* Mit Wearables einsteigen 🡪 hohe Akzeptanz, non-invasiv/ nicht störend/ non-intrusiv, wird von vielen getragen, Lehrer:innen tragen das sowieso, Menschen tracken ihre Parameter 🡪 welche Parameter ergeben sich daraus für Lehrpersonen (Begründung, dass wir Stress mit Fitnesstrackern erhoben haben) 🡪 Übergang zu Teacher Stress
* Verbreitung von Fitness Trackern generell in Bevölkerung (Verkaufszahlen, wie viele Leute/ Lehrpersonen tragen sie; Fitbit kann als Bsp. aufgeführt werden)
* Mehr Theorie zu Classroom Management 🡪 **Kompetenz**, die Lehrpersonen haben sollten (subjektive Stör- und Sicherheitserleben, Berufserfahrung, usw.) 🡪 Appraisal nicht über Self-Efficacy (SE) laufen lassen 🡪 SE komplett rauslassen
* Lazarus-Modell mehr einbinden (über Job-Demand-Resources-Modell belesen 🡪 auch hier wird Bedeutung von Ressourcen betont, um zu untermauern, dass wir uns auf valide Sichtweise stützen)
* Tobias Kärner / Kyriacou-Modell anschauen und an unser Setting anpassen (Teacher characteristics: Berufserfahrung)
* Typischer Stressor: Störung (aber gesamte Micro-Teaching-Unit betrachtend, nicht einzelne Störungen); typische Ressource: Erfahrung im Umgang damit
* Im Theorieteil: Stress baut sich auf, vor stressiger Situation geht HF bereits in Höhe
* First page (Introduction) vorschreiben
* Im Diskussionsteil: begründen, dass wir uns nicht einzelne Störungen angeschaut haben, sondern die Gesamtlektion (da Stress kumulativ entsteht und es zeitliche Verzögerungen gibt bei Arousal; aaaaußerdem: Daten lassen Analyse nicht zu)
* Wearables 🡪 HR als ein Parameter, der erfasst wird und ein Indikator für Stress 🡪 Stress im Lehrberuf (Lazarus-Modell) 🡪 Classroom-Management als professionelle Kompetenz

# Introduction

In the last decade, commercial wearables have become increasingly popular and accepted among the wider population. The impact of these devices comes in concrete data: Valued at USD 61.30 billion in 2022, the market for wearable technology has experienced robust growth and is expected to continue to expand with an annual growth rate of 14.6% from 2023 to 2030 [@https://www.grandviewresearch.com/industry-analysis/wearable-technology-market]. International Data Corporation (IDC), a global provider of market research and advisory services for the technology industry, reports that the substantial growth in the wearable market has primarily been driven by smartwatches and wrist-worn fitness trackers [@richter2018global]. The most frequently used wearables in research projects are Fitbit, Garmin, Misfit, Apple, and Polar. These brands, already existing for several years, have shipped a substantial quantity of devices [henriksen2018using].

In addition to the ease of use, perceived usefulness, and enjoyment [@peng2022acceptance], the success of these devices is based on the fact that they are equipped with biosensors providing users with behavioral (e.g., step count, distance walked) and physiological data (e.g., HR, skin temperature). The general public is thus offered the opportunity to use low-cost, lightweight devices to monitor their physical activity and health routines in their everyday lives. In contrast to occasional clinical observations, they enable the collection of big data over a longer period, whereby wrist-worn wearables are less intrusive than complex medical devices (e.g., electrocardiograms) that have to be attached to the body [@godfrey2018z].

The use of wearables has already been investigated across a wide range of domains, such as medicine [@hughes2023wearable; @yetisen2018wearables], sports [@secckin2023review; @ adesida2019exploring] or entertainment [@helmer2009smart; @cciccek2015wearable]. In educational contexts, research about the use of wearables is meager.

* Arriba-Pérez (2017) 🡪 S. 324: use of wearables in educational contexts

While there are studies on how wearables can be used in the educational context to support teachers in monitoring student activity in the classroom [@quintana2016keeping; @de2017towards], there is a research gap on the use of wrist-worn wearables by teachers. Especially wrist-based fitness trackers, which are being used by the majority of the population anyway, could offer the possibility of analyzing physiological parameters to gain deeper insights into the stress and strain experienced by teachers which is particularly relevant due to the increased stress levels in the teaching profession [Referenz].

HR measurements as a parameter that is measured by most fitness trackers are becoming increasingly important in research on stress experience. They represent an important physical and emotional stress indicator, as an increased workload is associated with increased HR [@sachs2014]. Furthermore, they allow a more objective recording of stress than self-reports without interrupting the teaching process [@runge2020].

However, capturing HR in an educational context at scale requires the use of low-cost and non-intrusive instruments. Fitness trackers worn on the wrist have the potential to be a promising tool in this context [@ferguson2015].

To date, few studies use fitness trackers in teaching and learning settings often with very small samples [@ertzberger2016; @lowe2016]. @runge2020 alone examined teacher stress and showed that high HR indicates more stress in teachers (\*N\* = 4 teachers). Robust studies on whether fitness trackers are efficient, low-cost, and robust measurements for assessing teachers' physiological stress during teaching remain a desideratum.

Therefore, this study examined whether HR measures using fitness trackers are suitable for capturing differences in physiological arousal between pre-teaching, teaching, and post-teaching phases. Considering the relevance of cognitive appraisal in classroom management, we additionally tested teachers’ self-report data as a predictor for high HR measures in the teaching phase.

