Physiological Data and the Study of Mathematics Teachers' Emotions: Using GSR data to Trigger Teacher Reflection

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Teachers' emotions while they teach and how these may play out in their students' experience of mathematics lessons is under-researched. Here, we present a proposition for the incorporation of a type of data not typically included in the study of teacher emotions while they teach: physiological data. Specifically, we present our use of a GSR (Galvanic Skin Response) sensor as a tool that offers approximate indications of how teacher emotions vary during lessons. We report from a study in which experienced secondary mathematics teachers were interviewed before and after observation and video recording of their lessons, during which they wore a GSR device. Episodes from the lessons—selected on the evidence provided by the video recordings, the observations, and the GSR sensor—were used to trigger teacher reflection in the post-lesson interviews. A particular focus in the interviews was placed on the interplay between how the teachers' emotional intensity varied during the lesson and their teaching actions. The findings show that the use of the GSR sensor revealed aspects of this interplay not evidenced in the other data sources. The findings are presented using evidence from two participants. We propose that the use of GSR data in tandem with other types of data has the capacity to strengthen teacher reflection on how their emotional intensity may vary during a mathematics lesson and the impact of this variation on the lesson. The paper concludes with outlining the benefits for teacher education and professional development of using this unobtrusive yet insight-generating technology as an effective trigger for pedagogical reflection.

Keywords · mathematics teacher education research · emotional intensity · mathematics teachers · professional development · GSR sensor · physiological data · reflection on video data

In mathematics education, and in the social sciences at large, there has been a surge of investigations into how physiological data might support the study of teaching and learning (Di Lascio et al., 2018; Inglis & Alcock, 2012; 2018; Lee et al., 2019). In this paper, we present a rationale for research into mathematics teachers' affect using physiological data as a tool for teacher reflection. We ground our rationale in evidence emerging from the use of physiological data from a Galvanic Skin Response (GSR) sensor. The sensor was used to identify episodes that occurred during observed, video-recorded mathematics lessons and included high response data points. We then invited teachers to reflect on what occurred during those episodes. This article reports on part of a larger study that aimed to explore how teachers shared their emotional relationship with mathematics in lessons (Lake, 2017a). The research reported in this paper seeks to answer the following research question:

> *What insights into mathematics teachers' emotions during lessons can we gain from the use of physiological data (such as GSR sensor data), particularly in tandem with other data such as lesson observations and pre-/post-interviews with teachers?*

Physiological Data in Education and Mathematics Education

In recent years, there has been progress in the use of physiological data in line with new and accessible technology that has moved this use out of laboratories (e.g., in the context of numeracy tasks, Hughes, 2001) and into naturalistic settings (e.g., in the context of driver training, Rajendra & Dehzangi, 2017; or for education, Lee et al., 2019; Strohmaier et al., 2020). Incorporating the use of data sources other than, for example, observation and interviewing, is an innovative approach to studying engagement with mathematical activity, with eye tracking methods being one example (Inglis & Alcock, 2012; 2018; Hannula, 2018).

Galvanic Skin Response (GSR)—or Electro-Dermal Activity (EDA)—data are used in research to measure, for example, anxiety or excitement. Historically, measurements of skin conductance, such as the method used in this study, have been common within biological psychology (Raine, 2002) and in the study of emotional regulation (Harley et al., 2019). GSR measurement is seen as a suitable physiological channel for detecting changes in emotion from participants engaging in emotion regulation strategies (Gross, 2002). For example, D'Mello et al. (2011) examined GSR data in relation to disequilibrium in the mind and disharmony in the body and reported that anxiety, confusion, and frustration could be noticed viscerally during deep learning and, for mathematics, effortful problem-solving (Goldin et al., 2011).

GSR applications also appear in risk analysis research. For example, Crone et al. (2004) observed that, when given a gambling task, people's GSR levels increase before making a risky choice, particularly for successful performers. This type of finding suggests that there are elements of emotional response associated with engagement in specialised tasks such as gambling, as Crone et al. propose, or problem solving (Goldin et al., 2011) that are possible to identify through physiological measurement. As mathematics teaching and learning situations typically involve such deep learning and effortful problem-solving, we see these findings, including from outside mathematics education, as potentially pertinent within our field.

The use of GSR technologies for pedagogical purposes is still rare in the context of the classroom, and, when used, usually focussed on student data. For example, Lee et al. (2019), in order to evaluate active learning and identify moments in lessons that elicit engagement, used wearable GSR sensors and digital images to study an after-school, activity-based model for learning called Makerspace. Conjecturing that drawing on multiple data sources may improve the reliability of their analysis, Lee at al. used self-reported evidence from a participant survey and facial expression data in tandem with GSR data. They found a moderate correlation between electrodermal activity and self-reported engagement. Specifically, the correlation between the survey total engagement score and peaks per person was found to be $r = .671$ ($p = .048$). These researchers also considered 23 moments of whole group engagement—exact times when many students were simultaneously exhibiting GSR peaks—and reported that those moments were associated with peer socialisation and interactive instructional discourse, as well as physical making activities. Their findings indicated there is value in drawing on physiological data to explore emotions in social situations such as group activity in a classroom.

In a university context, Di Lascio et al. (2018) deployed GSR data to explore engagement and reported that "features related to the momentary engagement are the most effective to discriminate engaged from non-engaged students" (p. 3). Also in a university context, Strohmaier et al. (2020) compared electrodermal activity (EDA) with self-reporting of anxiety, and suggested that, for the mathematics undergraduates who participated in their study, the predictive value of EDA as a measure of state for affect was better than self-reporting.

One of the few school-based studies that directly considered emotions in relation to physiological data came from the field of intelligent tutoring (Arroyo et al., 2009). The study used data from a variety of sensors (including a wristband GSR sensor) and compared this to self-reporting of emotion from students through regular, and potentially intrusive, questioning. The multi-faceted design included facial emotion detection software and captured in-the-moment elements of student emotions whilst learning. It did, however, require students to sit in front of a computer screen. The study claimed that more than 60% of students' self-reports of emotion could be automatically inferred from physiological data.

