumulation of glutamate in the lateral prefrontal cortex, measured by magnetic resonance spectroscopy, and by a shift in economic decision-making towards options requiring less effort and yielding more immediate reward. The sample was small and the metabolic interpretation is one of several possible, but the study is notable for linking a subjective state to a measurable neurochemical change and a behavioural consequence within a single design. Boksem and Tops (2008) had earlier argued that mental fatigue should be understood as an adaptive signal that the cost of continued effort has begun to exceed its expected benefit rather than as simple resource depletion, an account consistent with the effort-related functions of accumbens dopamine (Salamone *et al*., 2007).

For teaching, this reframes end-of-day depletion. If fatigue is a computed cost-benefit signal rather than a depleted store, then the willingness to sustain effortful, responsive teaching depends on the perceived value of the outcome as much as on accumulated load, which connects the sustainability pillar directly to meaningfulness. The connection is theoretically coherent and has not been tested in teachers.

7.5 Autonomic and Interoceptive Regulation

Heart rate variability has been proposed as an accessible index of prefrontal regulatory capacity. Thayer *et al*. (2012) reported a meta-analysis of neuroimaging studies showing that variability in the high-frequency band covaries with activity in a network including the ventromedial prefrontal cortex and amygdala, supporting its use as an index of top-down inhibitory regulation. The inference should be handled carefully. Grossman and Taylor (2007) argued that respiratory sinus arrhythmia is strongly influenced by respiratory parameters and metabolic demand, and that treating it as a direct index of cardiac vagal tone without controlling for these factors produces unreliable conclusions. Studies using heart rate variability in classroom settings, where physical activity and speech both alter respiration substantially, are particularly exposed to this problem.

Interoception, the perception of internal bodily states, provides a related mechanism linking bodily regulation to emotional experience. Critchley and Garfinkel (2017) reviewed evidence that interoceptive signals contribute to emotional feeling states through insular and cingulate processing, and that individual differences in interoceptive accuracy relate to emotional and anxiety-related outcomes. This provides a plausible route by which contemplative training might alter emotional regulation, since such training explicitly cultivates attention to bodily state.

7.6 Interventions and their Evidence

Intervention evidence is the most decision-relevant part of this literature and the most heterogeneous. Roeser *et al*. (2013) reported two randomised waitlist-control trials of mindfulness training with teachers, finding reductions in occupational stress and burnout and improvements in attention and self-compassion, with several effects maintained at three-month follow-up. Jennings *et al*. (2017) reported a cluster-randomised trial of the Cultivating Awareness and Resilience in Education programme with 224 teachers in high-poverty schools, finding improvements in adaptive emotion regulation, psychological distress and observed emotional support in classrooms, with effects on instructional outcomes smaller than those on teacher-reported outcomes.

Quantitative synthesis tempers this. Iancu *et al*. (2018) meta-analysed interventions aimed at reducing teacher burnout and found small overall effects, with the largest effects for personal accomplishment and the smallest for depersonalisation, and with considerable heterogeneity attributable to intervention type and outcome measure. von der Embse *et al*. (2019) systematically reviewed teacher stress interventions and reported that most studies had methodological limitations including absent or weak control conditions, short follow-up and reliance on self-report outcomes that were conceptually close to the intervention rationale. Tang *et al*. (2015) reviewed the neuroscience of mindfulness meditation and concluded that reported neural changes are plausible but that the field is limited by small samples, active-control deficiencies and inconsistent practice quantification.

The theoretical rationale for these programmes rests on the prosocial classroom model, which proposes that teachers' social and emotional competence and well-being shape classroom climate, relationship quality and, through them, student outcomes (Jennings & Greenberg, 2009). The model is well specified and widely adopted, and the trial evidence supports its proximal predictions more strongly than its distal ones.