**## Wearable Devices**

Wearables (also referred to as wearable devices, wearable computers, or wearable electronics, @cciccek2015wearable) are defined as electronic devices that are either directly worn on the body or loosely attached to a person and integrated into clothing or accessories to serve as a convenient all-in-one solution [@godfrey2018z]. Essentially, wearables are designed to be worn continuously by users, gathering data such as location, movements, and vital signs via wireless sensors enabling users to interact with these devices anytime and anywhere [@cheng2017underlying].

Attempts to classify wearables reveal different approaches in the literature: The IDC (2017) for example divided wearables into six categories: basic wristbands (fitness bands), basic watches (hybrid watches as the evolution of fitness bands), smartwatches (advanced watches with for example integrated apps), clothing (e.g., step-counting shoes), earwear and others [@idc2017shipments]. In contrast, @cciccek2015wearable classified wearables into three categories (wearable health technologies, wearable textile technologies, and wearable consumer electronics) and stated that wearables must be characterized by attributes such as hands-free operatable, portable, useful, reliable, practical, multi-functional, mobile, socially acceptable, etc. (p. 46).

In the last decades, wearable technologies such as fitness trackers have become widely popular and accepted as a mass product by the population [@park2020user]. Several factors contribute to the widespread acceptance of these devices: Wearable technologies such as fitness trackers excel at monitoring various aspects of physical activity, including HR measurements, distance traveled, steps taken, or calories burned. This data provides users with valuable insights into their daily activity and cardiovascular health levels in their natural everyday lives, supporting them in setting personalized fitness and health goals [@nuss2021effects] or providing information about stress levels [@hao2018chrv]. Further advantages are the portable, non-invasive nature of these devices, the ease of use, and especially, the low costs compared to complex laboratory methods for determining vital parameters (e.g., HR, blood pressure, skin temperature, physical activity), @hajj2023].

The combination of these factors makes wearable devices such as fitness trackers an ideal technology for utilization in different domains such as healthcare, entertainment, and fitness purposes [sinha2019taxonomy]. Considering the features, benefits, and rapid adoption of these devices in recent years, some studies have also investigated their potential use in education as they represent a promising new technology that can offer additional advantages for formal and informal learning environments for both students and teachers [@koutromanos2020use].

@de2017towards pointed out that despite the scarcity of existing literature on wearables in the educational context, two different approaches can be identified: (1) On the one hand, there is research on wearables as educational tools to create particular projects and investigate their potential in teaching and learning situations @shadiev2018study, for example, showed that students performed best in learning English when using smartwatches. (2) On the other hand, there are studies using wearables to analyze physiological data from users in teaching-learning contexts to detect students' skills and improve their performance profiles. byun2018feasibility evaluated the practicality and effectiveness of an intervention with wearable fitness tracker devises to promote physical activity among preschoolers. Students utilizing the wearable device exhibited notably reduced sedentary behavior and increased overall physical activity levels.

However, in most studies, the focus is on students, especially to support their learning [@koutromanos2020use]. Despite the enormous potential of wearables, there is a desideratum of studies that deal with important recorded parameters and in particular their significance for teachers.

**# HR as a Vital Parameter and Indicator of Stress**

One important health parameter assessed by most wrist wearables is HR measurement. HR indicates the number of heartbeats within a certain time interval, which is usually heartbeats per minute and is therefore expressed in min-1 or beats per minute (BPM) [@hottenrott2007]. HR can be detected and measured using various methods via wearables, including sensors based on electrocardiogram (ECG) or phonocardiogram (PCG) [@mukhopadhyay2017wearable]. Another smart technique used by most fitness trackers on the market is photoplethysmography (PPG) which is an optical method with an inexpensive and non-intrusive technique to assess HR by flashing green lights to measure changes in blood volume [@allen2007photoplethysmography].

@sammito2015guideline stated in his guidelines for the application of HR the following points: At rest, the average HR (HRrest) of adults typically ranges from 60 to 80 BPM. The maximum HR (HRmax) can be reached during physical activity or exertion, but varies depending on individual factors such as age, sex, and fitness level and decreases with age. With the suggested formula *HRmax = 207 – 0.7 × age*, the HRmax of a 31-year-old person would be around 185 BPM, whereas sex or fitness level has not been considered in this formula.

Physiologically, HR is regulated and influenced on short-time intervals by the autonomic nervous system which is divided into two distinct components: the sympathetic and the parasympathetic nervous system [@pham2021]. An increase in the activity of the sympathetic, known as the “quick response” system, results in HR being speeded up (“fight or flight”). Increased activity of the parasympathetic as the counterpart known as the “relaxed response” system, has the effect of slowing down the HR (“rest and digest”) [@battipaglia2015].

In addition to the autonomic nervous system and genetic factors, human HR is influenced by numerous external factors such as social, personal, psychological, environmental, and behavioral factors [@wang2022] and depends largely on the intensity of strain “in response to physical and mental workload” [@sammito2015guideline, p. 1]. Physical and mental strain are therefore factors that directly influence HR and lead to an increase in HR [@custodis2014heart]. This can be explained by the fact that short-term or acute psychological stress activates the hypothalamic-pituitary-adrenal axis. The production of glucocorticoids by the adrenal glands then stimulates the cardiovascular tissue and provides feedback to the central nervous system to prevent activation of the hypothalamic-pituitary-adrenal axis. At the same time, stimulation of the cardiovascular tissue during stress causes an increased HR [@junker2021]. Accordingly, it can be assumed that stress-induced excitation of the sympathetic nervous system leads to activation of the cardiovascular system, which is why an increasing HR can be regarded as an indicator of increasing stress on the cardiovascular system [@kyriacou1978].

Although there are other physiological markers of the cardiac system’s activity as more accurate indicators of stress (e.g., HR variability), research indicates a strong correlation between stress measurements such as HR and HR variability [@rieger2014heart; @ vrijkotte2000effects]. Thus, HR serves as a reliable indicator of acute psychological stress.

