Expression of Emotions and Physiological Changes during Teaching

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Abstract We investigated the expression of emotions while teaching in relation to a teacher's physiological changes. We used polyvagal theory (PVT) to frame the study of teaching in a teacher education program. Donna, a teacher-researcher, experienced high levels of stress and anxiety prior to beginning to teach and throughout the lesson we used her expressed emotions as a focus for this research. We adopted event-oriented inquiry in a study of heart rate, oxygenation of the blood, and expressed emotions. Five events were identified for multilevel analysis in which we used narrative, prosodic analysis, and hermeneutic-phenomenological methods to learn more about the expression of emotions when Donna had: high heart rate (before and while teaching); low blood oxygenation (before and while teaching); and high blood oxygenation (while teaching). What we learned was consistent with the body's monitoring system recognizing social harm and switching to the control of the unmyelinated vagus nerve, thereby shutting down organs and muscles associated with social communication – leading to irregularities in prosody and expression of emotion. In events involving high heart rate and low blood oxygenation the physiological environment was associated with less effective and sometimes confusing patterns in prosody, including intonation, pace of speaking, and pausing. In a low blood oxygenation environment there was evidence of rapid speech and shallow, irregular breathing. In contrast, during an event in which 100% blood oxygenation occurred, prosody was perceived to be conducive to engagement and the teacher expressed positive emotions, such as satisfaction, while teaching.

Becoming aware of the purposes of the research and the results we obtained provided the teacher with tools to enact changes to her teaching practice, especially prosody of the voice. We regard it as a high priority to create tools to allow teachers and students, if and as necessary, to ameliorate excess emotions, and change heart rate, oxygenation levels, and breathing patterns.

Keywords polyvagal theory · wellness · emotion · prosody · vagus nerve · science teacher education

Resumen Investigamos la expresión de las emociones mientras se desarrollan las clases, a través de los cambios psicofisiológicos de los maestros. Utilizamos la teoría polivagal (TPV) para enmarcar el estudio de la enseñanza en un programa de formación de docentes. Donna, una profesora-investigadora, experimentó niveles altos de estrés y ansiedad previo a empezar a dar clase y durante la misma. Implementamos la investigación orientada a eventos para estudiar aquellos relacionados con la frecuencia cardiaca, la oxigenación de la sangre y la expresión de emociones. Se identificaron cinco eventos a los que se les aplicó un análisis multinivel utilizando la narrativa, análisis prosódico y métodos hermenéuticos-fenomenológicos para conocer más acerca la expresión de emociones cuando Donna

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presentaba aumento de la frecuencia cardiaca (antes y durante la clase); bajo nivel de oxigenación de la sangre (antes y durante la clase); y alto nivel de oxigenación en la sangre (durante la clase). Lo que concluimos fue consistente con lo que se reportó en el monitoreo del cuerpo, reconociendo daño social relacionado con el control de la desmielinización del nervio vago, la disminución de la función de algunos órganos y músculos, asociados con la comunicación social principalmente con irregularidades en la prosodia y en la expresión de emociones. En los eventos que involucraron frecuencia cardiaca alta y poca oxigenación de la sangre, el ambiente fisiológico se asoció con patrones confusos en la prosodia y menos efectivos, incluyendo entonación, ritmo del habla y pausas. La poca oxigenación de la sangre fue evidencia de hablar rápido, pasar saliva y una respiración irregular. En contraste, durante un evento en el cual se registró el 100% de la oxigenación de la sangre, la prosodia se percibió relajada y la maestra manifestó expresiones positivas tales como satisfacción mientras impartía la clase. En relación con los propósitos de la investigación y con los resultados obtenidos, pudimos ofrecerle a la maestra herramientas para efectuar cambios en su práctica docente, especialmente en la prosodia. Consideramos que es una prioridad crear herramientas que les permitan a los profesores y estudiantes, si fuera necesario, disminuir el exceso de emociones que alteran la frecuencia cardiaca, los niveles de oxigenación y los patrones de respiración.

Palabras clave Teoría polivagal · bienestar · emoción · prosodia · nervio vago · formación de profesores de ciencias

A multilogical approach to research on emotions

Our interest in research on emotions began when Ken (first listed author) led a study of science teaching and learning in an urban high school in West Philadelphia (Tobin, Seiler, and Walls 1999). Two of his doctoral students were taking a course with Randall Collins (2004), who was using a pre-publication draft of his book on interaction ritual chains as a core resource for the course. Collins' theory illustrated how coparticipants create a shared mood as they synchronized their actions during an activity. We began to adopt Collins' theory and as our studies progressed in the years ahead (e.g., Ritchie, Tobin, Roth, and Carambo 2007), we employed additional social theories, affording a stronger focus on face-to-face interactions and associated emotions (e.g., Ritchie, Tobin, Sandhu, Sandhu, Henderson, and Roth 2013). First, we adopted Jonathan Turner's (2007) frameworks involving primary, secondary, and tertiary emotions and Paul Ekman's theories of facial expression of emotion (Ekman 2004). Also, we embraced social neuroscience and endeavored to learn from Richard Davidson's work on emotional styles (Davidson with Begley 2012). In addition, we examined how emotional type and intensity relate to prosody – looking at how the energy of an utterance is distributed across energy bands during conversation/verbal interaction. As the emotional content of talk increases, the proportion of the energy associated with higher frequency formants (i.e., energy bands) tends to increase (Tobin and Ritchie 2011). As a speech sound generated by the larynx passes through the vocal tract, its characteristics are affected by the morphology of the tract. These features of speech are called *formants.*

Since a significant amount of our research in the U.S. was situated in public urban high schools, it was imperative that we learn how to ameliorate excess emotions that were unproductive/counterproductive and thereby create and sustain wellness. Our research over almost 20 years indicated that many of the science classes in our studies were characterized

by lengthy periods of dysfunction in which a handful (or sometimes more) of students disrupted teaching and learning (Tobin, Seiler, and Walls 1999). Anger and fear characterized teachers' and students' expressed emotions and absenteeism was a factor that mediated the enacted curriculum and learning. Kenneth Tobin and Reynaldo Llena (2011) described how intense levels of anger disrupted a science class and appeared to have a deleterious effect on the teacher's wellness. Following heart surgery, and ongoing problems when he taught, the teacher-researcher (i.e., Reynaldo) announced that: "Teaching makes me sick." Subsequently, his doctor advised him to quit teaching or face the high probability of heart attack while teaching. This situation catalyzed our determination to identify toolkits to ameliorate intense emotions if and when necessary. Hence, we were very interested in relationships between emotion and wellness, and began to explore physiological expression of emotion (Tobin 2016a) – salient insights being provided in an unexpected resource; a book on yoga and chronic pain, in which Kelly McGonigal (2009) explained how breathing was associated with expressed emotions. McGonigal referenced the work of Pierre Philippot, Gaëtane Chapelle and Sylvie Blairy (2002) in which the use of characteristic breathing patterns associated with an emotion led to the production of that emotion. For example, happiness/joy was produced when participants used slow, deep, regular breathing through the nose. Similarly, anger was produced with fast, deep, irregular nasal breathing, and sadness occurred when participants used nasal breathing with average amplitude and frequency. We reasoned that emotions and physiological variables could be manipulated reflexively, thereby constituting an intervention to mediate the type and intensity of the emotions produced. Integral to incorporating this work into our ongoing research was the identification of tools that would show physiological differences that could occur when breathing was manipulated – such as during breathing meditation, which we planned as an intervention in our research. We decided that a finger pulse oximeter (see Calderón, this issue), which provides measures of heart rate, oxygenation of the blood, and the strength of the pulse, would provide compelling data on physiological changes that occur during teaching and learning.