Also drawing on a multitude of data sources, Morrison et al. (2020) used a mock classroom to examine which parts of experiences when learning about climate change—a potentially emotive issue—produced the most physiological reactions from the different inputs of video, worksheet, discussion, and direct questioning in geography lessons. Their findings suggested that GSR evidence was a robust proxy for engagement. They found significantly higher overall GSR readings for students who reported as engaged and especially when engaged in dialogue. Similarly, Blickstein et al. (2017), examined GSR data for evidence of arousal levels and as a proxy for creativity. This was to determine the relative effectiveness of two instructional approaches during students' online activity: giving detailed instructions for a task versus giving general, challenge-based instructions. They found that the latter elicited higher GSR measurements. These examples suggest that there is growing use of GSR data in the study of emotions in educational (school and university) settings, although currently mostly for learners (Horvers et al., 2021).

Physiological Data and the Study of Mathematics Teachers' Affect

The study of emotion—as opposed to more stable affective traits such as belief or attitude—has been growing into a productive area of investigation in mathematics education research (Hannula, 2019). While recognising that, in learning mathematics, the separation of cognition and affect is artificial (McLeod, 1992) is not new, studying the inseparability of intellectual and affective meaning continues to attract research interest. For example, Roth and Walshaw (2019) highlighted this inseparability by endorsing the notion that "affect is integral to intellect; intellect is one of the consequences of the affective nature of an organism's life" (p. 112). The study of affect, however, is challenging. Amongst the challenges faced by researchers who study emotion are the multiplicity of affective terms in the field, whether to study affective traits of individuals or in a social context and the complexity of studying emotional states in action and in context (Hannula, 2019). Underlying many of these challenges is the over-reliance of many methods used in the field on self-reporting. As Pekrun (2019) noted,

> Self-report [...] is limited to reports about consciously accessible emotion and cannot capture emotions in real time. This is true not only for retrospective assessments but also for situational self-report using experience sampling methodology. (p. 1810)

Complementing self-reporting with other data sources, such as observation and physiological data, to explore the "temporal dynamics" (Pekrun, 2019, p. 1810) of emotions whilst engaged, for example, in academic endeavours, then emerges as a potentially promising way forward.

In tandem with considering the challenges of self-reporting emotions generally, the study of teacher emotions specifically faces an additional challenge: experienced teachers often automate their thinking processes as their experience grows (Anderson, 1990; Herbst & Kosko, 2014). For example, and particularly pertinent for the support of pre-service or new in-service mathematics teachers, mentors find articulating their knowledge and decision-making processes challenging (Ethell & McMeniman, 2000; Loughran, 2007).

Our study is predicated on the assumption that analogous automation may apply to articulating emotions about teaching. Teachers react instinctively and intuitively whilst teaching and, over time, teaching behaviour patterns become established and unquestioned and therefore elusive or harder to self-report (Herbst & Kosko, 2014). We also note that an experienced teacher may have more emotional stability and hence less observable, or memorable, emotions (Frenzel et al., 2021). We have therefore searched for ways to address the limitations of self-reporting through collecting datasets, such as lesson observations and lesson recordings, which complement datasets that rely heavily on self-reporting (such as interviews).

Another assumption that our study is predicated on is that teacher emotions are an important element of what teachers choose to do in lessons and of how their students may experience mathematics in lessons (Hagenauer & Volet, 2014). As Titsworth et al. (2013) found, exposing students to positive emotions supports recall, and, as Mottet and Beebe (2000) found, there is significant emotional contagion[1] in the classroom between teachers and students. This has repercussions for several aspects of students' learning experience, such as time spent on a task. Additionally, there is

[1] The triggering of an emotion in an individual or a group that mimics another individual or group (Hatfield et al., 1994).

significant gestural variation across cultures (Farsani, 2015) and this may affect how exactly this emotional contagion manifests itself and plays out.

There are extensive psychological works on categorising emotions, such as Ekman's (2013) classification of seven basic emotions (fear, anger, happiness, surprise, contempt, disgust, and sadness). Our focus is less on characterising teachers' emotions, or the valence of these emotions ("the pleasantness of an emotion ranging from positive or pleasant to negative or unpleasant", Horvers et al., 2021, p. 7869), and more on the characteristic of arousal, namely "… the amount of physiological activation that occurs when an emotion is triggered" (p. 2).

In the research reported in this paper, we distinguish between a teacher's emotional intensity as the un-valanced magnitude of emotional response in each moment and the modes of engagement in the lesson—and acknowledge the two as dialectically connected. One way in which we treat emotional intensity and engagement as distinct is in the data sources we use to identify each. GSR data provides access to emotional intensity and observation/interview data provides access to engagement.

A Rationale for a Focus on Mathematics Teachers' Emotional Intensity

In resonance with Hannula (2012), who distinguished between stable affective traits and emotional states, we see emotions as "in-the-moment", fluid and transitory. In terms of intensity, we see emotion as energy, as suggested by Lakoff and Johnson (1999), "… the tension of excitement level produced by the interaction of brain processes of perception, expectation, memory and so forth" (p. 176). Intensity boosts cognitive functioning and—crucially for the educational setting of our study—is energy that connects an individual with their social surroundings. For teachers, their "individual affect can be understood as [a] filter through which they reflect on their practice and come to understand new aspects encountered during professional development activities" (Frade et al., 2010, p. 247).

Although teachers' emotions have been the object of research (Frenzel et al., 2016: 2021), how observable, and therefore measurable emotions may be, has attracted little attention. As Izard (2011) suggested, first order, or basic emotions are readily attributable to children, but become much more nuanced and connected with cognitive processes and motivations with maturity. Furthermore, "situational constraints" (Scherer, 2005, p. 703), such as expected behaviours and norms, will limit their externalisation and therefore observability, unless the emotions are strong. Emotions with comparatively higher intensity are most likely indicative of utilitarian emotions, which Scherer described as the sense of "facilitating our adaptation to events that have important consequences for our wellbeing" (p. 706).