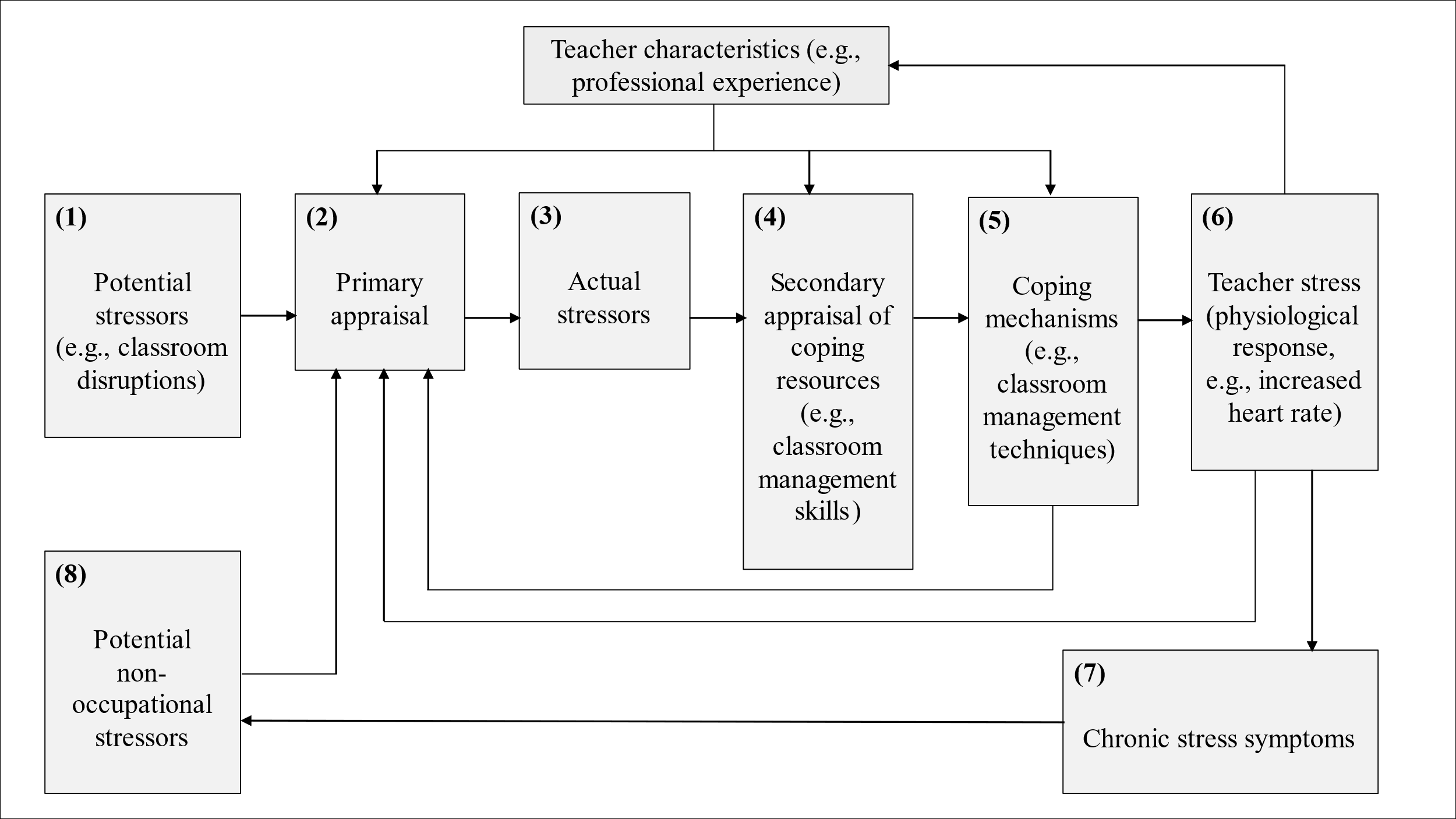
**## Stress in the Teaching Profession**

This correlation between stress and increased HR is particularly essential in the teaching-learning context, as the teaching profession is one of the most stressful professions compared to other occupational groups, facing a variety of stressors during everyday work [@smith2000; @herman2020].

However, we need to clarify what stress means and how it is caused. According to @kyriacou1978, teacher stress can be defined as

“a response of negative affect […] usually accompanied by potentially pathogenic physiological and biochemical changes (such as increased heart rate […]) resulting from aspects of the teacher's job and mediated by the perception that the demands made upon the teacher constitute a threat to his self-esteem or well-being and by coping mechanisms activated to reduce the perceived threat.” [@kyriacou1978, p. 2].

This definition of teacher stress is based on the ideas of the integrative framework of the transactional stress model by Lazarus and colleagues [@lazarus1981stressbezogene; @lazarus1984stress]. Lazarus' stress theory initially served as a model, which @kyriacou1978 subsequently modified and tailored to the teaching-learning environment [@dick2013belastung]. For our study, we adopted the model of @van2006stress who made slight modifications to the model of @kyriacou1978.