Changing interpretive frameworks

For a number of years we have adopted a multilogical framework (Tobin 2016a) that has evolved within overarching theories that include hermeneutic-phenomenology (Ricœur 1992), ethnomethodology (Garfinkel 1967), and a critical stance that reflects the work of Paulo Freire (2002). An important departure from many sociocultural frameworks is our grounding in William Sewell Jr's (2005) theory of culture that emphasizes a dialectical relationship between patterns of enactment, characterized by thin coherence and ever-present contradictions (Tobin 2016a). From a methodological perspective, our research involves a search for patterns and contradictions as normal conditions for what happens in a social field. Accordingly, it is essential that learning from difference is a central part of a multilogical bricolage we employ to design studies that are authentic, emergent, and contingent. Emergence and contingence apply not only to the design of a study, but also to the multilogical framework.

As we were writing earlier versions of this paper it was clear that the most important elements of the study would involve expressed emotions in the voice, face, interactions with others, and physiology – especially heart rate and oxygenation of the blood. A wellness practitioner introduced a preferred interpretive framework. Ken explains,

I received an email from a colleague who was a Jin Shin Jyutsu (JSJ) practitioner in Australia. She suggested I watch an interview with Stephen Porges, on polyvagal theory (PVT) (https://www.youtube.com/watch?v=8tz146HQotY). I clicked on the link with a sense that I was about to learn even more about my strong interest in complementary approaches to wellness. It only took a few sentences from Porges for me to realize that his work was central to the research we were doing.

PVT addresses many issues that are central to teaching and learning because of the necessity for social communication to be effective whenever teaching and learning are goals, even when they are not the primary goals. Porges (2011) explains how PVT addresses three modes in which humans can find themselves in social settings: socially communicative; fight or flight; and immobilization. These three modes have evolved from an ancient unmyelinated (reptilian) vagus nerve that still persists and operates in mammals, in concert with a more sophisticated myelinated vagus nerve. Myelin is a fatty white substance that surrounds the axon, forming an electrically insulating layer that enhances the efficiency of neural transmission. Importantly, the unmyelinated portion of the vagus coexists with the myelinated portion, each originating in a different part of the brainstem.

Although we were aware of Darwin's research on facial expression of emotion, we were unaware that he foresaw the centrality of the vagus nerve (then known as the pneumo-gastric nerve) in the expression of emotion. Darwin (1872) stated that,

> When the mind is strongly excited, we might expect that it would instantly affect in a direct manner the heart; and this is universally acknowledged … when the heart is affected it reacts on the brain; and the state of the brain again reacts through the pneumo-gastric nerve on the heart; so that under any excitement there will be much mutual action and reaction between these, the two most important organs of the body. (p. 69)

Porges grounded PVT in the work of Darwin. If a person perceives an environment to be physically and socially safe, the tools for social communication are accessible to him/her. Salient to teaching are: prosody of the voice (i.e., pitch, amplitude, speech rate …); facial expressions; eye gaze; capacity to differentiate human voice from background noise; and relatively automatic abdominal breathing and swallowing. Porges noted that, "when the environment is appraised as safe, the defensive limbic structures are inhibited. This makes it possible to be socially engaged with calm visceral states" (Porges 2011, Loc 129 of 7127). In a safe environment (i.e., physically and socially) a full range of emotions can be expressed physiologically and can be observed in the face and voice. Numerous physiological variables support social communication, including heart rate, strength of pulse, oxygenation of the blood, and breathing pattern.

According to PVT, when an environment is perceived as physically and/or socially unsafe a fight-flight mode of conduct can occur. This might be evident in aggressive (i.e., and negative) emotions and conduct that is consistent with the metaphor of combat – either attacking or retreating. When this occurs prosody may be monotonic and not conducive to communication. Also, in this mode, a person might not clearly hear what others are saying because of an inability to differentiate the human voice from other environmental noise. Furthermore, the myelinated vagus shuts down when social and/or physical risk heightens. If this happens there may be no control of facial muscles and associated expressions that communicate emotions conducive to effective social communication. Instead, the emotions produced are likely to reflect a spectrum of anger (fight) and/or fear (flight).

The nervous system continuously evaluates risk by processing information in the environment using the senses. Neuroception, which occurs in the primitive parts of the brain (i.e., limbic system), is subconscious and assesses whether situations are safe, dangerous, or life threatening. A critical problem arises when neuroception signals danger – that social and/or physical harm is possible (e.g., teaching new students or subject matter perceived to be difficult), in which case the heart rate and/or the oxygenation level might signal, through the unmyelinated vagus, that immobilization is desirable. At this moment there can be a rapid and involuntary (i.e., unaware) shutdown associated with a sudden/quick change in heart rate and a rapid decline in blood oxygen. In such circumstances a person might experience a change in blood pressure, lightheadedness, and even a panic attack. Immobilization might be evident as inability to think and speak, fainting, and lack of physical mobility in parts of the body. This can happen even though a person is not aware of danger in a cognitive sense. Significant to this study, neuroception might signal danger on entry to a new environment or meeting a new person. Porges indicated that mammals are unable to survive for long in this shutdown mode and if immobilization occurs, it is necessary to revert to modes of functioning that sustain life. If teachers and/or students reach this state, wellness is immediately jeopardized and it is important that tools are available for self-help and assisting others.

Generalizability of our research

Our view of knowledge, as cultural enactment, is connected with an understanding of generalizability that is rooted in learning and changing rather than statistics and its underlying assumptions (Tobin 2016a). We do not seek to generalize what we learn from our research to participants like those involved in this study (i.e., statistical generalizability), and we do not accept models that view what we learned as applicable mainly or only to Australians, or people like Australians. Instead, we seek to learn from the research and apply what we learn, as we think desirable, throughout the lifeworld. Accordingly, as a result of being involved in research, one's practices across the lifeworld change, opening up the possibility that those who interact with us in day-to-day life also will change as a result of being-with us. We refer to this form of generalizability as ripple effects, or learning at elbows of others (Roth and Tobin 2002). As is the case with all forms of enactment, two related components are salient – conscious action to change practices based on awareness of some of the benefits of the research, and changes enacted based on new knowledge produced during the study without conscious awareness.

As we do our research, we seek to share what we learn with participants in an unfolding way. This may involve presenting evidence and letting participants know and understand the theories that frame our research. Furthermore, we present what we have learned in ways that are descriptive, often using narratives supported by thick description. We point out that there are contradictions for any claims we make, and context nuances what we learn and the future applicability of what we are learning. We regard it as important for participants to make decisions about the need for collective and individual changes based on what we are learning from research. We value providing rich descriptions of what we have done, why we did it, what we learned, what we hope to do and learn next, and how they, as coparticipants, are situated in the research. Furthermore, in our descriptions of our research we seek to contextualize and nuance what we learn so that readers of the texts we publish can decide

whether and how to adopt and adapt what we have learned to suit their own goals and the contexts in which they practice.