Two structural points deserve emphasis. First, almost all intervention evidence targets the individual teacher, whereas the correlational evidence points towards working conditions, administrative support and workload as the principal determinants of strain (Nguyen, Pham, *et al*., 2020; Zhou *et al*., 2024). This mismatch is the substance of the critique that the well-being turn individualises structural problems (Wilkins *et al*., 2025), and it is an empirical claim that can be tested by comparing individual-level and organisational-level intervention effects, which has rarely been done. Second, the job demands-resources framework predicts that resources buffer demands and drive engagement through distinct processes (Bakker & Demerouti, 2017), and conservation of resources theory predicts that resource loss is more consequential than resource gain and that losses spiral (Hobfoll *et al*., 2018). Both frameworks imply that intervention timing matters, and neither prediction has been tested longitudinally in teachers with physiological outcomes.

Recovery is the mechanism by which allostatic cost is discharged. Sonnentag and Fritz (2015) developed the stressor-detachment model, arguing that psychological detachment from work during non-work time mediates the relation between job stressors and strain, and that stressors themselves impair the detachment needed to recover from them. Teaching has features that obstruct detachment, including preparation and marking that migrate into non-work time and emotional involvement that does not terminate at the end of the working day. Emotional labour research supports this: Hülsheger and Schewe (2011) found meta-analytically that surface acting, meaning the display of unfelt emotion, was associated with impaired well-being and reduced performance, whereas deep acting showed weaker and more favourable associations. Teachers engage in extensive emotional display regulation, and appraisal-based accounts of teacher burnout position this as central to the strain process (Chang, 2009).

7.7 Consequences for Learners

Teacher strain does not remain within the teacher. Oberle and Schonert-Reichl (2016) measured morning salivary cortisol in 406 elementary school pupils and found that pupils in classrooms whose teachers reported higher burnout showed elevated morning cortisol, after adjustment for several classroom and individual covariates. The study is cross-sectional and cannot establish direction, and cortisol elevation is not itself an outcome of educational interest, but it is among the few studies to demonstrate a physiological correspondence between teacher occupational state and pupil biology. At the behavioural level, Klusmann *et al*. (2022) found in a large sample that teachers' emotional exhaustion was associated with student-reported instructional quality, and that instructional quality mediated the association with student outcomes, although the mediated effects were small. Madigan and Kim (2021) systematically reviewed the association between teacher burnout and student outcomes and found consistent negative associations with achievement and motivation, alongside evident risk of confounding by school context. Aldrup *et al*. (2018) showed that the relation between student misbehaviour and teacher well-being was mediated by the quality of the teacher-student relationship, indicating that the causal traffic runs in both directions.

Table 4 summarises the intervention and mechanism evidence for sustainability. The pattern is that occupational outcomes are well documented, individual-level interventions produce small and short-lived effects, biological indices are either inconsistent or drawn from non-teaching populations, and organisational-level interventions with measured outcomes are largely absent. The table records effect direction and principal limitation rather than pooled magnitudes, because the outcome measures across these studies are not commensurable and reporting a single figure would misrepresent them.

8. Interpersonal Neural Coupling as a Candidate Mechanism of Transmission

8.1 Second-person Neuroscience and the Pedagogical Stance

The proposition that teaching involves a specialised communicative stance predates the imaging literature. Csibra and Gergely (2009) proposed that human infants are prepared to interpret ostensive signals, such as eye contact, infant-directed speech and contingent responsiveness, as marking the ensuing information as generalisable and culturally shared, and argued that this constitutes a dedicated system for the transfer of knowledge. The evolutionary elaboration of the argument holds that natural pedagogy solves the problem of transmitting opaque cultural knowledge that cannot be acquired by observation alone (Csibra & Gergely, 2011). The account has been contested empirically, and some of its specific predictions about gaze-following have not been supported, but the broader claim that instructional communication carries distinctive interpretive markers remains influential.