*Figure 1* A model of teacher stress (adapted from van Dick 2006, p.37, modified by the author)

The model highlights the interaction between an individual and the environment, whereby stress refers to any event that exceeds a person's adaptive resources [@lazarus1990theory]. This model will be explained using an example (based on @dick2013belastung): A teaching unit with classroom demands such as classroom disruptions [@karner2021teachers] is an objective aspect of a teacher's work and represents potential occupational stress factors in the teaching profession (box 1). If classroom disruptions occur, the teacher first evaluates the situation (box 2) either positively as a challenge, considers the disruption to be irrelevant, or negatively as a potential threat. The stress model is only relevant in the last case when potential stressors are evaluated as actual stressors (box 3). In the next step, during the second appraisal (box 4), the teacher considers whether he/she has sufficient resources available to deal with the stressors. In the best case, the teacher has both external (e.g., supportive colleagues) and internal (e.g., classroom management skills) resources at his/her disposal. During both primary and secondary appraisal processes, the individual characteristics of the teacher, such as teaching experience, play a particularly important role. Based on the evaluation of resources and his/her characteristics, the teacher will try to cope with the situation (box 5) and, for example, use classroom management strategies to stop the disruption. If the teacher is unable to cope, he/she experiences stress (box 6). Teacher stress is mainly characterized as a reaction to negative affect (e.g., anger or depression), which is generally followed by other symptoms that can be seen as reactions to teacher stress. The response of negative affect can be a psychological (e.g., job dissatisfaction), physiological (e.g., increased HR), and behavioral (e.g., absenteeism) stress reaction [huang2022class; @kyriacou1978]. Over the long term, if classroom disruptions occur again and again during teaching lessons and the teacher is unable to successfully manage the classroom due to insufficient effective classroom strategies, the result is chronic stress reactions (box 7). In addition, there may be burdens that are not directly related to the job (e.g., illness, financial difficulties) which, in addition to the professional demands, exhaust the teacher's resources and thus make it more difficult to cope with potential stressors (box 8).

For our research goals, we are particularly interested in potential stressors in the classroom such as classroom disruptions (box 1), and their impact on the physiological component in terms of an increased HR (box 6), which can be interpreted as an indicator of stress based on existing research [@clays2011perception; @schubert2009effects].

### HR in Teaching-Learning Contexts

In the educational context, there is a particular interest in finding adequate indicators and quantitatively measurable parameters for teacher stress and burnout [@fisher2011; @ junker2021]. Previous research on teacher stress often focused on the psychological experience of stress using self-report questionnaires with single-item measures (“I find teaching to be very stressful‖”) [@chaplain2008; @goker2012] or questionnaires with multiple scales (e. g. Teacher Stress Inventory; @fimian1990; @liu2020]. However, self-reported data in the measurement of stress raises concerns about the validity and accuracy of causal inferences for several reasons, including response biases such as social desirability [@razavi2001self] or recall bias [@van2016accuracy]. Because self-reported data fail to capture actual physiological stress responses in real-life situations, ambulatory assessment methods using a variety of assessments are recommended e.g., additional physiological measures such as HR as objective data [@trull2013ambulatory; @ wettstein2020ambulatory]. Furthermore, HR as a physiological measurement provides researchers with objective insights into teachers’ affectivity and stress levels without interrupting the teaching process [@donker2018; @runge2020]. To gain a more detailed insight into teacher stress, @wettstein2021 recommend, for example, measuring physiological parameters before, during as well as after teaching. Thus, measuring HR in teaching-learning contexts has enormous potential as it can enable teachers to independently identify stress responses and possible stressors during teaching to develop coping strategies, such as classroom management skills.

Despite this potential, there are only a few studies that investigated physiological indicators. The studies recorded teachers’ HR using expensive and intrusive electrocardiographs (ECG devices). The results revealed that HR as an indicator of stress can be used to map different HR courses during teaching depending on the teachers’ activity. The HR increased especially during teacher-centered activities when teachers had to take a leading position in the student-teacher interaction [@sperka1995; @scheuch1997psychophysische; @donker2018; @junker2021]. @sperka1995 for example recorded the HR of 16 pre-service teachers during their first lesson. The results showed that the first lesson is linked to significantly increased psychophysiological activation in terms of an increased HR. The activation effect was particularly prominent at the beginning of the lesson and decreased in the course of the lesson due to the pre-service teachers’ active coping processes, meaning that the active management of the interaction with the students helped the teachers regulate their HR.

Other studies that measured the teachers’ HR using electrocardiographs identified typical potential predictors for increased HR values such as typical stressors, e.g., class size [@huang2022class] or low student engagement and motivation [@junker2021]. @junker2021 for example recorded the HR of 40 teachers using an Ambulatory Monitoring System with seven electrodes during a real classroom lesson to find out to what extent main stressors within the classroom (e.g., low student engagement and motivation, teacher-centered activities) can predict teachers’ HR as an indicator of physiological stress during teaching. @junker2021 were able to prove that teacher stress caused by those stressors during teaching can be quantitatively measured by an increase in HR.

In addition to these studies that measured HR using cost-intensive and intrusive ECG devices, there are a few studies that used low-cost, wrist-worn fitness trackers to investigate HR trends in teaching-learning situations [@Darnell2019; @chalmers2021]. However, it is very important to note that these studies did not measure teachers', but college students' HR. @Darnell2019 for example measured the HRs of 15 medical college students using wrist-worn devices during lecture classes. The analysis revealed a constant decrease in HR from the beginning to the end of a lecture, whereas the HR peak was reached during active learning sessions. The researchers proposed the first robust measurements of HR changes during lectures and recommended using personal fitness trackers during various phases of learning and teaching. @chalmers2021 examined the usability of the average HR measured with a Fitbit fitness tracker of 30 medical students and 30 normative participants to identify physiological changes during stress tasks, whereas the average HR increased significantly between the resting and stress phases for both groups.