Participants in the study

Donna, a co-author of this paper, was a co-principal investigator of the study that researched the expression of emotion in the context of science teacher education. Donna was teaching a science education course consisting of 49 graduate students, each with a major in science or mathematics. Each class was two hours long. Donna agreed to wear a finger pulse oximeter in the second class of the 13-week course, thereby providing an opportunity for this study of the physiological expression of emotion. Data from the oximeter were electronically recorded three times per second as Donna taught the class. Our particular foci in this paper are variations in heart rate and concentration of oxygen in the blood as Donna teaches.

In order to obtain resting data for Donna, we asked her to sit quietly for about 10 minutes, focusing on her outbreath. During this time a finger pulse oximeter measured and recorded her heart rate and blood oxygenation. Donna's concentration of oxygen in the blood varied between 98-99% (mean: 98.2%; sd: 0.4%), and her heart rate ranged from 60-69 beats per minute (bpm) (mean: 63.3bpm; sd: 1.8bpm).

After the course was completed Donna selected two males and two females from the class to provide insights into her teaching. Pseudonyms for the four students are David, Gene, Amy, and Cath. Donna selected students she regarded as highly suitable to provide alternative perspectives on what was happening, and why it was happening. At the end of the semester, the students were invited to review video segments preselected by the research team as corresponding with various changes in the oximeter data. During these stimulated recall interviews/ reflective discussion sessions, the researchers initially asked the students to pause each video segment when something that occurred caught their attention. Once the students were afforded the opportunity of self-guided reflection, the researchers also asked more specific questions aligned with the focus of the study.

Event oriented inquiry

We developed event-oriented inquiry from Sewell (2005), who studied history and we were attracted to his focus on contradictions that transformed the course of history. We found it useful to consider an event as "a spike in the curve" (Tobin, Ritchie, Hudson, Oakley, and Mergard 2013), giving priority to the concept of salient contradictions. We initially considered an event to be a contradiction that changes the nature of what is happening. Accordingly, a key step in event-oriented inquiry is to identify a salient contradiction, describe the event in which it occurs, and select a beginning and end for the event.

> On the other hand, when events happen in a more protracted manner, it is essential to consider the temporal framework and frames of reference being used to determine the effect of events (Moore 2011). Even the most mundane aspects of an interaction may be important for the narrative and should not be simply ignored or glossed over to create a more coherent story. Events have both temporal and contingent qualities that do not always allow for a seamless narrative. Thus, when viewing video and audio data and selecting events for further analysis, it is important to keep track of the narrative in its totality (Ritchie and Newlands 2016).

Ongoing research at Brooklyn College, led by Konstantinos Alexakos and Kenneth Tobin, sensitized us to two physiological concerns (Alexakos 2015). Some teachers were teaching with excessively high heart rates and others were teaching with surprisingly low blood oxygen concentrations. In the study we present in this paper, as we prepared a variety of research tools, we set up the oximeter, which began recording, while we turned our attention to situating the video and audio recorders, which we started when Donna began to teach. Accordingly, we had a pre-teaching segment of the oximeter data for which there was no video and audio recording.

When we examined distributions of heart rate and blood oxygenation we looked for spikes in the curve, illustrative of unexpected values for heart rate and blood oxygenation. The spike in the curve that captured our attention was a heart rate of 118bpm. This spike happened in the pre-teaching part of the research. Also, we identified a segment of the pre-teaching phase in which Donna expressed low oxygenation levels. That is, we identified two events in the pre-teaching phase. When we re-viewed the video of the lesson we identified three additional events associated with Donna's oximeter readings: relatively high heart rates; low oxygenation levels; and high blood oxygenation levels. Accordingly, the five events for this study involve the pre-teaching phase immediately prior to the beginning of the lesson (two events) and the teaching phase (three events).

Overview of the remainder of the paper

In the next section we present descriptive statistics for heart rates and oxygenation levels in eight different contexts. Then, we focus on the pre-teaching phase, including the first two events, which occurred prior to the start of Donna's teaching. The subsequent section addresses the teaching phase, providing perceptions of the lesson as a whole and our study of three events that arose in the teaching phase – associated with high heart rates, low blood oxygenation (hereafter LBO) levels, and high blood oxygenation (hereafter HBO) levels respectively. We conclude by considering transformative implications of what we learned for teachers and students.

Descriptive statistics for heart rates and oxygenation levels in differing contexts

Descriptive statistics were calculated for the oximeter data in eight different contexts listed below:

1. Donna's resting pulse;
2. all data obtained for the pre-teaching and teaching phases;
3. heart rate and blood oxygenation levels when blood oxygenation levels were at least two standard deviations below the mean oxygenation level obtained in context 2 above;
4. heart rate and blood oxygenation levels when heart rate values were at least two standard deviations above the mean obtained in context 2 above;
5. heart rate and blood oxygenation levels in the pre-teaching phase;
6. heart rate and blood oxygenation levels in the teaching phase;
7. heart rate and blood oxygenation levels in each of the five events; and,
8. heart rate and blood oxygenation levels in a post-lesson taught in 2016.

<<Insert Table 1 about here>>

Events 1 and 2: Emotional expression before teaching

Oximeter data for the pre-teaching phase (duration 30m 48s) included the highest heart rate of 118bpm and the lowest blood oxygenation levels of 92%. Based on these spikes and differences from Donna's resting values, we identified and studied the following two events within the pre-teaching phase.

Event 1: A high heart rate event

From a careful examination of the heart rate versus time curve, in the region prior to the lesson commencing, we identified points either side of the spike of 118bpm, which signaled the start and end of increased heart activity. This involved an interval of 42s.

Event 2: An unexpected drop in blood oxygenation

About 18 minutes after the heart rate spike, the oxygen concentration dropped to 92% and remained constant for a 10s interval, rising to 93% for 1s, and dropping back to 92% for the remainder of the event. During this event of duration 37s the sudden fall in blood oxygenation and subsequent recovery is a matter for additional research that utilizes multiple data resources. Later in this paper we explore these issues further through the study of variations in prosody and breathing patterns in two events (events 4 & 5) that involve a) low and b) high blood oxygenation while teaching. In these later analyses audio, video, and student perspectives contribute to our learning.

Donna's perspectives on the pre teaching events (1 & 2)

Donna's narrative (below) provides insights into her anxiety about working with new students in areas of science that she did not feel she had the necessary science knowledge to handle if the lesson veered from her plan. The following narrative provides further insights into her feelings prior to the start of the lesson.

> *Donna: Prior to teaching Lesson 2 I felt a bit flustered because I had a lot to set up for the lesson and a lot to think about. I like to be very organized (I especially like getting into the room early so that I can get everything set up before the lecture and then chat to the students). In this lesson I was splitting the students up into groups so that they could meet other students in the class. I had to get the room organized for this early activity. I had made cards with symbols of chemical apparatus on them so that as the students arrived they took a card with a picture and went and sat with that group. I remember feeling anxious and nervous about how this would work out since I had not tried it before with this group. The anxiety was due to not knowing the students very well and feeling like I have to make a good impression in the first few weeks.*

Donna was concerned about the logistics of the lesson and it is likely that her concerns about her teaching performance before she was teaching were signaling to her unmyelinated vagus nerve that social harms were present. In this context, the two spikes, associated with high heart rate and low oxygenation levels are consistent with the myelinated vagus nerve transferring control to the unmyelinated vagus, mobilizing her body for fight-flight activity.