Table 4. Sustainability of inspirational teaching: mechanisms, intervention evidence and principal methodological limitations

Target	Evidence Type and design	Direction and magnitude of finding	Principal limitation	Supporting references
Burnout as a distinct construct	Narrative and quantitative review of construct overlap	Substantial shared variance with depressive symptomatology	Discriminant validity weaker than separate literatures imply	Bianchi *et al*. (2015); Maslach & Leiter (2016)
Endocrine and immune biomarkers of burnout	Systematic review of biomarker studies	No consistent association with any single biomarker; cortisol findings inconsistent in direction	Heterogeneous sampling protocols and case definitions	Danhof-Pont *et al*. (2011)
Brain structure and connectivity under chronic occupational stress	Cross-sectional imaging in occupationally exhausted adults; one follow-up study	Reduced mediofrontal and cingulate volume, enlarged amygdala, impaired prefrontal-amygdala regulation; partial reversibility reported	Small samples from few groups; not conducted in teachers; direction of causation unresolved	Blix *et al*. (2013); Golkar *et al*. (2014); Savic (2015); Savic *et al*. (2018)
Daily cognitive effort and fatigue	Within-participant spectroscopy with economic decision task	Prefrontal glutamate accumulation and shift towards low-effort choices after daylong cognitive work	Small sample; metabolic interpretation not unique	Boksem & Tops (2008); Wiehler *et al*. (2022)
Autonomic regulation as an index of regulatory capacity	Meta-analysis of neuroimaging studies; methodological critique	High-frequency variability covaries with prefrontal-amygdala network activity	Respiratory and metabolic confounds limit field use	Grossman & Taylor (2007); Thayer *et al*. (2012)
Mindfulness-based training for teachers	Two randomised waitlist-control trials; cluster-randomised trial; review of neural evidence	Reduced stress and burnout; improved emotion regulation and observed emotional support; smaller effects on instructional outcomes	Waitlist rather than active controls in early trials; short follow-up; self-report outcomes aligned with intervention rationale	Jennings *et al*. (2017); Roeser *et al*. (2013); Tang *et al*. (2015)
Teacher burnout interventions generally	Meta-analysis and systematic review	Small overall effects; largest for personal accomplishment, smallest for depersonalisation	High heterogeneity; weak control conditions; publication bias not fully addressed	Iancu *et al*. (2018); von der Embse *et al*. (2019)
Recovery and emotional labour	Theoretical model with supporting evidence; meta-analysis	Impaired detachment mediates stressor-strain relations; surface acting associated with impaired well-being	Largely cross-sectional and diary-based; occupational specificity untested in teachers	Chang (2009); Hülsheger & Schewe (2011); Sonnentag & Fritz (2015)
Transmission to learners	Cross-sectional physiological study; large-scale survey with mediation; systematic review	Elevated pupil morning cortisol in classrooms of more burnt-out teachers; small mediated effects of exhaustion on outcomes via instructional quality	Direction of effect not established; confounding by school context	Klusmann *et al*. (2022); Madigan & Kim (2021); Oberle & Schonert-Reichl (2016)

Note. Effect magnitudes are described qualitatively because outcome measures across these designs are not commensurable. "Partial reversibility" refers to a single follow-up study and has not been independently replicated

Methodologically, this connects to the argument that social cognition studied in isolated observers differs from social cognition during genuine interaction. Schilbach *et al*. (2013) argued for a second-person approach in which participants engage reciprocally rather than observing social stimuli, and Redcay and Schilbach (2019) reviewed the accumulated evidence that interactive and observational paradigms recruit partially distinct neural systems, with interaction engaging reward-related and motor regions not reliably engaged by observation. Teaching is an interactive activity, so the argument applies to it with particular force.

8.2 What Classroom Hyperscanning has Found

Hyperscanning refers to the simultaneous recording of neural activity from two or more interacting people, most commonly with electroencephalography or functional near-infrared spectroscopy (Czeszumski *et al*., 2020). Hasson *et al*. (2012) proposed brain-to-brain coupling as a general framework in which the speaker's neural dynamics drive corresponding dynamics in the listener, and Kingsbury and Hong (2020) extended the framework across species and levels of analysis.