Beyond observability, we also concur with Scherer's (2005) concerns about researchers' "labelling" of participants' emotions in ways that may differ significantly from participants' "lay persons' self-report" (p. 696). Given the pitfalls of emotion labelling, we aim to infer an emotion and its impact through its intensity, while also recognising that we ought to do so with caution. As Scherer stated, "it is difficult to differentiate the aspect of intensity of feeling from bodily excitation. Thus, extremely intensive anger is likely to be characterized by high arousal whereas intense sadness may be accompanied by very low arousal" (p. 719).

An implication of examining emotion through the lens of intensity is that defining and labelling specific emotions becomes less significant. Instead, observing teachers using emotions as energy to regulate themselves and their classrooms becomes central. Using emotions enables a teacher to function in the classroom where a motivating desire for resolution of need is the primary driver within the dynamic and complex context of classroom teaching. The term motivating desire suggests affective discomfort that is a need met by fulfilling a short-term goal (Goldin, 2011). As Graham and Taylor (2014) noted, emotions "can be a filter through which the perceiver may make rapid judgements in situations where there is much ambiguity" (p. 115). According to Op't Eynde et al. (2006), a further implication of the intensity lens on emotion is that small differences and changes are important. This emphasis implies that research should be centred on the detail of classroom activity and on how the activity is experienced in social interaction. Emotions, whilst transitory and fluid, emerge in a context in relation to an object, such as a person, belief, or goal, to which to attach the emotion (Mottet & Beebe, 2000; Hagenauer &

Volet, 2014). It is this local aspect of learning and teaching in mathematics education that our combination of observation, video and GSR data tools was designed to capture.

As we mentioned earlier, expressing positive emotions has been identified as beneficial (Fredrickson, 2001; Barsade, 2002; Hatfield et al., 1994), especially for student learning (Mottet & Beebe, 2000). In the social context of the classroom, intensity is significant for the effectiveness of emotional contagion (Hatfield et al., 1994). Barsade (2002) confirmed that stronger emotions are more effective in forming collective emotion, even with negative emotional valence. Higher intensity may call an interlocutor to pay more attention. This may lead to more contagion than if the idea to be communicated were to be expressed with comparatively lower energy.

Mathematics teachers frequently repeat lessons of similar content, and in a repeated experience, an individual may not continue to experience and show the same emotions. Similarly, mathematics teachers may internalise their emotions whilst teaching—mathematics can be stereotypically, and rather reductively, seen as a less emotive area of the curriculum (Roth & Walshaw, 2019). Emotional intensity during interaction is also likely at points of potential discord or breaks in expectations between teacher and student(s), but these too may be missed by observation, especially if the associated emotions are not externalised by the teacher. As a teacher's emotional intensity increases, their internal engagement might increase, and hence physiological indicators—such as the ones captured by a GSR sensor—might show a change. Developing a collective affective pathway, as when modelling mathematical engagement in class, is also likely to be effortful for teachers. Recognising such moments may be helpful for teachers when reflecting on and developing their practice.

The proposition that we put forward in this paper is that by identifying points of emotional intensity during mathematics lessons and inviting teachers to reflect upon these, valuable insights may emerge.

The GSR Sensor and its use to Trigger Teacher Reflection

Galvanic Skin Response (GSR) measures small changes in skin humidity as this is one indicator of stress or excitement in the body. Sweat gland activity (the human body has about three million sweat glands) changes the secretion of moisture, which changes electrical conductivity. It is the small change in humidity across the skin between two points, measured in microsiemens (μS), that the GSR sensor records. A device that takes the measurements is the eSense® (Mindfield Biosystems, 2020). It is a portable skin response sensor (Figure 1) that attaches to a mobile phone[2] to record the data.

Figure 1. The GSR Sensor used in the study. The cable connects to a mobile phone.

The sensor records the GSR, and the data, at five points per second, are presented on a graph to show changes over time (e.g., during a lesson in which a teacher wears the sensor). Figure 2 shows a GSR graph obtained during a pilot trial of our study. For practical purposes, we used the first and second fingers (Figure 1) of the non-dominant hand as per Crone et al.'s (2004) recommendations.

[2] https://www.mindfield.de/en/Biofeedback/Products/Mindfield®-eSense-Skin-Response.html

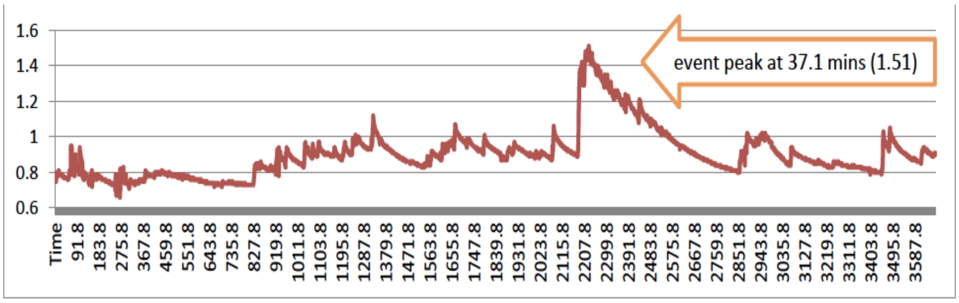


Figure 2. Graph from an early trial of the sensor during a 60 min teaching session by one of the authors. Unit in the *x*-axis is seconds; unit in the *y*-axis is microsiemens (μS).

There is, however, a delay between experiencing and recording. Figner and Murphy (2011) suggested delay varies from around 0.5 sec. to 5 sec., but this could be longer. In our study, this delay implied the need to combine the deployment of GSR data with other methods of recording the events of a mathematics lesson—such as carefully timed observation notes and video recordings of the lesson with synchronised timings. Combined, these data and the GSR data were used to identify episodes occurring around peak GSR readings. We paid particular attention towards selecting episodes that were long enough to accommodate for the anticipated delay. In most cases, we framed the selected episode within a 3-minute bracket around each peak. The peaks indicated events of interest over an interval, not just a point or moment in time. Selected episodes were then discussed with the teacher. In this manner, the GSR peak indications became one of the criteria for selecting the video segments to initiate the discussion with the teacher (Derry et al., 2010).