Events 1 and 2, which occurred prior to the video and audio data recorders were activated, and are a reminder that negative emotions, such as worry and fear, can manifest prior to teaching. That is, fear for what might occur can produce stress and anomalous heart

rate and blood oxygenation levels. Porges (2011, Loc 5697 of 7127) noted that, "If behavior is detected as dangerous, then the sympathetic nervous system is activated to support the fight-or-flight mobilization behaviors." It seems likely that high heart rate and LBO levels, via neuroception, might activate the unmylenated vagus nerve to protect the body against potential social and/or physical harm. If neuroception detects danger and/or harm then the myelinated vagus nerve can shut down, ceding control to the unmylenated vagus nerve that supports mobilization of fight-flight forms of conduct – including the prosody of the voice and other social communication skills. If this scenario is viable, an important implication is for Donna to stay in the moment, rather than allowing fear-related emotions to stick and initiate undesirable physiological responses. There is a plethora of research suggesting that breathing meditation can be used to become mindful, focusing attention on the present, and ensuring that emotions do not stick to present conduct (Powietrzynska and Tobin 2016). Also, breathing meditation can change a person's emotions and initiate a transition back to control via the myelinated vagus, thereby resuming social activity and shutting down the unmyelinated vagus (Porges 2011). In the next sections of the paper we employ video and audio files, as well as narratives from Donna and four students, to complement analyses of oximeter data in three events associated with: high heart rate (event 3), LBO levels (event 4), and HBO levels (event 5).

A whole lesson focus: How are emotions expressed?

Physiological trends as Donna taught

The oximeter data set for the lesson, duration 1h 10m 4s, the mean for blood oxygenation was 98%, about the same as the resting level. The mean heart rate of 93bpm was approximately 50% higher than the resting level of 63bpm.

What Donna planned to teach in the lesson

The course Donna was teaching was the first in a suite of three science curriculum courses – curriculum and pedagogy for teaching science in the junior years of schooling (i.e., grades 7-10).

> *Donna: In lesson 1, I had taught part of a junior science lesson (i.e., evaporation and condensation through a demonstration), and I asked the pre-service teachers to list aspects of the lesson that were successful and aspects that could have been improved. I planned to incorporate the suggestions for improvements into the second lesson in which I taught part of a junior science lesson. During this second lesson, I planned to demonstrate one teaching strategy (i.e., a discrepant event – where the outcome is unexpected) – that pre-service teachers could use in a junior science classroom that was engaging as well as affording them an opportunity to learn or revise a science concept. The discrepant event required me to shoot mentos (a candy) into a bottle of diet coke so that an eruption of the ingredients would spray out of the opening, resulting in a spectacular visual display. Pre-service teachers were to explain what caused the eruption within their small groups. Following this, I planned for a whole-group discussion to explain the eruption that would enable the introduction of other teaching strategies such as role play for the explanation of science concepts (e.g., pre-service teachers can act out three scenarios: the movement of carbon dioxide molecules as they are drawn to the surface of the mentos as it sinks through the soda; the escape of the*

molecules from the surface of the mentos; and the rush of carbon dioxide pushing soda out of the mouth of the container). After the discrepant event and explanation, I planned to ask the pre-service teachers to pretend they were Grade 8 science students and write down questions students may ask. This was to afford me another opportunity to introduce a fun activity where the questions, which were to be written on small pieces of paper, could be scrunched up and thrown into a container held by one of the pre-service teachers. I planned to take a bottle of lemonade as a back up in case students asked what would happen if the soft drink was changed in one of their questions. After these questions were read out and answered by me, I planned to complete the lecture as guided by the PowerPoint™ (PPT) slides, where there were questions and summaries regarding the readings students had completed prior to the lecture as well as information about the Australian Curriculum.

Emotions while teaching

In the following narrative Donna lays out what she intended to teach and her expressed emotions throughout the lesson.

Donna: Right at the beginning I was feeling a little bit nervous but I settled down once I could refer to the PPT about how I could improve the year 8 science lesson that I had done the week before. When my notes are there (i.e., on the PPT presentation) I am less nervous and I have something to refer to if I forget what I am going to say. I am always more nervous at the start of a semester when I don't know the students and they don't know me – which was the case in lesson 2 – I am still building rapport.

The discrepant event makes me nervous and anxious because I worry that it won't work and also that I may be asked complicated science questions that I can't answer. I have lots of thoughts running through my head some of these include: Is this really an example of a discrepant event? How can students learn any science from me doing this? Do I just show them the didactic approach in the end when I explain it so that I revert to transmission of knowledge? This is a one-off … so what? I am not sure how this leads to any real scientific meaning. I like getting the student involved but I am always a bit worried about how this will turn out. I think about how the student can help and not be "laughed at" but rather "laughed with." I try to maintain a calm disposition on the outside but there is a lot that I am thinking about and the anxiety builds. Part of that anxiety is that I am trying to think about so much while I am doing the experiment until it is all over … and I relax a bit more.

When the experiment didn't work, I felt a bit embarrassed and then disappointed because I usually have a spare bottle of coke to try it again but I didn't have one this time. When I am asking for explanations about the discrepant event I feel concerned/anxious/nervous because there are a few theories about why it works and scientifically I find them tricky to explain (and I sometimes struggle to explain it clearly to the students, especially those with little science background.) While the students are discussing why the mentos in the coke erupted, I am reviewing my notes so that I can explain it accurately. Again – I am feeling a bit anxious at this point and there is always a sense of relief when I have finished this part of the demo. When I have finished the science explanation of the mentos and coke I worry that I have just demonstrated the didactic approach – what's in my head rather than getting them to

construct their own knowledge – but how do I do this when they would not really have the knowledge to explain the experiment?

When I role play the motion of the carbon dioxide molecules [i.e., part of the explanation for the discrepant event] I feel a bit silly but I also feel happy that I actually got the students out to help me to explain a science concept. There is a sense of satisfaction that I have moved away from 'chalk and talk.' After the experiment, I momentarily forgot what was next and went to the PPT to refresh my memory and then there is a moment of relief that I know what to do.

While students are working in groups to write questions I feel relaxed and happy because it gives me time out to think but also I enjoy hearing them talk to each other. I like a noisy classroom and I don't like being the centre of attention all the time. Hearing students talking and engaging in the topic makes me feel content and like I am 'successful' as a teacher. Before I call for their attention I am worried that I might interrupt valuable conversations to gather the whole class responses so I am concerned about timing at this point. When students were throwing the paper in the bin I was feeling happy because it was fun and the activity went well. I did the lemonade experiment very quickly and I was once again relieved when this part was over. Anxiety may have increased a bit when I had to explain the difference between the lemonade and coke but I skated over this to move onto the next question. After the questions were read out I relaxed more because the next phase of the lesson was very familiar to me. I have done this part many times before and I enjoy getting the students to give me their perspectives on the readings etc. ... I also feel a bit of pride when they come up with good answers and I feel successful at getting the students to share ideas. I really enjoy this part of teaching. The rest of the lesson I am calmer and more confident and I realize that my knowledge is far greater than the students' and I can answer their comments and questions thoughtfully and intelligently. My confidence and calmer demeanor continues to the end of the lesson.