Findings in instructional settings are consistent in broad outline. Dikker *et al*. (2017) recorded portable electroencephalography from a class of secondary school students across eleven sessions over a semester and found that group-level neural synchrony predicted class engagement and social dynamics, with synchrony higher during more engaging instructional formats. Bevilacqua *et al*. (2019) reported that student-to-student and student-to-teacher synchrony in the same setting varied with the students' liking of the teacher and with focus at the start of the class, and predicted retention of content. Zheng *et al*. (2018) used functional near-infrared spectroscopy in instructor-learner dyads and found that coupling in the anterior cingulate emerged before the learner's response and predicted teaching outcome, which the authors interpreted as the instructor's predictive modelling of the learner's knowledge state. Pan *et al*. (2020) found that instructor-learner coupling discriminated between scaffolding and explanation-based instructional approaches and predicted learning. Outside formal instruction, Nguyen, Schleihauf, *et al*. (2020) showed that interaction quality during mother-child problem solving moderated neural synchrony, indicating that synchrony reflects relational quality rather than mere co-presence.

Quantitative synthesis supports a moderate association. Zhang *et al*. (2022) meta-analysed studies of interpersonal neural synchronisation during teaching-learning interaction and reported a positive association with learning outcomes, moderated by the nature of the interaction and by the region examined. Lu (2025) reviewed the field's movement from laboratory to classroom and identified ecological validity and analytic standardisation as the two principal challenges.

8.3 What Synchrony is Not

The interpretive limits are substantial and are frequently understated in secondary accounts. Novembre and Iannetti (2021) argued that hyperscanning designs, being correlational by construction, cannot establish that inter-brain coupling causes behavioural or cognitive outcomes, and that causal claims require the ability to manipulate coupling directly, for instance through simultaneous multi-brain stimulation. Their argument applies directly to educational uses of the method, where synchrony is routinely described as supporting learning rather than as accompanying it.

Three further problems deserve statement. Synchrony can arise from shared exposure to the same external stimulus without any interpersonal process, and distinguishing genuine interpersonal coupling from stimulus-driven co-variation requires careful control conditions that are hard to implement in classrooms. Analytic flexibility is high, since researchers choose among frequency bands, connectivity metrics, time windows and surrogate-data procedures, and this flexibility inflates the probability of positive findings in the absence of preregistration. Sample sizes are small relative to the effects that brain-behaviour association studies can reliably detect; the demonstration that reproducible brain-wide association studies require samples orders of magnitude larger than those typically used (Marek *et al*., 2022) concerned a different design, but its underlying point about the inflation of small-sample brain-behaviour correlations transfers.

Reverse inference compounds these problems. Interpreting anterior cingulate coupling as evidence of predictive modelling of a learner's knowledge state requires that anterior cingulate engagement be relatively selective for that function, which it is not (Poldrack, 2006). The pattern by which an attractive neurobiological account of a social process is adopted in advance of its evidential base has a recent precedent in the intranasal oxytocin literature, where a large preregistered replication found no support for a general trust-enhancing effect that had been widely reported and applied (Declerck *et al*., 2020). The lesson is not that synchrony research is unsound; the classroom findings are internally consistent and methodologically improving. The lesson is that a marker of engagement should not be described as a mechanism of learning until the causal test has been done.

Social baseline theory offers a complementary account of why interpersonal presence matters that does not require inter-brain coupling. Coan and Sbarra (2015) argued that the brain treats social proximity as a baseline resource, and that the perceived availability of others reduces the metabolic and attentional cost of managing threat and effort. Applied to instruction, the implication is that a reliably supportive teacher lowers the regulatory demand on learners, which is a claim testable with individual-level physiology and does not depend on synchrony at all.

9. Toward an Integrated Neurobiopsychological Account

9.1 Four Coupled Regulatory Loops

The evidence reviewed supports an account in which the four constructs are not parallel virtues but functionally coupled regulatory processes operating on different timescales. Empowerment operates on the appraisal of controllability and, through it, on the

magnitude and termination of the stress response. Meaningfulness operates on the valuation of outcomes and therefore on the willingness to expend effort whose returns are delayed and uncertain. Agility, understood as regulated flexibility rather than as an omnibus disposition, operates on the moment-to-moment adjustment of instruction and depends on the prefrontal control systems that the first two processes protect or deplete. Sustainability is the integral of the other three over time, expressed as the cumulative allostatic cost of the work and the adequacy of recovery.