Concurring with Brophy (2003) that video provides a potentially useful emotional distancing from actions in the classroom, we used GSR data, in tandem with lesson observation and video recordings to create triggers for reflection (Beswick & Muir, 2014; Clarke et al., 2013) during our interviews with the teachers. In doing so, we focused also on what Major and Watson (2018) described as a less common focus in professional development settings: how teachers identify and articulate their emotions, and how they may use these emotions in their teaching. In our study, we wanted to engage in reflection with the teacher as soon as possible after the recorded teaching events and use our selection of episodes to initiate a discussion with the teacher on what they themselves considered as important events in the recorded lesson.

In tandem with the video segment—typically selected for making a particular point or provoking reflection (Ineson et al., 2015)—the GSR data excerpt (an area with a notable peak in the graph), provided a conversation starter without a pre-determined agenda (Coles, 2013). The teacher was aware that our selection was based on the presence of a peak and that we were interested in exploring events in the lesson around that time. We stress that we aimed to distinguish emotions related to these events from "low intensity moods that have little impact on behavior" (Scherer, 2005, p. 702).

We acknowledge caveats in the use of GSR data in context. We recognise the significant uncertainty in interpreting GSR data, even if the interpretation is co-constructed with the teacher who experienced the emotional intensity that the GSR sensor records. We also acknowledge that there is some arbitrariness in the decision to use the maximum recorded value in each mathematics lesson as the focus of the subsequent discussions with the teacher. We note that, on every occasion, we used the maximum measurements in conjunction with other evidence in the video and in the observation notes to trigger reflection on the part of the teacher.

Thompson and Zeuli (1999) identify stimulating cognitive dissonance and allowing time for reflection on experiences as elements of effective professional development. We propose that—alongside video excerpts (Clarke et al., 2013)—physiological data can provide welcome additional stimulus and focus for teacher reflection, particularly in detecting and reframing their beliefs, such as which emotions to display and when. In this paper, we claim that the combination of video and GSR data segments deployed as triggers for discussion with the teachers' generated insights of significant value—to the teachers and to the researchers alike. In what follows, we sample said insights from the datasets we collected from two teachers, Carol, and Debbie.

Using GSR Sensor Data to Generate Teacher Reflection: The Examples of Carol and Debbie

Context, Participants, Data Collection and Data Analysis

The study that we draw on in this paper (Lake, 2017a) used a combination of standard (observation with video and video-recall stimulated interview) and physiological methods for collecting and analysing data to investigate the role of teacher emotional intensity in secondary mathematics classrooms. The reality presented in this research is a contextual snapshot. One aiming to provide a rich description (Lincoln & Guba, 1985) of the examined context and a sense of the whole (Connelly & Clandinin, 1990); a report "grounded in examples" (Sharma, 2013). First, we conducted pre-observation career storytelling interviews with eight experienced mathematics teachers from Norfolk, United Kingdom. Participants held qualified teacher status (QTS) certification and had at least three years of experience. Choosing teachers with some experience potentially minimised the interference of the often-extreme emotions associated with being a new teacher (Chen et al., 2022).

The pre-observation interviews were followed by the observation and video recording of two lessons (rehearsal and actual) during which the teachers' GSRs were measured. The conditions of the two lessons (e.g., regarding camera positioning and presence of the same observer) were kept as similar as possible although with a different class of students. We recognise the limitations of a fixed camera position (Kosko et al., 2021) but we note that research ethics constraints (relating to participant consent) only allowed us to point the camera at the teacher. Each lesson observation was followed shortly after by a post-lesson interview. This comprised a reflective discussion with the teacher in which we used video-stimulated recall with a focus on purposefully selected lesson segments approximately 3 minutes in duration. The selection of video clips to share with the teachers was informed by the highest GSR sensor readings and by the observation notes taken by the researcher (the first author) during the lesson. The graphs of the GSR sensor readings were not shared until the end of the interview, but the teachers knew that the focus of the discussion was on emotions, and their use, whilst teaching.

To analyse the teachers' modes of engagement in mathematics lessons, we used a combination of Goldin et al.'s (2011) *engagement structures*—originally designed for students but shown to be portable to the study of teachers (Lake & Nardi, 2014; Lake, 2017a)—and *positioning theory* (Harré & van Langenhove, 1999). Goldin et al.'s (2011) engagement structures cover modes of engaging with mathematics such as "I'm really into this" (IRIT), "Let me teach you" (LMTY), "Don't disrespect me" (DDM), "Look how smart I am" (LHSIA), and "Get the job done" (GJD) (see Khalil et al., [2019] and Lake [2017a] for a detailed account of the nine strands and their use). It is common for either students or teachers to dip in and out of engagement structures, sometimes showing characteristics of more than one structure, but according to Goldin et al. (2011), at any moment there will be a dominant one that directs emotional reactions.

We combined the engagement structures lens with positioning theory (Harré & van Langenhove, 1999), which attends to the subtleties of interlocutors' discourse, for example in a classroom setting, and identifies how teachers and their students position themselves in relation to each other. The theory highlights how interlocutors can accept, reject, or negotiate positions in a fluid, highly interactive and emotionally driven way.

Through the combined lenses of engagement structures and positioning theory, we established connections and affective patterns across the pieces of evidence from the different datasets we collected from each teacher. We examined the interview recordings and the video episodes for affective elements such as emotive words or non-verbal indications such as laughter. We then searched the transcripts and video for emerging themes or patterns to develop an Engagement Structure account per teacher.

In this paper, we draw on evidence from the datasets of two teachers, Carol and Debbie. We selected these teachers as their GSR graphs (Figures 3–6) seemed to indicate divergence between the GSR data and the lesson observation / video recording data. Also, how the two teachers presented affectively in the observed lessons was quite different. Carol showed few observable strong emotions and rarely smiled, whilst Debbie was constantly and cheerfully active. In what follows, we demonstrate how the interpretation of the two teachers' actions and responses were substantially impacted on, and enriched by, using the GSR data.