Perspectives on Donna's narrative

Donna's narrative contains about 30 allusions to emotions, 13 positive (e.g., pride, satisfaction, happiness) and 17 negative (worry, anxiety, disappointment, and embarrassment). An issue that arises is that Donna experienced predominantly negative emotions prior to beginning the lesson (see events 1 & 2). These data suggest that Donna regards the lesson with some trepidation, as an activity that is potentially uncomfortable for Donna because she does not know her students well and also because the science underlying the discrepant event is not in an area of science in which she reports to have strength. Accordingly, activation of parasympathetic modes of conduct associated with fight-and-flight and immobilization are possible, and physiological activity associated with social communication may not be activated (Porges 2011). According to PVT, neuroception occurs in what Porges described as primitive parts of the brain, without a person being consciously aware of what is happening. If the environment is assessed to be physically or socially unsafe, a sequence of neural processes facilitates adaptive defense behaviors. In a social setting, such as the methods class in which Donna was teaching, a relatively new group of students for her, the physiological response to the assessment of risk might include modes of conduct such as high heart rate, flushed cheeks, increased perspiration, and feeling faint. Interestingly, when the body is in fight, flight, and/or freeze mode there can be large drops in

blood pressure, LBO, and an inability to express facial emotions, less prosodic variation, and difficulty in differentiating the human voice from background noise. Physiological conditions such as these do not seem to be conducive to good teaching and learning. In subsequent sections of the paper we investigate the possibility of some physiological changes like these occurring as Donna taught.

Variations in prosody

The four student participants each reviewed the three events for which we had video and audio resources. All four students commented on the relevance of discrepant events in their science teaching. They were free to comment on any aspect that caught their attention and if it did not come up we asked them about aspects of prosody.

Amy considered Donna's teaching to be very engaging. When we brought prosody to her attention, she could hear differences in events 3, 4 and 5, but she did not know what to make of those differences.

Cath did not notice prosody as salient, and when a researcher brought it to her attention, she could hear differences in prosody in the video clips for the three events, but she did not consider these differences to be important. Cath considered Donna to be lacking confidence in the third event, especially in comparison to the fifth. She justified this claim in terms of Donna's speech fluency.

David's initial reflections involved recollections of his thoughts during the lesson and what was happening in terms of the use of discrepant events to teach science. When Ken asked: "anything particularly engaging"? David replied: "nothing that jumps out and grabs your attention." Prosody and proxemics were neither raised nor discussed. In response to a direct query, David volunteered that the clips he reviewed were fairly typical of Donna's teaching. David then mentioned volume and pitch as he argued that Donna's intonation was easy to listen to, in comparison to teachers who spoke in a monotone. David provided several more examples of Donna reflecting excitement through her speech – speed of delivery, pitch, and body language.

Only Gene, who had an undergraduate major in communications, addressed prosody directly and continuously throughout his review of events 3, 4 and 5. In his general comments about the video clip Gene explained that he found the content quite helpful because Donna provided useful information on how to approach certain aspects of chemical science – which he regarded as an area of his weakness. Gene liked the practical nature of what was done. Some of Gene's comments about prosody are presented in subsequent sections.

Event 3: Teaching with a relatively high heart rate

> *Donna: As the lesson started I relaxed more as I referred to the PPT to explain the characteristics in the lesson that they had suggested were absent in last week's lesson and that I needed to include in this week's demonstration. As I was reading the PPT I remember thinking "can I achieve all of this in the one discrepant event today?" I remained quite nervous throughout the whole of this short episode leading up to the discrepant event.*

The third event, duration 2m 2 s, occurred 21m 40s into the lesson. The mean heart rate was 111bpm and the blood oxygenation averaged just above 97%.

An initial analysis identified approximately 1m 43s of teacher talk in which Donna critiqued some of her own practices and explained what was to happen in the forthcoming lesson.

Within the first 6 seconds Donna makes a distinction between explaining science concepts to this group, which has a science background, and a year 8 class. Donna emphasizes the word *eight*, in the utterance "year 8," and it comes across as a shrill sound. With the use of PRAAT (Boersma and Weenink 2016) we examined the prosody of the word eight in relation to the surrounding text. The power of the wave in the air for the word eight was much higher than the power in the air of the surrounding text. The peak intensity occurred at 5.2s and at that point in time a spectral slice showed the distribution of energy for particular formants. On this occasion levels of energy were obtained for formants 1 to 3, most energy being associated with the second formant (1,737 Hz). The proportion of energy associated with higher formants no doubt explains the shrill sound of the word eight that was subjectively experienced and noted in Gene's account. These changes in prosody are consistent with the myelinated vagus not regulating pathways that control the breath, muscles of the larynx and pharynx, and heart rate (Porges 2011). We looked at the energy versus time graph produced in PRAAT and noticed an additional 6 spikes associated with high-energy utterances. We then analyzed each of these utterances using similar methods to those we used when we analyzed the utterance of "year 8." With the exception of the first utterance the remaining five were similar to what we obtained for the analysis of the word eight. In each case Donna uttered a shrill sounding word that contains a higher proportion of the energy in formants 2 and 3.

We also examined the pace of Donna's utterances in terms of the number of syllables per second (sps) and the frequency of the high intensity peaks. The pace of Donna's talk was 3.8sps and there was an average of 2.6 high intensity peaks per second.

Students' perspectives on the prosody of the high heart rate event

Donna asked Gene specifically about the quality of her oral delivery.

> *Donna: just in terms of my voice was there anything about that that you wanted to comment on in that clip?*
>
> *Gene: I noticed at some points, more the intonation of your voice … You were putting emphasis on certain words that didn't really seem to have too much relevance.*
>
> *Donna: Hmmm*
>
> *Gene: like you go to a point and you'd have a high pitch or a distinctly lower pitch. And these were particular buzzwords that weren't really key concept words. So, it was sort of a bit confusing because you'd be paying attention to that particular word trying to think of how it relates and I couldn't really find any correlation.*

When questioned by Donna about whether he noticed this intonation pattern in class, Gene confirmed that he did. What he described as an incorrect pattern of intonation threw him in the wrong direction. According to Gene, Donna elongated the word expanding, increasing the duration of the last syllable. This change in intonation drew his attention to the word expanding rather than to the concept Donna was trying to develop. … "It throws me in the wrong direction." Gene also noted that, "you altered it from a good normal use."

Our analyses using PRAAT indicated that Donna's voice fluctuated in frequency and intensity and, as was pointed out by Gene, there were words that were elongated to provide emphasis. For example, when Donna said the word elaboration, its duration was approximately 1.5s, with most energy occurring in the first syllable. The intensity of the sound dropped from the first to the fifth syllable. The frequency range was from 100 to 600 Hz (for the first formant). In this approximately two-minute event, 10 words had similar distributions of energy, intensity, and frequency.

When Amy was asked whether improvements could be made or if there was anything annoying occurring she mentioned that event 3 may have been a bit loud – although on numerous times she indicated that, because of its energy, this event was more engaging than events 4 and 5.

Event 4: Teaching with relatively low blood oxygenation levels

We identified a fourth event associated with a sustained dip in the blood oxygenation levels, commencing 20m 33s after the beginning of the lesson and continuing for 38s. During this event, Donna circulated a bin around the pre-service teacher class to demonstrate one non-threatening way to collect student questions in high school science classrooms. The pre-service teachers wrote science questions on pieces of paper, Donna then moved around the room as students threw the scrunched paper into the bin.