The couplings are directional and specifiable. Controllability appraisal modulates prefrontal regulation of stress circuitry (Amat *et al*., 2005; Maier & Seligman, 2016), and prefrontal integrity is what flexible instructional adjustment requires (Diamond, 2013; Uddin, 2021). Chronic strain degrades those same prefrontal systems (Arnsten, 2009; Savic, 2015), which predicts that sustainability failure should manifest first as reduced instructional responsiveness rather than as reduced subject knowledge. Effort allocation is a cost-benefit computation in which the perceived value of the outcome is one term (Boksem & Tops, 2008; Salamone *et al*., 2007), which predicts that meaningfulness should moderate the rate at which a given workload produces exhaustion. Each of these predictions is testable and none has been tested in teachers.

9.2 Inspiration Within the Account

Inspiration, on this reading, is not a fifth construct but the observable output of the other four operating in a favourable configuration. A teacher with sufficient discretion to act on professional judgement, a clear sense of the work's value, intact regulatory capacity for real-time adjustment and adequate recovery is in a position to display the responsive, affectively engaged conduct that students recognise as inspiring. The transmission from that conduct to student state is best supported at the behavioural level (Frenzel *et al*., 2009; Keller *et al*., 2016), plausible at the level of value-based social learning (Klucharev *et al*., 2009), and interesting but unproven at the level of inter-brain coupling (Novembre & Iannetti, 2021; Zhang *et al*., 2022).

This account is deliberately deflationary about the contribution of neuroscience to immediate practice. It does not identify any classroom technique that follows from neural evidence and not from behavioural evidence, which is consistent with the sceptical position (Bowers, 2016; Howard-Jones, 2014). Its value is different: it constrains what can be claimed, it identifies which professional recommendations are biologically implausible, and it specifies the measurements that would adjudicate between competing explanations. Teacher-facing neuroscience literacy may serve a related function, altering how teachers conceptualise learning and their own agency without prescribing techniques (Dubinsky *et al*., 2013, 2022; Immordino-Yang *et al*., 2019; Jolles & Jolles, 2021).

Table 5 sets out which relationships within the account are established, which are plausible but untested in teaching populations, and which are unsupported. The distinction is the central analytical contribution of this review, because the field's principal weakness is not the absence of evidence but the routine presentation of relationships from the second and third categories as if they belonged to the first. Reading down the confidence column shows that no link running from a neural mechanism to an instructional outcome in teachers currently qualifies as established.

Table 5. Established, plausible and unsupported relationships within an integrated neurobiopsychological account of inspirational teaching

Proposed relationship	Evidential status	Basis for the classification	What would change the classification	Supporting references
Perceived control over work reduces strain in teachers	Established at the psychological level	Consistent associations across independent teacher samples, though predominantly cross-sectional	Longitudinal or intervention designs with objective strain outcomes	Lee & Nie (2014); Skaalvik & Skaalvik (2014); Tsang *et al*. (2022)
Controllability appraisal buffers stress responding through prefrontal inhibition of stress circuitry	Established in animals; plausible in teachers	Direct causal manipulation in rodents; no human occupational test	Human studies measuring perceived control and prefrontal regulation concurrently	Amat *et al*. (2005); Maier & Seligman (2016)
Meaningfulness sustains effort under delayed and uncertain returns	Plausible; untested in teachers	Effort allocation is value-sensitive in laboratory paradigms; purpose framing improves persistence in students	Diary or intervention studies in teachers with effort-based outcomes	Salamone *et al*. (2007); Wiehler *et al*. (2022); Yeager *et al*. (2014)
Eudaimonic well-being has a specific peripheral inflammatory signature	Unsupported	Original finding did not survive independent reanalysis	Adequately powered preregistered replication	Brown *et al*. (2014); Fredrickson *et al*. (2013)
A general professional agility can be trained and transfers across teaching demands	Unsupported	Measures show weak discriminant validity; executive-function training transfers narrowly	Independent validation of measures plus randomised training trials with transfer outcomes	Diamond (2013); DeRue *et al*. (2012); Smith & Watkins (2024)
Chronic occupational	Plausible;	Convergent cross-sectional	Prospective imaging	Arnsten (2009);