So far, only one study known to the author has combined both aspects (hand-worn wearable and recording of teachers’ HR): In the study conducted by @runge2020, HR was one of several parameters used to identify stress in four teachers based on physical characteristics using a Fitbit fitness tracker. Another aim was to find out to what extent affordable fitness trackers and the provided parameters can be used to measure teacher stress. @runge2020 concluded that stress in the teaching profession can be mapped using fitness trackers' indicators. In particular, it was found that the combination of a high number of steps, a high HR, and short sleep is an indicator of stress and that poor student behavior is the stressor that is perceived most frequently. It should be noted that the generalizability of the results is limited due to the small sample size of four participants.

The studies show that the HR of teachers (and students) changes depending on the activity and stressors during teaching, whereby teacher-centered phases and less engaged students in particular lead to an increase in the HR. To gain a more detailed insight into these processes of the development of teacher stress, it is relevant to look at the individual phases between potential stressors (box 1) and the occurrence of teacher stress (box 6) in the model (see Fig. 1).

### Classroom Disruptions as Potential Stressors

The causes of teacher stress are diverse and the investigation of these is relevant, as it has been shown that there are important connections between stress and resources on the one hand and stress-induced health issues on the other [@krause2013messung]. Student misbehavior such as classroom disruptions, disrespect, and disciplinary problems is one of the most influential stressors and key risk factors for teacher health [@boyle1995structural; @aloe2014multivariate]. @ aldrup2018misbehavior found in their research that teachers who perceive more misbehavior also reported decreased work enthusiasm and increased emotional exhaustion. A positive relationship between teachers and students is therefore crucial for the professional well-being of teachers and thus also influences the perception of stress and strain.

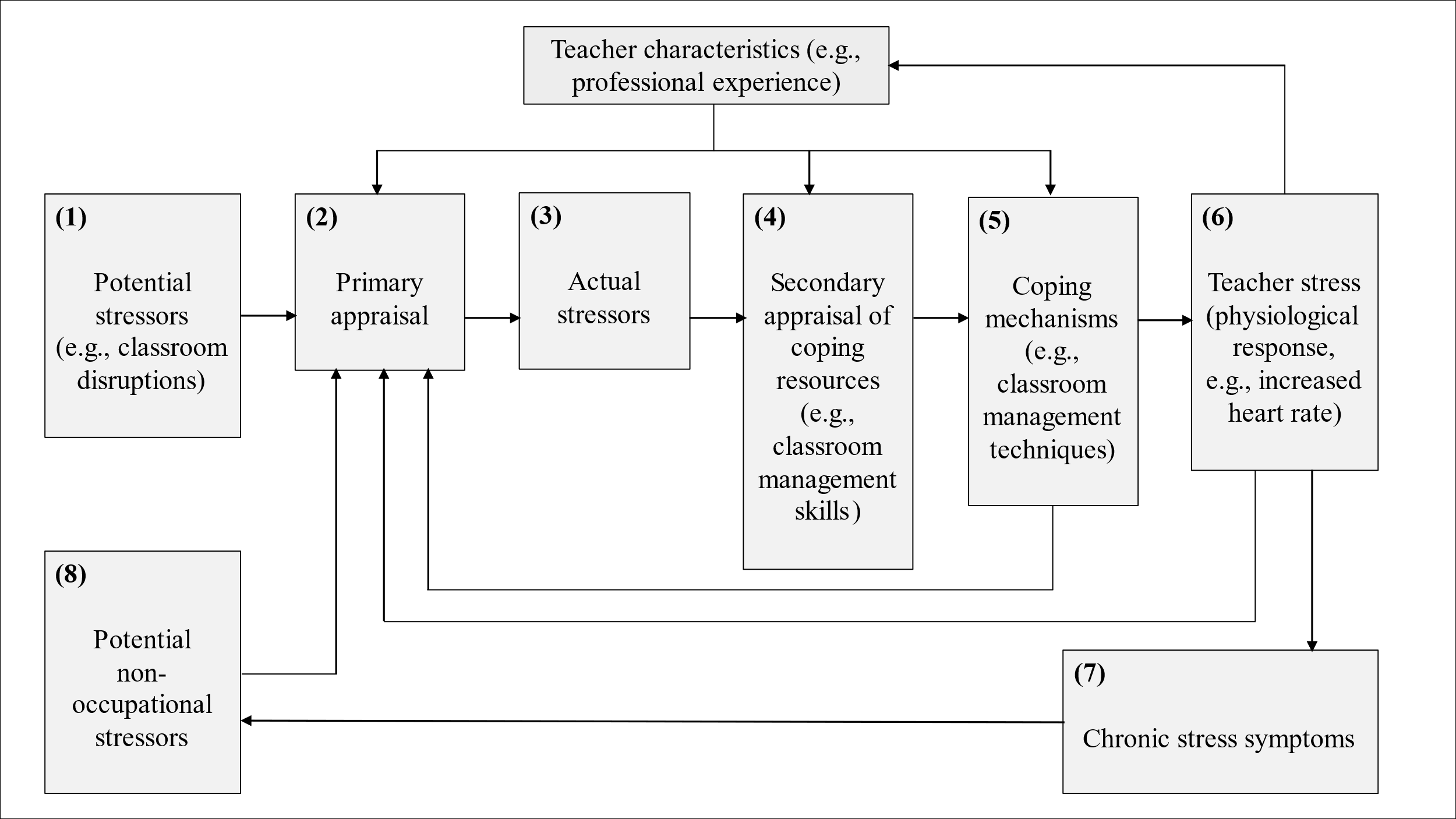
In contrast to disciplinary conflicts and disrespect, classroom disruptions are linked to the teaching process. They can be defined as “events that impair, interrupt or make the teaching-learning process impossible by partially or completely overriding the conditions under which teaching and learning can take place” [own translation, @lohmann2007schulern, 13]. Classroom disruptions can be differentiated according to various aspects, e.g., intensity and severity [@steins2010]; active and passive disruptions [@scherzinger2018aggressive]; focusing on the teaching-learning process [@lohmann2007schulern].