The teachers rehearsed the wearing of the GSR device in earlier sessions and became more and more comfortable with wearing it during lessons. We also informally practised with the device (Figure 1) in university sessions. Both school and university teachers rehearsing with the device stated that, within a few minutes, they felt almost unaware of the presence of the device cable and Velcro rings tied around their fingers. Because the device is small, the teachers used sleeves to hide the wires and placed the mobile phone in a belt-bag provided. There was no restriction of normal movement. Students were aware of the presence of a classroom observer and camera, and that the filming was of their teacher. The teachers volunteered participation in the study in response to our call for expressions of interest and the study was granted ethical approval by University of East Anglia Research Ethics Committee.

The excitement and interest engendered by using the GSR device was notable in all participants, who appreciated its novelty. Participants were aware of, and happy with, the risk that the GSR graph may reveal hitherto tacit elements of their emotions (Herbst & Kosko, 2014) during lessons. In fact, they were overtly curious about potential revelations. There was also reconciliation with the fact that, occasionally, the device proved unreliable (for example, in one rehearsal nothing was recorded).

The career storytelling, pre-observation interview, the lesson videos, the lesson observations, the sensor data, and the post-lesson stimulated recall interviews combine to form a potent dataset that may tell many and varied stories of each teacher and their professional life from an affective point of view. We claim that the physiological data collected through the sensor, and presented to the teachers in the GSR graph, provided one window onto these stories. The graphs attended to patterns and change during the act of teaching, and we invited teacher interpretation of the graphs. We were particularly interested in stories that may take a different turn once the GSR data are considered. Carol and Debbie's are two such stories.

Carol: GSR Data Reveal a Contrast Between a Cool Exterior and the Turmoil Inside

At the time of data collection, Carol had been teaching students 11–18 years of age in a secondary school for eleven years. In the pre-observation career story-telling interview, Carol described herself as "a teacher first, then a maths teacher":

> I think my teaching is probably better because I feel like I have not always understood everything and I think that's how I come in at it with the weaker children whereas some people I have met in the profession who absolutely love maths, don't always appreciate that not everyone gets it.

Such nurturance views align with the dominant engagement structure for this teacher LMTY (Let me teach you): a need to support students with a driver to seek problem resolution.

For the video-recorded, GSR-recorded lesson, Carol chose a Year 10 (ages 14–15 years) class of 19 students. The lesson involved a noisy and active collection, recording and creating graphical representations of relative frequency data. Each table of three to four students conducted a different investigation, but with a similar potential outcome in terms of the application of the expected graphical representation. The students either repeatedly flipped coins to find out if they were fair or rolled a die to find the probability of getting each number. The three students who appeared in the episode discussed in the post-lesson interview used dice and appeared engaged and attentive. Although Carol used an interactive whiteboard in the middle of the 60-minute lesson to demonstrate how the graph students were to create might look, she mostly spent the time circulating amongst the groups of students. Carol commented that,

> I was interested in the fact that the [die] was one I had got out of a Christmas cracker, so it wasn't necessarily going to be a fair [die], but we didn't know. So, I felt I was setting them a challenge.

We saw this statement as indicative of Carol's second dominant engagement structure IRIT (I'm really into this) supported by CTO (Check this out), both of which evidenced a strong commitment to providing carefully designed mathematical challenge to students.

Carol maintained an interested, yet calm demeanour, with consistently tranquil voice and movement. However, the GSR graph (Figure 3) generated from the lesson suggested somewhat otherwise. Given the visible calmness, we expected less variation in the graph, for example, fewer or lower-value peaks. There were various peaks in the graph (e.g., over 2.5 µS at approximately minutes 25, 27 and 44 as well as the highest peak, 2.64 µS between minutes 56 and 57). There was also notable variation in the distributions of the GSR readings for Carol (shown as box plots in Figure 4). We note that, in Figure 3, we provide the GSR data for both occasions in which Carol wore the GSR sensor: the first was a rehearsal lesson and the second is the video-recorded lesson. We provide both to convey to the reader a sense of the range in Carol's measurements over more than one lesson.

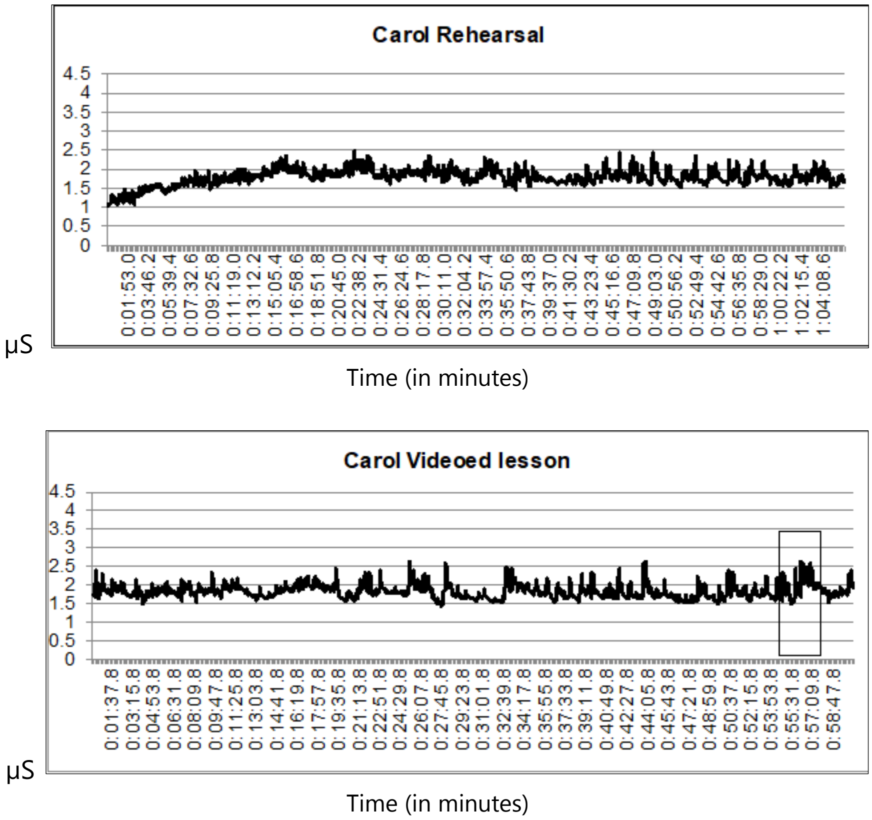


Figure 3. Carol's GSR sensor recordings (top: rehearsal; bottom: recorded lesson). The boxed segment at the bottom graph indicates the selected episode discussed in the post-lesson interview (highest value: 2.64 µS), which occurred between minutes 55 and 57.