Proposed relationship	Evidential status	Basis for the classification	What would change the classification	Supporting references
strain degrades prefrontal regulatory capacity	demonstrated outside teaching	imaging in occupationally exhausted adults from a small number of groups	cohorts including teachers	Blix *et al*. (2013); Savic (2015)
Teacher burnout has a characteristic cortisol profile	Unsupported	Systematic review found no consistent biomarker association	Standardised multi-sample protocols in large teacher cohorts	Danhof-Pont *et al*. (2011)
Teacher occupational state corresponds to pupil physiology	Plausible; single-study evidence	One cross-sectional study with adjusted models; direction unresolved	Replication with longitudinal design and behavioural outcomes	Oberle & Schonert-Reichl (2016)
Inter-brain synchrony causes learning	Unsupported as causal; established as correlate	Correlational designs cannot license causal inference; meta-analytic association is moderate	Multi-brain stimulation or comparable causal manipulation	Novembre & Iannetti (2021); Zhang *et al*. (2022)
Teacher affective state transmits to students through observable instructional behaviour	Established at the behavioural level	Replicated multilevel findings in classroom samples	Experimental manipulation of displayed behaviour	Frenzel *et al*. (2009); Keller *et al*. (2016)

Note. "Established" denotes replicated evidence from designs adequate to the claim; "plausible" denotes mechanistic evidence from populations other than teachers or from designs that cannot support the causal claim made; "unsupported" denotes claims contradicted by replication attempts or resting on measures of inadequate validity

10. Future Directions

The priorities set out below are ordered by the extent to which they would resolve interpretive ambiguity in the existing evidence rather than by feasibility.

The first and most consequential requirement is prospective measurement of allostatic and regulatory indices in teaching populations. Current inferences about the biological cost of teaching rest on cross-sectional imaging of occupationally exhausted adults drawn largely from non-teaching occupations and from a small number of research groups (Blix *et al*., 2013; Savic, 2015; Savic *et al*., 2018), and on a biomarker literature that has not converged (Danhof-Pont *et al*., 2011). What is needed is a cohort of early-career teachers followed across at least five years, with repeated measurement of prefrontally dependent executive performance, structural and resting-state imaging at intervals, standardised multi-sample cortisol protocols with documented adherence, and concurrent occupational records of workload, discretion and attrition. Outcome measures should include observed instructional quality alongside self-reported strain, because the prediction that regulatory degradation manifests first in instructional responsiveness cannot be tested with self-report alone. Such a study would settle whether the structural findings reflect consequence or vulnerability, which no current design can do.

The second priority is to test the proposed coupling between meaningfulness and effort sustainability. The theoretical claim is that perceived value of instructional work moderates the rate at which a given workload produces exhaustion, deriving from cost-benefit accounts of fatigue (Boksem & Tops, 2008; Wiehler *et al*., 2022). This is testable at moderate cost using intensive longitudinal designs, in which teachers provide repeated within-day measures of perceived meaning, effort and fatigue alongside objective indices of workload and, where feasible, end-of-day performance on effort-based decision tasks. A design of this kind would distinguish between the hypothesis that meaningfulness prevents depletion and the alternative that it alters the willingness to tolerate it, which have different implications for intervention.