@eckstein2022 emphasizes that the term *classroom disruption* can be used when at least one person involved in the teaching-learning process is disturbed in their thought process or emotional experience. A teaching disruption can therefore be regarded as a co-constructivist phenomenon [@eckstein2022].[[1]](#footnote-1) Classroom disruption can occur in the context of a multifactorial structure, whereby two fundamental processes interact with each other: behavior that deviates from the norm and the subjective perception of disruption. Whether an incident is perceived as a classroom disruption depends on the subjective appraisal of the recipient, whereas the context, the teaching experience, and the personality traits of the disrupted and the disruptive person need to be taken into account [@eckstein2016].

In this regard, parallels to the transactional stress model emerge very clearly: When faced with stressors such as classroom disruptions, teachers assess both the stressors' relevance (primary appraisal) and their capacity for overcoming stress (secondary appraisal). How teachers evaluate the demands placed on them depends on the interaction between their characteristics such as biographical details (e.g., teaching experience) and their perception of the demands. Primary and secondary appraisals are regarded to have an impact on teachers coping mechanisms. Coping strategies in turn have an impact on the immediate stress reaction, long-term health, psychological well-being, and social functioning [@kyriacou2001; @obbarius2021].

### Classroom Management Skills and Professional Experience as Resources

As @kyriacou2001 emphasizes, it is essential to consider the identified sources of teacher stress within the framework of a teacher’s perception, individual traits, and environmental factors.



The model highlights the interaction between an individual and the environment, whereby stress refers to any event that exceeds a person's adaptive resources. The model proposes that personal cognitive appraisal processes have a significant impact on a stress reaction. It is critical to distinguish between two types of cognitive appraisal: When faced with stressors, a person assesses both the stressors' relevance (primary appraisal) and their capacity for overcoming stress (secondary appraisal). How teachers evaluate the demands placed on them depends on the interaction between their characteristics and their perception of the demands. Teachers’ characteristics such as biographical details (e.g., sex, age, teaching experience) may be of high importance for the appraisal. Primary and secondary appraisals are regarded to have an impact on a person's coping mechanisms. Coping strategies in turn have an impact on the immediate stress reaction, long-term health, psychological well-being, and social functioning [@obbarius2021].

Stress includes in addition to motivational and cognitive components physiological aspects [@blascovich1999]. Thus, the response of negative affect can be a psychological (e.g., job dissatisfaction), physiological (e.g., increased HR), and behavioral (e.g., absenteeism) stress reaction [huang2022class; @van2001stress]. Psychosomatic stress symptoms such as an increasing HR result from an interaction of situational stressors and person-specific available resources [@rotter2020]. Stressors are considered antecedents of teacher stress and can be classified as physical (e.g., class size), psychological causes (e.g., student misbehavior), or a combination of both physical and psychological (e.g., high workload) [@chen1997teacher].

### Fitness Tracker in Educational Contexts Assessing HR

Most of the studies were conducted in the context of sport and health to evaluate the accuracy of wrist-worn fitness trackers. To date, there have only been a few studies using wrist-worn fitness trackers in the field of education to examine the relation between physiological, psychological, and other phenomena experienced by teachers and (college) students.

In a pilot study, @pakhomov2020 examined the HR data of college students using Fitbit devices. In addition to the HR data, the subjective self-assessment of everyday stressors was collected and evaluated. @pakhomov2020 showed, using Fitbit fitness trackers, that inexpensive smartwatch wearables are suitable for detecting both standardized and naturally occurring psychosocial stress.

In their study, @wang2020 researched the influence of social, psychological, personality-related, and behavioral factors on the HR measured with Fitbit fitness trackers of over 600 college students and concluded that HR increased with an increasing number of social contacts, indicating that HR is not only a physiological but also a social-psychological phenomenon.

@shachter2022 investigated the relationship between HR recorded via Fitbit fitness trackers and self-reported data in foreign language speaking performance in 10 university language students during three seminar sessions and found that there were correlations between self-reported negative feelings and increased HR in students.

Since the 1970s, increasing efforts have been made to realize precise measurements of HR in mobile form, as it was only possible with the ECG at that time. These efforts were driven in particular by competitive sport, resulting in the first portable HR measuring devices in the form of chest straps and wristbands being used only in this field. In the meantime, HR measurements and the associated monitoring of individual stress levels have become established both in the fitness sector and in competitive sports [@hottenrott2007].

This development has led to commercial wearable fitness trackers becoming increasingly popular among the wider population in the last decade to record physical activity in everyday life or in the context of health-promoting research [@jachymek2021; @gagnon2022; @feehan2018accuracy; @fuller2020; @jo2016; @hajj2023]. This can be explained by the low costs compared to complex laboratory methods for determining vital parameters (e.g., HR, blood pressure, skin temperature, physical activity), the portable, non-invasive nature of these devices, and the ease of use [@hajj2023]. The majority of fitness trackers on the market assess HR using photoplethysmography (PPG), which is an optical method with an inexpensive and non-intrusive technique to assess HR by flashing green lights to measure changes in blood volume [@allen2007photoplethysmography]. Among all fitness trackers, Fitbit devices are one of the most popular wearables and have been used in most studies [@fuller2020].