> *Donna: I was excited and interested to see how the "bin" activity would play out with the group. David did a good job of taking the bin around and this usually generates a bit of laughter from the students. I was happy that they laughed and that indicated to me that it was going to be a successful teaching strategy. I felt relieved that the students were responding positively at this point. I was really pleased that the lemonade question came up first (I couldn't believe my luck!) because I could demonstrate what would happen, however, I felt a bit anxious about whether it would be successful or not and if I needed more in-depth explanations to explain the extra experimental work. Fortunately I could skate over the explanations a bit but the anxiety is evident when I get tongue tied with "gellan gum." I am enjoying the surprise element of the questions in the bin and the students were listening to them as I read them out. I felt nervous that there may have been some difficult questions but I soon realised that most of them were very straight forward and quite repetitive. So there is still some anxiety during the "bin " activity but also relief as I make my way through the questions and realise that they are very simplistic and ones that I have answered before. I feel a sense of satisfaction if I can give a good explanation quickly after reading the question. I would be grateful that I had prepared thoroughly for the lecture because many of the questions I had thought about beforehand. I was embarrassed when I left two questions at the bottom of the bin and quickly rectified this by reading them out.*

The oximeter data for event 4 showed blood oxygenation to have a mean of 92% and heart rate to average 102bpm. Donna spoke quickly and with very few breaths in approximately 32s of the audio and video recording of this event, in which she gave practical advice to her students about what to do if there is time remaining when the planned work is completed. A transcript of the event is provided below:

```
01. … questions. Now that little activity you could do (0.4s)
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02. at the end of a lesson so you got about five or ten minutes to go bells about to ring but you know the kids are a bit restless and (0.5s)

03. gosh what am I gonna do for the last five to ten minutes (0.02s)

04. the teacher next door's gonna complain if I let them out early (0.8s)

05. get them to write down a question about something you just taught them in class (1s)

06. ah for a bit of fun [the n on fun is elaborated for 0.23s] get them to throw it in the bin (0.4s)

07. and answer those questions (0.05s)

08. oh no Erica oh sorry (0.5s)

09. you are sitting there thinking I didn't answer your question. There were two hiding under the plastic bag (1.3s)

10. Sorry about that.

We display the transcript as we hear it – as 10 utterances – bursts of speech separated by relatively short periods of silence. Two of the nine pauses are less than 0.1s and are heard as a run on from the previous burst of speech. Arguably there is sufficient time for a breath in each of the other pauses, which range from 0.4s to 1.3s. Based on the transcript and careful viewing of the video, it is possible and likely that these seven pauses are sites for shallow (possibly thoracic) breaths. The duration of each of the seven bursts of speech (including the length of the silent pause following the last word) are: 2.9s, 7.2s, 2.0s, 4.0s, 5.9s, 5.0s, and 0.7s. Based on these data, the breaths that occurred, if any, were irregularly spaced.

Immediately after each possible breath there was an increase in the power of the wave in the air. Variation in pitch was evident throughout the monologue, although in the seconds prior to each breath the pitch was less varied (i.e., more monotonic). Within each burst of speech the power declined from the beginning to the end. Typical of this pattern is the second utterance. The first five words in the second utterance (at the end of the lesson) have a duration of 1.7s and average power of 70dB (2.9sps). The next six words have duration of 1.0s and average intensity of 68dB (7sps). The next eight words (or ten minutes to go the bells about to ring) has duration of 1.5s, an average pace of 8sps. The average intensity of this speech segment is 65dB. The "tail" for the second utterance contains 9 words and a filler word (and) – duration 1.5s, average intensity 63dB, and pace 6.7sps.

The speech quickens toward the end of the utterance. In terms of syllables per second, the bursts of speech in utterance two have pace of 2.9, 7.0, 8.0, and 6.7 respectively. The final word (and) serves as a filler of 0.5 seconds, tailing off in intensity from 65dB to 54dB (the level of the background noise). Perhaps Donna's relatively low number of breaths and rapid-fire style of speaking in utterance 2, which is typical of each of the utterances, is related to the low blood oxygen level in event 4. We note that the pace of speaking is much higher in this event than in the high heart rates event (event 3). Arguably, as Donna ran out of oxygen, her speech decreased in intensity and quickened until the next shallow breath occurred.

The "barely discernible," irregular nasal breathing pattern may have produced emotions on the anger (e.g., aggravation) and fear continua (e.g., apprehension). If this occurred then

neuroception might afford the unmyelinated vagus operating in fight-flight mode with the myelinated vagus shutting down. In circumstances such as these changes might be expected in breathing and hence oxygenation of the blood, changes in prosody, and difficulties in differentiating human voices from background noise. Also, facial expressions might not reflect emotions being enacted because the facial muscles are not operating efficiently.

Horrible breathing habits

After David reviewed events 3, 4 and 5 the conversation focused on the breathing patterns Donna used in event 4. Ken remarked to David: you know a lot about breathing. Show me where she takes a breath in the low oxygenation event. David's background in martial arts meant that he was well rehearsed in breathing exercises and had awareness of different breathing patterns such as thoracic and diaphragmatic. Immediately following Ken's request, David showed interest and became very engaged as he re-viewed the salient video, this time without sound. He noted: a couple of very shallow breaths. "There is one on raising the upper body at about the 12s mark … but she doesn't have any deep breathing." David then reviewed the audio file and came to the same conclusion. He noted with a smile – "horrible breathing habits."

Gene immediately highlighted Donna's use of higher pitch in a few places and also some filler words to gather her thoughts between utterances. When asked by Alberto about breathing patterns he indicated that in the first 18 seconds Donna used upper chest breathing and from 18 seconds onwards her breathing used the lower chest. He went on to explain that different prosody and breathing patterns apply to different purposes of speech. His preference was for consistency with the established conventions and he was distracted when Donna broke from convention – as occurred in events 3 and 4.

Amy did not notice anything in particular about the low oxygenation event until she was guided by a question asked by Ken: where does Donna take a breath? Amy then re-analyzed the event, with and without audio. After a while she noted: "she breathed back there, but that was quite a long time … she's running out of oxygen." When she was asked for evidence that a breath had occurred Amy mentioned a long pause, but then seemed uncertain. Amy, Donna, and Ken then looked frame by frame to see if there was any evidence of Donna moving her chest during the utterance. At one stage Amy queried, as she laughed: is she breathing? I don't know!

Event 5: Teaching with high blood oxygen concentration

The fifth event commenced 45m 20s after the start of the lesson, duration 3m 16s. The event was defined by an increase in blood oxygenation to a maximum of 100%. The mean oxygenation was 98% and mean heart rate was approximately 92bpm.

A characteristic that stands out in this event is emotional effervescence. During an event in which there is verbal interaction and quick transitions to different modes of engagement and grouping of students, there is an instance of spontaneous laughter. Donna moves through the center of the class, reducing her physical distance from most students. Initially, Donna addresses criteria that students can potentially use to enhance performance on assessment tasks. Students have mutual focus from which entrainment can provide a foundation for shared positive mood. When Donna asked students to select a student from each group according to whether s/he walked or cycled to the university, there was a ripple of

conversation with occasional laughter from individuals. Possibly there was an expectation that the selected person would represent the group in the activity. However, about 40 seconds later Donna made a request that was probably unexpected, instructing the selected person to select another representative from the group. As Donna made this request there was an audible ripple of laughter that ran through the class. For the remainder of the event there was a "positive buzz" that permeated the class.