The third priority concerns the agility construct. Before any biological investigation is warranted, the measurement problem must be addressed, since instruments with weak discriminant validity cannot support specific mechanistic claims (Smith & Watkins, 2024). The appropriate next step is independent psychometric work establishing whether teacher adaptability measures capture variance beyond general mental ability, openness, self-efficacy and emotional stability, followed by criterion validation against observed instructional response to genuinely novel classroom situations. Only if incremental validity is demonstrated does the neurocognitive question become tractable, and it should then be framed in terms of the stability-flexibility trade-off rather than flexibility alone (Uddin, 2021).

The fourth priority is causal work on interpersonal neural coupling. The correlational ceiling of hyperscanning is now well recognised (Novembre & Iannetti, 2021), and the field's next contribution depends on designs that manipulate rather than observe coupling, or that at minimum implement rigorous control conditions distinguishing interpersonal coupling from shared stimulus-driven variation. Preregistration of frequency bands, connectivity metrics, time windows and surrogate procedures is a minimum requirement given the analytic flexibility of the method. Sample sizes should be planned against realistic effect estimates from existing quantitative synthesis rather than against convention (Zhang *et al*., 2022). A parallel line of work should test whether the practically relevant classroom effect can be obtained without appeal to coupling at all, for instance by testing the prediction from social baseline reasoning that perceived teacher availability reduces individual regulatory demand in learners (Coan & Sbarra, 2015).

The fifth priority is a direct comparison of individual-level and organisational-level intervention. The correlational evidence identifies working conditions, discretion and administrative support as principal determinants of teacher strain (Nguyen, Pham, *et*

al., 2020; Zhou *et al*., 2024), whereas nearly all trial evidence targets individual coping (Iancu *et al*., 2018; von der Embse *et al*., 2019). A factorial trial in which schools are randomised to a validated individual programme, a workload and discretion intervention, both, or neither, with common outcomes measured over at least one academic year, would test the individualisation critique empirically rather than rhetorically (Wilkins *et al*., 2025). Outcomes should include retention, observed instructional quality and at least one physiological index, and follow-up should extend beyond the immediate post-intervention period, since short follow-up is a recognised weakness of the existing trials.

The sixth priority is methodological standardisation for field psychophysiology in classrooms. Heart rate variability is an attractive index because it is inexpensive and unobtrusive, but its interpretation requires control of respiratory and metabolic confounds that classroom settings maximise (Grossman & Taylor, 2007). Development and validation of a reporting standard for classroom-based autonomic measurement, specifying posture, speech, physical activity and respiratory covariates, would make the accumulating body of such studies interpretable and comparable.

A longer-term direction concerns the measurement of inspiration itself. No physiological index has been validated for the state, and proxies drawn from awe and elevation research have not been shown to correspond to it (Oleynick *et al*., 2014; van Elk *et al*., 2019). Progress requires an elicitation paradigm with acceptable ecological validity for instructional contexts, validated against the established self-report structure, and tested for convergence with behavioural indices of the approach-motivational component. Until such a paradigm exists, neurobiological claims about inspiration in teaching will remain claims about adjacent states.

Two cross-cutting requirements apply to all of the above. Geographical representation must widen, since the empirical base is drawn overwhelmingly from North American, European, Australasian and East Asian school systems, and the working conditions that drive teacher strain differ substantially across systems facing the largest workforce shortfalls (United Nations Educational, Scientific and Cultural Organization, 2024). Studies must also report null and disconfirming findings, since the interpretive problems identified throughout this review, from biomarker inconsistency to contested transcriptional findings, are precisely those that selective reporting produces.

11. Conclusions

Inspirational teaching is a real and consequential phenomenon that is not currently explained by neuroscience, and the review's central conclusion is that the gap between what is claimed and what is demonstrated is wide, systematic and remediable.