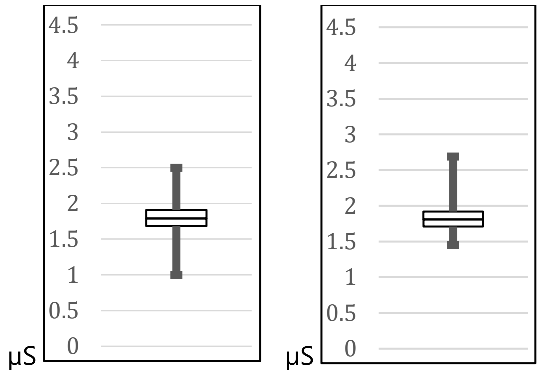


Figure 4. The variation in GSR measurements across Carol's lessons (rehearsal, left; observed and video recorded, right) does not show any extreme values.

At approximately minutes 25 and 27, there were higher concentrations of peaks and an additional peak at minute 44. Cross examination of lesson events from the video recording and the fieldnotes indicated that, during the episodes at minutes 25 and 27, Carol was having trouble finding what was needed on the computer, whilst at minute 44, Carol briefly stopped the class to model a graph to students. Any of these points could be used to form a discussion with Carol.

The GSR data indicated that there was some variation between rehearsal and the videoed lesson. Some of the variation may have been due to lower readings at the start of the rehearsal. There were, however, more slightly higher readings (over 2.5 μS) for the videoed lesson compared to rehearsal, and the rehearsal showed more frequent lower range readings.

The episode chosen for Carol to initiate discussion in the post-lesson interview included the maximum reading at around minute 56 of the videoed lesson. In this episode, Carol exhibited characteristics of mild frustration or puzzlement in a predominantly calm, positive lesson. These interpretations were also based on observation notes and coincided with Carol's account in the interview. Carol's emotions in those moments were articulated mainly as apprehension or perhaps doubt, visually expressed in the video as biting her lip and putting her head on one side and then the other. The mild, just about visible gestures were considered in tandem with the respective GSR measurements. Carol stated, "... because I knew they should be able to do it [draw the graph], but they weren't giving me anything back." Carol assigned this doubt to either the group dynamic or lack of understanding of why the students were not responsive:

> ... because I hadn't given them a relative frequency graph, I wanted them to just come up with it (yes), but they got themselves in such a muddle with it and were trying to graph ... the boy this side, J, he'd drawn a bar chart ... But they weren't getting the cumulative aspect of it.

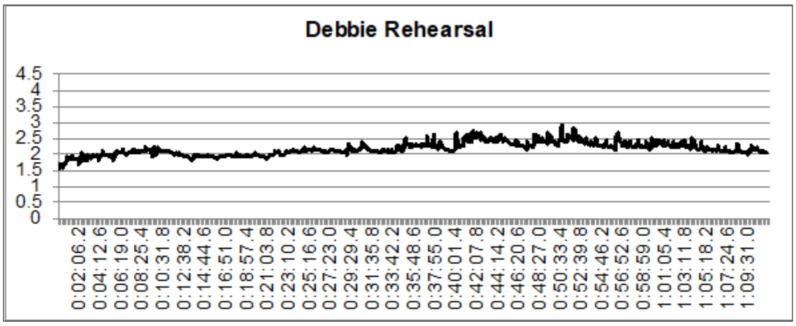
Carol's response, as observed in the recording and subsequently explained, was to shift from instructional mode to conversational mode. Accordingly, she sat down with the group. The minute 56 peak in the GSR data prompted Carol to reflect on what she did. Her responses revealed emotional turmoil that steered her towards specific pedagogical actions. Carol explained her actions as, "... trying to get down on their level and having more of a conversation." One student in the group was new to her class, and Carol later expressed concern that she did not have a strong relationship with him. "J should be top of the group, but he is not achieving, and he's come from someone else. So, he's still a little bit of an unknown." Carol thought that this lack of familiarity with the student may have shifted her out of her comfort zone and may account for the higher GSR sensor measurement. We credit the GSR sensor for affording us, and Carol, the opportunity to fully appreciate the subtle emotional nuances of the episode that seem to unfold around the GSR data peak.

Debbie: GSR Data Reveal a Contrast Between a Dramatically Energetic Exterior and a Calm and Steady Inside

Debbie, in her third year of teaching, worked in the same school as Carol, and taught students 11–18 years of age. In the pre-observation interview, Debbie stressed that, in teaching, there were "different challenges every single day," To her, teaching "is never dull, it's lots of things but it is never boring." Debbie stated, "I go with the philosophy of fun. If I am not having fun in the lesson, if I am not enjoying myself, then the kids aren't either." Debbie also said, "I tr[y] to let [their] personality come through a bit, have a bit of a laugh with them, whilst they do the work." Debbie valued modelling the enjoyment of doing mathematics (dominant engagement structures: LMTY and IRIT). The use of the sensor in this case enabled insight into the teaching of an observably expressive and dynamic teacher.