Donna called on the first group and a male student gave an example of a misconception that can arise in a science class. Donna acknowledged what was said and commented that someone in that group was doing excellent reading. Her allusion to somebody doing excellent reading reinforced the criterion she had previously provided for earning a good grade in this course. Donna then elaborated on the contribution, giving what she referred to as a simplistic example of a grade one child thinking that clouds are made of cotton wool. She then called on a second group and a female student made a comment that alluded to social and cultural influences on learning. Donna provided a critical analysis of this contribution, indicating that this is not always the case. She then paraphrased what the student had said before inviting her to elaborate. The student did so, referring to a reading someone in the group had used as a basis for the contribution.

Donna: I relaxed more during the "The Australian Curriculum" part of the lecture and my words are flowing more freely and I am using more hand gestures. My confidence is increasing and I am on a roll! I am quite relaxed explaining the book to the class and sharing this resource since this is a very easy part of the lecture to explain.

Group work gives me a break and I am happy to see students talking about something that is relevant and hopefully through these interactions they are learning something useful. Just getting them to talk is a success since they are so quiet and hardly know each other early in the semester. As I walked around I was pleased with the comments I was hearing. I like including little tricks like "turn to the person on your left etc. ..." to get a reaction from the students. This makes me happy to see them smile at the different teaching strategies. I was happy with how this part of the lesson was proceeding and I relaxed more. When students began to contribute answers I was interested in their comments and pleased that they had completed the task that I set.

As I was walking around listening to the students' discussion, I was pleased to hear the noise in the room and that they were on track with the task. This was an opportunity for me to think about the next part of the lesson. I have never tried this activity before where I get the students to talk about their readings. I was also pleased that some students had done the readings because I remember not expecting many of them to have completed this task, however, since it was in the second week of semester I was sure that some students would be keeping up. When I brought the group to my attention I used different teaching strategies to get them all involved such as "find the person in the group who walked or cycled to school etc." This is always good fun and the students seemed to respond well. I reinforced the importance of reading throughout the semester because this has not been done well in the past. Some of the students' responses were difficult for me to respond to especially the cultural comments since this is outside of my field of expertise. When I asked groups to "elaborate" on the topic, I was often buying some time to think of an appropriate response. I was also conscious of trying to keep the discussion going with questioning so that it was not just Question-Answer-Response which seems to be a habit of mine and I feel more "successful" as a teacher when the discussion lasts

longer and has more involvement from a variety of students. I find it difficult to get the discussion building with this group so I plan strategies to get them thinking and talking. I liked this episode when I watched it because the students seemed engaged and I managed to keep the conversation going for a period of time. I also was pleased that readings had been completed.

Donna's narrative clearly suggests her emotions in this event were positive and on the happiness continuum. Gene noted that the prosody conformed to his expectations: "the intonation is actually quite accurate." In this case Gene felt that elongation and pitch served to emphasize the appropriate words in the utterance. That is, intonation helped to convey meaning to a greater extent than in the event associated with teaching with a high heart rate. These data support an assertion that the myelinated vagus was appropriately engaged, affording social communication. Of course, if the 100% blood oxygenation had been sustained over a longer time interval we presume the neuroception system would have responded by shutting down the myelinated vagus nerve and transferring control to the unmyelinated vagus nerve.

Gene felt that event 5 was the most engaging of the events he reviewed during the stimulated reflective discussions (i.e., more so than events 3-4) – because Donna had used an intonation pattern that was consistent with convention. He noted that different intonation patterns were associated with different contexts such as introducing new material, connecting what has been introduced to what students know, and reviewing material. Amy also noted that, in this HBO event (event 5), Donna's voice was smoother, lower, and quite different than her voice in the high heart rate event (i.e., event 3). Amy explained that in the HBO event Donna was speaking slower. In contrast, to the high heart rate event (event 3), differences in pitch and many changes in intonation ensured that listeners would not get bored. In summary, the students' reviews were consistent with Donna being an effective communicator in event 5, selected because of a HBO spike.

Our analyses of the prosody of Donna's oral delivery in event 5 supported the perspectives expressed by the students. Her social communication appeared to be effective throughout the event. For example, Donna appeared quite relaxed as she began to get students' responses to some queries about students' understandings about science. She elaborated on the first response she received in the following way:

01. If the kids [i.e., high school students] come into the classroom already with ideas about how the world works
02. a very very
03. simplistic example is little kids or perhaps grade oners think that clouds are made of cotton wool.

Utterance 01 had pace of 3.2sps (66dB) and utterance 03 had pace of 3.7sps (64dB). Utterance 02 (a very very) was expressed emphatically – that is, relatively slow (3.8sps) and loud (67dB). The maximum sound occurred on the first very and peaked at 81dB.

If we suggest students should be reflexive about prosody it is important that they are aware of prosody and what it means. If they are to consciously consider whether prosody makes a difference to teaching and whether it impacts learners, it seems important that they have had time to think about the construct and its connections to social life. Without knowledge and personal experience with prosody, it is difficult to see how students, for example, would have a set of values about prosody and articulate very much about their preferences for how a teacher could and should speak in different contexts.

Benefits to participants of our research

The design of our ongoing research seeks to ensure that participants, including researchers, learn from research and understand others' perspectives on issues that are relevant to the research. Changes in practice also are planned to allow collectives (e.g., females, males) and individuals to benefit from the research. Social justice and care also are overarching characteristics of how we conduct research. In the study we report in this paper a primary concern was that Donna, an Australian science teacher educator, would benefit from the research and so too would her colleagues and students. Importantly, the goal of learning from the research would not be at the expense of excess social harm to Donna, other participants in the research, or stakeholders associated with the institution. In regard to Donna learning from this ongoing research in which she is involved, she commented:

> *Donna: This year I taught Science Curriculum One in first semester, two years after the "shrill voice" data that was collected during the same unit in 2012. I had reflected on the shrill voice since being part of the study. I can't remember exactly what I did last year (2013) when I taught this unit but it would have been similar strategies to what I used this year (2014).*
>
> *One of the most important strategies is the reflection/thinking that I do in the car on the way to work. I think through what I am going to teach and picture myself doing a good job and go over the lecture outline in my head. I usually say a prayer that it will go well.*
>
> *When I arrive at work I get everything organized and set up the room so I have the technology ready, PPTs up, YouTube videos open because this helps me manage the stress of teaching a big class. This class has many students with strong backgrounds in science. Because they are so enthusiastic and keen, I want to be thoroughly prepared so I usually over prepare for the first few weeks and read a lot about the topic that I am teaching. This is so I am prepared for any questions they may have. There is a lot of reading that I do at home prior to teaching the class. The thorough preparation contributes to a calmer teaching approach for me.*
>
> *Just before the class comes in I check over my notes and lesson plan then consciously think positively about the class … I say to myself "just enjoy it" or "have fun." When the students come in I make sure I greet them, smile and say their name if I can remember it. I try to chat to them about something relevant to their lives. When I begin teaching I try and remind myself that if I enjoy the class, they will too and so I relax a bit more as the class progresses. I also consciously listen to the tone of my voice for the pitch and if it is getting too loud I bring down the volume. I know the difference between shrill and loud. Shrill is when I am nervous, speak too fast and am not completely confident about what I am teaching. Shrill often occurs when I am rushing from one thing to the next. My voice is high pitched during these instances. I have tried to overcome this by being calm at the start of the lesson through good organization and planning, consciously listening to my voice, and consciously thinking positive thoughts.*