Of the four constructs examined, empowerment has the most secure mechanistic anchor. The demonstration that behavioural control alters the consequences of an otherwise identical stressor, and that a specific prefrontal region detects the presence of control, gives the psychological literature on teacher autonomy a coherent biological rationale. The rationale remains an inference across levels of analysis, because no study has measured perceived professional control and its putative neural mediators in the same individuals. Meaningfulness has a plausible reward-related basis in the engagement of ventromedial prefrontal and ventral striatal circuitry by self-relevant valuation, and it has robust observational support at the level of long-term health outcomes, but its most widely cited peripheral biological signature did not survive independent reanalysis and should not be cited as established. Agility is the weakest of the four. The neurocognitive literature on flexibility is sound, but the professional construct that borrows its name is measured by instruments with weak discriminant validity, and the assumption that flexibility is uniformly beneficial is contradicted by evidence that flexibility and stability trade off. Sustainability is the best evidenced at the level of occupational outcome and the least secure at the level of biomarker. Burnout overlaps substantially with depression, has no reproducible endocrine profile, and is nevertheless routinely described in biological terms that the evidence does not support.

The transmission of inspirational states from teacher to learner is best supported at the behavioural level, where teacher affect and displayed enthusiasm predict student affect and engagement in replicated multilevel designs. Interpersonal neural synchrony in classrooms is a genuine and internally consistent finding, moderately associated with learning outcomes across studies, and it should be understood as a marker of joint engagement rather than as a demonstrated mechanism of learning. The causal test that would justify the stronger interpretation has not been performed.

Read together, these conclusions support an account in which empowerment, meaningfulness, agility and sustainability function as coupled regulatory processes rather than as independent professional virtues. Discretion protects regulatory capacity; regulatory capacity enables responsive instruction; perceived value sustains effort whose returns are delayed; and cumulative strain degrades the prefrontal systems on which the others depend. The account is coherent, it generates specific and testable predictions, and every one of those predictions remains untested in teaching populations.

The practical implication is a matter of restraint as much as of direction. Nothing in the reviewed evidence identifies an instructional technique that follows from neural findings rather than from behavioural ones. What the evidence does support is scepticism towards professional development that promises brain-based enhancement of teaching, attention to the structural determinants of discretion and workload rather than to individual coping alone, and recognition that the capacity for inspiring teaching is a biological resource that working conditions can either protect or erode.

12. Limitations

This review is a narrative synthesis and carries the limitations intrinsic to that design. Selection of sources was purposive and iterative rather than exhaustive and sequential, and although search concepts, sources and eligibility rules were specified in advance and are reported in full, the possibility of selection bias and interpretive bias cannot be excluded. A different reviewer applying the

same criteria might have weighted the contested findings differently, particularly in the sections dealing with peripheral biomarkers and inter-brain coupling, where the interpretation of a mixed literature involves judgement.

Searching was restricted to sources accessible without subscription, and the review therefore does not incorporate records available only through subscription-based citation indexes. Records in languages other than English were not screened, which is likely to have reduced coverage of research from systems facing the most acute workforce pressures and to have reinforced the geographical concentration noted throughout. The evidence base is drawn predominantly from North American, European, Australasian and East Asian settings, and the generalisability of findings on discretion, workload and strain to other education systems is uncertain.

The literatures synthesised differ so substantially in design, measurement and unit of analysis that quantitative synthesis was neither possible nor appropriate, and comparisons of evidential strength across constructs are therefore qualitative judgements rather than calculated contrasts. Much of the occupational evidence is cross-sectional and single-source, which limits inference about direction and inflates associations through shared method variance. Much of the neural evidence derives from small samples in task-based paradigms whose replication status is unknown, and several key mechanistic findings come from a small number of research groups working with overlapping participant pools. Long-term evidence is scarce across all four constructs, and no study identified followed teachers for a period sufficient to observe the cumulative processes the review describes.

Two fields covered here are developing quickly. Classroom hyperscanning and the measurement of occupational strain are both subject to rapid methodological change, and conclusions about their evidential status reflect the position at the final search date rather than a settled assessment. Finally, the integrated account offered in Section 9 is a synthesis derived from the reviewed evidence rather than a validated model, and its constituent relationships carry the differing levels of confidence stated explicitly in the accompanying analysis.

Consent

It is not applicable.

Ethical Approval

It is not applicable.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Author has declared that no competing interests exist.

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