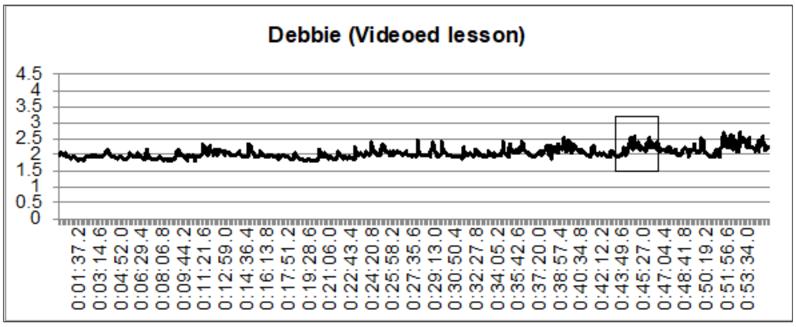
For the video-recorded, GSR-recorded lesson, Carol chose a Year 7 (students 11–12 years of age) class of 24 students. The lesson involved problem solving with a Tarsia puzzle, which required conversion of units. A worksheet on angles of elevation was available to the students to engage with once they had completed the Tarsia puzzle. Debbie was an active teacher and moved quickly from table to table throughout the lesson, and she encouraged the students to explore ideas. Recording the class from the back was a useful position to keep up with Debbie's rapid movements around the class. The second highest GSR value (2.58 µS,) (Figure 6) informed the selection of the video clip used in the post-lesson interview given that the highest sensor value for Debbie occurred as students were leaving (2.65 µS, around minute 51).

µS



Time (in minutes)

µS



Time (in minutes)

Figure 5. Debbie's GSR sensor recordings (top rehearsal; bottom: recorded lesson). The boxed segment at the bottom graph indicates the selected episode discussed in the post-lesson interview (second highest value of 2.58 µS), which occurred between minutes 43 and 47.

The episode began with Debbie as instructor, but she was soon engaged in doing the Tarsia problem-solving activity alongside the students. Debbie's positioning moved between facilitator and instructor in a rapidly changing pattern that we interpreted as high interest in, and adaptability during, the classroom activity. Given Debbie's vigorous and rapid movements as well as many emotional expressions—verbal, facial and gestural—often positioning herself as a child, using "we" or excited expressions such as 'Woo!' We expected more variation in the distribution of the GSR measurements (Figure 6). The box plots show consistency and stability across the lesson. There were no notable peaks; and, relative peaks appeared consistently across the lesson.

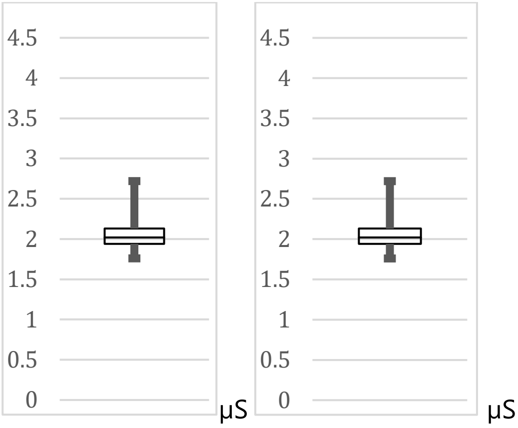


Figure 6. The variation in GSR measurements across Debbie's lessons (rehearsal, left; observed and video recorded, right).

In the episode selected to initiate discussion in the post-lesson interview, we saw Debbie moving rapidly from one group of students to another whilst answering and asking questions. She used playful language and body movements. Debbie waved her arms to show an aeroplane's flight path to two students who were engaged in the extension task on angles of elevation. "So, I was trying to do it with hands, so they sort of got the ... that's the sky, that's the ground, it's fallen into the sea ..." The peak reading, although only slightly higher than others, is around 2.5 µS. The highest value, 2.58 µS, occurred around the time that she expressed delight with student success, exclaiming "Woo! Woo!" Comparing GSR readings across the lesson, similar peak values appeared throughout, which were possibly associated with apparent excitement. Debbie's engagement structures were, like Carol, LMTY and IRIT, but in association with the performance engagement structure of LHSIA (Look how smart I am) and GJD (Get the job done). Debbie's episode interpretation aligned with GJD:

> The most stressful bit is when you have some finishing, some needing help, and you've got to deal with the ones who have finished, get them the work, the next bit of work, explain, and whilst keeping the rest of the class motivated to keep going because ... (yes) some people may have finished, but they've still got work to do, and then get them the questions, and then there's always queries about extension and ... so it's sort of a bit of juggling around six different things.

The noted peak in the selected GSR data excerpt, prompted teacher reflection that revealed not moments of emotional turmoil but a pattern of behaviour that Debbie described as part of a deliberately and consistently presenting persona in lessons; that of energetic, emotionally rich excitement about doing mathematics. We credit the GSR sensor for affording us, and the teacher, the opportunity to fully appreciate the steady, pre–meditated design that underpinned Debbie's teaching, which was well-evidenced in the relatively narrow variation in the GSR measurements.

Teacher Reflection on the Purpose and Utility of GSR Graphs

Both Carol and Debbie commented on their GSR graphs at the end of the stimulated recall interview. Carol, whose graph is the more variable, said of the video,

> I was shocked how calm I looked, I don't feel like I'm that calm ... perhaps I am not conveying [excitement], because a lot of it is the day to day of it, I've done it 20 times, 50 times, 100 times ...

Whereas, Debbie, who was constantly active whilst teaching, commented, "That's intriguing, maybe I look like I'm a bit mental but I'm actually pretty calm."

We credit the use of the GSR sensor for eliciting these reflective responses from the teachers and revealing the different ways in which these two teachers positioned themselves as facilitators of student learning. From positioning theory (Harré and van Langenhove, 1999), this supports student acceptance and negotiation rather than rejection. The dominant engagement structures for both Carol and Debbie were LMTY (Let me teach you) as the primary driver (dominant) and IRIT (I'm really into this) (used as a teaching strategy), supported by CTO (Check this out) for Carol and GJD (Get the job done) for Debbie. Both Carol and Debbie reported taking pleasure in their classroom teaching, in having strong relationships with their students, in being effective when communicating mathematics, and in caring for the emotional needs of their students. The use of the sensor with Carol and Debbie has revealed different, yet rewarding and effective ways to engage with students. It has also brought into discussion the commonly held, yet slightly superficial view that, to engage students, there must be some extrovert teacher expression of emotions (for Debbie this was the case, for Carol it was not). In both cases, the GSR data proved to be a resource that elicits additional and alternative insight.