It makes sense to tune into the body and changes that are associated with vagal tone. As far as the study of teaching is concerned, heightened awareness of heart rate, blood oxygenation levels, and characteristics of the breathing patterns being employed may provide salient views into wellness that can be manipulated consciously through learned interventions that

include intentional changes to breathing patterns, self-hugs, and facial expressions (Tobin 2016b).

> *Donna: this has been a really interesting process for me, as an experienced teacher, to pick up on things that I'm doing that I didn't realize I was doing, but I will perhaps be more mindful of now when I am teaching … I guess you can always be improving your practice … I probably could find ways to teach that are less energetic and … if you were teaching all day like that you'd probably get worn out.*

Donna taught a lesson in 2016 under similar circumstances to lecture 2, which was taught in 2012. We wanted to juxtapose the oximeter data from the 2016 lesson with the data we have used throughout this paper, and in particular, with Donna's claims to have learned and changed her teaching (see Table 1). The heart rate data were similar to those obtained for the 2012 lesson; however, in 2016 the mean oxygenation concentration was relatively low at 96%. These descriptive statistics are an invitation to look more deeply at the audio and video records from the post-lesson and to relate what we find to Donna's narratives and the oximeter data. Clearly there is a priority for further research on the topics we have addressed in this paper.

Neuroception, vagal tone, and wellness of teachers

Porges (2011, Loc 4418 of 7127) described slow exhalation as a "respiratory process associated with expressive social vocalizations [which] enhances the impact of the myelinated vagus on the heart, promoting calm states." This commendation of slow exhalation corresponds with a body of research on breathing meditation (Davidson with Begley 2012) and our own interventions to improve the quality of teaching and learning. Since Alexakos and Tobin began their research on the physiological expression of emotion (Alexakos 2015), they and many colleagues in the United States, have used 5m of breathing meditation followed by 10m of free writing, as activities to promote calm states and enhance mindfulness of teachers and learners (Tobin 2016b). In addition, Tobin has explained how individuals can use simple touches and holds of various body parts (i.e., self help) to ameliorate excesses of emotion, panic attacks, and other physiological symptoms associated with stress and emotional excesses (e.g., holding the thumb to minimize worry and become calm; index finger to ameliorate build-up of fear; middle finger to relieve excess anger or frustration; "pinky" finger to curb racing heart beat and reduce sadness; and ring finger to facilitate difficulties with breathing.)

We sent a request for Donna to provide baseline data for this study that used an oximeter to examine physiological data of a teacher while teaching. An email request contained the following excerpt:

> *Ken: Can you please sit with an oximeter on your finger in a quiet place for 10 minutes. I would like you to just think about your out-breath. No drama, no reading, no humming tunes … Just quietly doing nothing while the oximeter reads your resting biophysicals.*

In essence, the request was for Donna to engage in about 10 minutes of breathing meditation. She accomplished this and the evidence suggests that the myelinated vagus operated effectively, consistent with continuous neuroception that the social and physical environments were safe and conducive to social interaction (Porges 2009). Somewhat in contrast to this situation, while teaching, there is evidence presented in this paper that

Donna's prosody changed in association with physiological characteristics, including those we measured – heart rate and blood oxygenation. Since neuroception is continuous and operates without a person being aware or in control, we regard it as a priority to do more research on wellness of teachers and physiological changes as they teach, including the intervals of time prior to teaching. We can expand the range of physiological data to include the strength of the pulse, body temperature, and perhaps the changing concentrations of neurochemicals such as cortisol and oxytocin.

Heightening awareness of teachers and learners about breathing patterns, mindfulness, breathing meditation, and physiological variables, including heart rate and blood oxygenation levels, can provide them with options to monitor their body while teaching and learning are occurring. A reflexive approach provides opportunities for teachers to consciously change what is happening by acting contingently and emergently on the basis of what is happening and why they perceive it to be happening. Accordingly, body conditions, such as racing pulse, dizziness, light headedness, dryness of the mouth, changes in prosody, and inability to clearly hear what people are saying can be signs to take time out and engage in a brief period of meditation. Interventions such as breathing meditation and holding a finger (for example), may have dramatic implications for the quality of teaching and learning, and perhaps most important, for the health of teachers and students. Attention can be given to different forms of intervention. Whereas we have focused here on breathing meditation, we have already used other forms of meditation in our ongoing work – including walking meditation, compassion meditation, and touching the hands on strategic places on the body (Tobin 2016b). We regard it as a high priority to undertake further research, using authentic inquiry in which participants benefit from what is learned from research, as the research is ongoing. In our case, we regard interventions involving Donna and each of the co-authors of this paper to be important next steps.

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Author biographies

Kenneth Tobin came to the Urban Education doctoral program at the Graduate Center of CUNY in the fall semester of 2003. Presently he is coordinator of the Learning Sciences strand. Prior to his position at the Graduate Center Tobin had positions as tenured full professor at Florida State University (1987 to 1997) and the University of Pennsylvania (1997 to 2003). Before Tobin became a university science educator in Australia in 1974, he taught high school physics, chemistry, biology general science, and mathematics for 10 years. He began a program of research in 1973 that continues to the present day – teaching and learning of science and learning to teach science. His current research foci are on mindfulness and wellness on the birth-death continuum.

Donna King is a senior lecturer at the Queensland University of Technology. Prior to her appointment in tertiary teaching in 1999, she was a secondary science, mathematics, chemistry and religion teacher for ten years. She completed her PhD on context-based chemistry education in 2009, and currently researches in the fields of contexts for engaging middle school students in STEM and the emotions of students and teachers in both secondary and tertiary settings.

Senka Henderson is a researcher at the Queensland University of Technology, Brisbane, Australia. Prior commencing her career as a science educator, Senka taught pharmacology and biochemistry for 10 years at the Zagreb University and Central Queensland University, Rockhampton. She also worked as research scientist in biotechnology for 5 years. She has worked on three research projects related to emotions in university pre-service science teacher education and within a high school general science classroom with the other co-authors. Senka completed a Master of Pharmacology at Zagreb University and Ph.D. in biochemistry at Central Queensland University, Rockhampton.

Alberto Bellocchi is a senior research fellow (ARC DE160101053) at the Queensland University of Technology, Brisbane, Australia. His current research program focuses on developing understandings about the interaction between social bonds and knowledge construction in school science classrooms. Previous research has focused on emotional learning experiences in high school and university settings in the context of STEM education, use of analogies in chemistry, and context-based learning.

Stephen Ritchie is the Dean of Education at Murdoch University. Before taking up this position in 2013 he was the Professor of Science Education at Queensland University of Technology, where he also was the Editor-in-Chief of *Research in Science Education*. During 2015 he was the Acting Provost at Murdoch.

Table 1

Descriptive statistics for heart rate and blood oxygenation levels

Context	Heart rate (bpm)			Blood oxygenation (%)		
	Range	Mean	SD	Range	Mean	SD
Resting	60-69	63.3	1.8	98-99	98.2	0.4
All oximeter	72-118	94.3	6.7	92-100	97.6	1.0
Low oxygenation	85-111	95.0	5.5	92-96	95.3	1.4
High heart rate	108-118	110.3	1.8	96-99	97.6	0.6
Pre-teaching	85-118	100.6	8.0	92-99	96.7	1.7
Teaching	72-107	93.4	6.1	92-100	98.0	0.7
Event 1 (HPR)	102-118	106.7	3.8	96-98	97.0	0.6
Event 2 (LO)	102-105	102.2	0.5	92-93	92.1	0.3
Event 3 (HPR)	109-112	111.0	1.0	96-98	97.4	0.7
Event 4 (LO)	102-105	102.0	0.5	92-93	92.0	0.3
Event 5 (HO)	87-104	92.3	2.9	97-100	98.0	0.8
Re-teaching	75-127	91.2	7.6	93-98	96.1	0.8