In teaching-learning contexts, physiological measurements such as HR provide researchers with objective insights into teachers’ affectivity without interrupting the teaching process [@donker2018]. Thus, it is important to monitor HR accurately since this marker may be used to identify an individual’s level of experienced stress during an activity. As a result, there are a large number of scientific publications that deal with the validity and reliability of the parameters measured by fitness trackers [@montoye2017comparative; @muggeridge2021measurement; @gagnon2022; @fuller2020; @jo2016; @hajj2023; @jachymek2021]. Research on the reliability of Fitbit devices for the measurement of HR showed that this brand is accurate in controlled settings, depending on the activity level [@wallen2016accuracy; @hajj2023; @fuller2020; @jo2016]. For example, the Fitbit fitness tracker showed good measurement accuracy during resting phases [@jo2016; @muggeridge2021measurement] and for activities such as walking, jogging, and running [@hajj2023]. Findings in some studies indicate that the Fitbit fitness tracker showed a decrease in accuracy by underestimating the HR, especially at higher exercise intensities such as cycling [@thomson2019heart; @montoye2017comparative; @jo2016; @jachymek2021].

However, @chevance2022accuracy concluded in their systematic review and meta-analysis of Fitbit fitness tracker measures that the underestimation of HR has an acceptable range and that the accuracy depends on the context (e.g., quality of the study, type of activity). @gagnon2022 also sums up in his study that Fitbit devices can be used in research to detect stress-induced HR variation, but they cannot replace an ECG machine when precision is of the greatest importance.

## Assessing HR

In stress research, there is a particular interest in finding adequate indicators and quantitatively measurable parameters for teacher stress and burnout [@fisher2011; @ junker2021; @runge2020]. Previous research on teacher stress often focused on the psychological experience of stress using self-report questionnaires with single-item measures (“I find teaching to be very stressful‖”) [@chaplain2008; @goker2012] or questionnaires with multiple scales (e. g. Teacher Stress Inventory; @fimian1990; @liu2020].

There are only a few studies that investigated physiological indicators such as HR as an indicator of teacher stress during teaching-learning situations [@sperka1995; @scheuch1997psychophysische; @donker2018; @junker2021; @runge2020; @huang2022class].

@sperka1995 for example recorded the HR of 16 pre-service teachers during their first lesson. The results showed that the first lesson is linked to significantly increased psychophysiological activation in terms of an increased HR, whereas the activation effect was particularly prominent at the beginning of the lesson and decreased in the course of the lesson due to the pre-service teachers’ active coping processes (active management of the interaction with the students).

@scheuch1997psychophysische assessed the HR of 67 teachers during five real lessons, with results showing that the highest HR occurred during organizational activities, followed by teaching activities where the teacher directed the interaction.

@donker2018 investigated 80 teachers’ HR as a proxy for their affective response during a regular classroom lesson and coded their interpersonal behavior during teaching. The results indicated that teachers showed an increased HR when they had a leading role in student-teacher interactions.

@junker2021 recorded the HR of 40 teachers during a real classroom lesson to find out to what extent main stressors within the classroom (e.g., low student engagement and motivation, teacher-centered activities) can predict teachers’ HR as an indicator of physiological stress during teaching. @junker2021 were able to prove that teacher stress caused by stressors during teaching can be quantitatively measured by an increase in HR. In particular, teachers’ HR increased during teacher-related activities and when students showed less engagement and motivation.

In the study by @runge2020, HR was one of several parameters used to identify stress in four teachers based on physical characteristics using a Fitbit fitness tracker. Another aim was to find out to what extent affordable fitness trackers and the provided parameters can be used to measure teacher stress. @runge2020 concluded that stress in the teaching profession can be mapped using fitness trackers' indicators. In particular, it was found that the combination of a high number of steps, a high HR, and short sleep is an indicator of stress and that poor student behavior is the stressor that is perceived most frequently.[[2]](#footnote-2)

@huang2022class conducted a randomized, controlled experiment with 65 pre-service teachers. In a standardized virtual reality classroom, they investigated whether class size has a direct effect on physiological (HR) or psychological (subjective evaluation) stress reactions which could be confirmed for both aspects.

## Classroom Disruptions and Subjective Cognitive Appraisals

The relevance of measuring HR as an indicator of teacher stress is obvious: If teachers are exposed to a teaching-learning environment that they evaluate as stressful or disruptive (subjective disruption appraisal) over a long period and if they do not feel confident to deal with or overcome these disruptive situations (subjective confidence appraisal) because they have no sufficient resources and coping strategies, it can lead to negative personal and vocational consequences such as burnout, high turnover, and premature retirement [@jalongo2006; @unterbrink2007; @aloe2014]. Teacher stress is therefore an important aspect of the way teachers behave and react in the classroom.

However, according to the biopsychosocial model, an increased HR is an indicator of a situation that is judged by an individual to be goal-relevant and that requires attention as well as overt or cognitive action [motivated performance situations; @blascovich1996]. It is therefore difficult to use HR alone to distinguish between positive and negative psychological reactions to a situation. For this reason, it is necessary to assess other parameters, such as self-reported data of the cognitive appraisal of situations, to be able to distinguish whether participants in a study felt threatened or positively challenged in a situation [@blascovich1996].

Student misbehaviors such as classroom disruptions, disrespect, and disciplinary problems are some of the most influential stressors [@boyle1995structural; @aloe2014multivariate]. In contrast to disciplinary conflicts and disrespect, classroom disruptions are linked to the teaching process. They can be defined as “events that impair, interrupt or make the teaching-learning process impossible by partially or completely overriding the conditions under which teaching and learning can take place” [own translation, @lohmann2007schulern, 13]. Classroom disruptions can be differentiated according to various aspects (e.g., intensity and severity [@steins2010] or active and passive disruptions [@scherzinger2018aggressive]. @lohmann2007schulern for example distinguished four categories: verbal disruptive behavior (e.g., chatting, heckling), lack of eagerness to learn (e.g., looking at the phone, putting the head on the table), physical disruptive (e.g., clicking with a pen, drumming with the hands on the table), and aggressive behavior (e.g., attacking or insulting classmates).