Locating this paper within a wider context, analysis of the data from the original study (Lake, 2017a) resulted in the identification of four themes of teacher engagement: self (the teacher's take on their own mathematical identity), play (defined as a desirable activity in the classroom, governed by rules and involving imaginary situations such as role-play; Lake, 2017b), modelling (of how-to-be mathematical) and storytelling (using narrative and anecdote to convey mathematical content; Lake, 2017a, 2018). Examples of teacher emotions that proliferated in the data include: self-reported or observable teacher enjoyment (Lake, 2015), class laughter when teachers were being playful, and excitement when teachers used storytelling to convey mathematical meaning or changed the cadence and ambience of a lesson. The original study's findings highlighted that those teachers who talk about and build a climate supportive of engagement in learning mathematics, embed emotions within mathematics teaching in unique and connective ways (Lake, 2017a). In sum, the post-observation discussions, further spurred on by the sharing of the GSR sensor data, enabled the teachers to explore and articulate their emotions during the selected episode and, crucially, do so in tandem with reflecting on the interplay between how the teachers' emotional intensity varied during the lesson and their mathematical teaching actions.

Conclusion: GSR Data and Mathematics Teachers' Professional Development

So, what insights has the use of the GSR data provided into teacher emotional intensity during mathematics lessons and what are the implications for mathematics teaching, teacher education/professional development and research emerging from those insights? In this paper, we propose that the discussions with the teachers were enriched by using the GSR data. We supported this claim through showcasing examples drawn from the data collected for Lake's (2017a) study with a particular focus on two teachers, Debbie, and Carol. These examples show how the use of GSR data can highlight the variations in a teacher's emotional intensity during a mathematics lesson in ways that may not be traceable through other means, such as video and interview data. The data presented in this paper illustrate how GSR data can support teacher reflection on elements of their teaching.

Classrooms are emotionally laden spaces in which student learning needs arise and where rapid judgements and decisions about those learning needs are required. It is at these emotionally potent junctures that peaks in the GSR data might be expected. Analysis of GSR data, in conjunction with the engagement structure and positioning theory tools, revealed instances of internalised emotions during what may appear on video or in fieldnotes as effortless mathematics teaching.

There is much to be learnt about deliberate and instinctive placing of intensity whilst teaching, as teachers cannot continually sustain high emotional intensity. In terms of emotions expressed as humour, Ziv (2010) suggested that intensity plays a part in the lessening of fear and the associated tension. Anxiety which often manifests as tension is common in mathematical learning. Using emotions intensely at the right point—as Debbie's case shows—can be effective in shifting attention in a lesson away from what may be perceived by students as a negative situation. The idea of managing emotions of others through meta-awareness of intensity is not new. Amongst the participants, we observed what seemed to be unconscious and almost instinctively managed tailoring of intensity.

The GSR data gave insights into how a teacher may support mathematical learning, for example, when either a teacher is modelling how-to-be when learning mathematics to increase engagement, or attracting learners' attention; for Debbie, to make the mathematics memorable or, for Carol, homing in to resolve mathematical uncertainty in a group of learners. In both cases, the use of the GSR data led to shifting our initial interpretation of the observation and video data. In Carol's case, we would most likely have missed the emotional turmoil neatly placed underneath a cool exterior that was driving shifts in action during the lesson. We would have likely missed the emotional journey taken by Carol as she rapidly recognised and resolved the mathematical challenge the students in the class were facing. In Debbie's case, her vibrancy and explicitly shared emotions were shown by the contrastingly low intensity identified by the sensor was determined to be a strategy for energising her students' mathematical engagement.

The GSR sensor has its limitations. For example, the sensor is not intended to be a stand-alone tool. In this case, it was used in conjunction with interview and video data. Further, crucial to the validity and reliability of our analysis was to recognise that fluctuations of emotion during a lesson may be attributable to sources other than those directly linked with the events in a lesson per se. An illustration is the graph presented in Figure 2, where there was no perceivable pedagogical reason for the peak recorded, but where the reason for the peak was revealed in post observation discussion. Using the sensor data in tandem with our other data sources—for example, to explore with the participants whether certain emotions may be directly attributable to other events in their lives—mitigated against this risk.

The analysis presented in this paper begins to address concerns about the limitations of self-reporting as the sole source of evidence of affect (Di Martino & Sabena, 2010; Pekrun & Bühner, 2014; Roth & Walshaw, 2019). This is particularly pertinent in the case of mathematics teachers who may find articulating often deeply embedded, automated, implicit behaviours challenging (Ethell & McMeniman, 2000; Coles, 2013; Ainsley & Luntley, 2007). Our proposition for a repertoire of methodological tools that includes physiological data, such as those collected via a GSR sensor, derives from an early established desire to investigate whether rapid changes or intensity of emotions are suitably identifiable through observation and video alone since "[e]motions are highly elusive constructs that are both challenging to define scientifically and to capture empirically" (Frenzel et al., 2021, p. 250). We conclude with proposing the use of GSR data as promising triggers for mathematics teacher reflection and we see implications of this proposition for research in the future in regard to the use in teacher education and professional development.

Assessing the degree of emotional regulation is important for interpreting emotions of classroom teachers (Mottet & Beebe, 2000) as Carol's example shows: routine and repetition may generate emotional regulation that may inadvertently conceal a teacher's love of mathematics. For the teachers themselves, as well as for those who prepare teachers for the mathematics classroom or support their professional development, accessing and assessing the emotional nuance of the teaching experience is key. We are seeking ways to explore how GSR data can become part of the repertoire of tools used to study interactions in the mathematics classroom. Exploring fluid emotions in the mathematics classroom is known to be challenging (Frenzel et al., 2021; Roth & Walshaw, 2019; Scherer, 2005). The evidence in this study has emboldened our conviction that GSR data can have a central and catalytic role in considering emotions for teacher reflection and teacher development.

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