### Subjective Disruption Appraisal of Classroom Events

@ aldrup2018misbehavior found in their research that teachers who perceive more misbehavior also reported decreased work enthusiasm and increased emotional exhaustion. A positive relationship between teachers and students is therefore crucial for the professional well-being of teachers and thus also influences the perception of stress and strain.

However, the moment when an action or behavior in the classroom is considered disruptive depends on the subjective perception of the respective actors [@siestrup2010]. Therefore, the transition between “normal” and “disruptive” behavior in the classroom is fluid [@nolting2017storungen]. Verbal comments or glances can be disruptive for one person, while another misses them [@steins2010]. @eckstein2022 emphasizes in this regard that the term *classroom disruption* can be used when at least one person involved in the teaching-learning process is disturbed in their thought process or emotional experience. A teaching disruption can therefore be regarded as a co-constructivist phenomenon [@eckstein2022].[[3]](#footnote-3) Classroom disruption can occur in the context of a multifactorial structure, whereby two fundamental processes interact with each other: behavior that deviates from the norm and the subjective perception of disruption. Whether an incident is perceived as a classroom disruption depends on the subjective appraisal of the recipient, whereas the context, the teaching experience, and the personality traits of the disrupted and the disruptive person need to be taken into account [@eckstein2016].

### Self-Efficacy and Subjective Confidence Appraisal of Classroom Events

Students likewise feel disturbed in class, though they are on average less sensitive than teachers [@infantino2005; @montuoro2014student]. The explanation for this lies in the linkage of actors' perceptual patterns to their roles [@wettstein2016classroom] and personal and contextual factors [@eckstein2018; @makarova2014perception].

Personal characteristics on the teacher's side can be a low sense of self-efficacy, which refers to the subjective evaluation of the controllability of situations. In general, self-efficacy should be assessed in a domain-specific context. As a result, assessing teachers' job-related self-efficacy becomes crucial, gauging their subjective confidence in meeting the typical demands of their profession. Consequently, teachers with high self-efficacy are less susceptible to job-related stress and strain, as they are confident in their ability to perform successfully [@schwerdtfeger2008self].

Teaching self-efficacy in classroom management (as a sub-component of self-efficacy) means among other things the confidence and capability in dealing with misbehaving students [@emmer1991teacher]. Research has shown that self-efficacy is an important protective factor in preventing stress, emotional exhaustion, and burnout [@friedman2003self; @dicke2014self].

To date, only a few studies examined the relation between teachers’ HR as an indicator of physiological stress and teaching self-efficacy.

@schwerdtfeger2008self for example investigated the psychobiological relation of self-efficacy in 58 teachers and found that teacher self-efficacy positively correlated with higher HR during school time which the researchers interpreted “as elevated cardiac responses to the challenge of teaching.” [@schwerdtfeger2008se, p. 366].

In a virtual reality classroom session, bardach2023revisiting analyzed the effect of 56 pre-service teachers’ classroom management self-efficacy skills on stress responses. They assessed the HR as physiological stress during the session and self-reported stress as psychological stress after the session, while the results revealed no significant effect.

### The Influence of Teaching Experience on Self-Efficacy and Stress

@bandura1997wh stated that there are various factors influencing self-efficacy beliefs. In addition to vicarious experiences, verbal persuasion, and psychological arousal, mastery experience is the most important resource, “defined as a sense of satisfaction with one's past teaching successes.” [@tschannen2007differential, p. 945] As beginning teachers have less teaching experience than experienced teachers, it is obvious that teaching experience has a decisive influence on teachers’ self-efficacy beliefs. For example, beginning teachers report more negative experiences than career teachers [@gale2021mixed] or they perceive themselves as less self-effective than experienced teachers [@tschannen2007differential].

In a longitudinal study, @helms2016influencing investigated the correlation between self-efficacy, causes of stress, tension, and dissatisfaction among 338 beginning teachers over three years. The results revealed that self-efficacy negatively and stress causes positively correlated with tension and dissatisfaction.

For this reason, it can be stated that, in addition to self-efficacy, professional experience as part of teachers’ characteristics plays a crucial role when teachers are faced with stressors and need to appraise the stressors' relevance (primary appraisal) and their capacity for overcoming stress (secondary appraisal). The teaching profession seems to be very demanding and stressful, especially for beginning teachers. In particular the first five years, between 40 and 50 percent of beginning teachers change careers for a variety of reasons such as disciplinary problems with students [@ingersoll2003]. @fisher2011 investigated the extent to which age or teaching experience and job dissatisfaction are associated with an increased risk of burnout and stress among teachers. Although the results showed that stress had no significant correlation with age or teaching experience, it was found that teachers with less professional experience had a higher burnout score. @fisher2011 concluded that years of professional experience, burnout, and satisfaction in the teaching profession are statistically significant predictors of teacher stress.

1. This explanatory approach is illustrated in the interactionist theory model according to @eckstein2016. The model is based on the transactional model of the teacher-student relationship, which was developed by Nickel (1985) in the course of his analytical consideration of this relationship and contains various factors of the interaction processes of both teacher and students. [↑](#footnote-ref-1)
2. It should be noted that the generalizability of the results is limited due to the small sample size of four participants. [↑](#footnote-ref-2)
3. This explanatory approach is illustrated in the interactionist theory model according to @eckstein2016. The model is based on the transactional model of the teacher-student relationship, which was developed by Nickel (1985) in the course of his analytical consideration of this relationship and contains various factors of the interaction processes of both teacher and students. [↑](#footnote-ref-3)