Emotional Arousal of Beginning Physics Teachers During Extended Experimental Investigations

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Abstract: Teachers often have difficulty implementing inquiry-based activities, leading to the arousal of negative emotions. In this multicase study of beginning physics teachers in Australia, we were interested in the extent to which their expectations were realized and how their classroom experiences while implementing extended experimental investigations (EEIs) produced emotional states that mediated their teaching practices. Against rhetoric of fear expressed by their senior colleagues, three of the four teachers were surprised by the positive outcomes from their supervision of EEIs for the first time. Two of these teachers experienced high intensity positive emotions in response to their students' success. When student actions / outcomes did not meet their teachers' expectations, frustration, anger, and disappointment were experienced by the teachers, as predicted by a sociological theory of human emotions (Turner, 2007). Over the course of the EEI projects, the teachers' practices changed along with their emotional states and their students' achievements. We account for similarities and differences in the teachers' emotional experiences in terms of context, prior experience, and expectations. The findings from this study provide insights into effective supervision practices that can be used to inform new and experienced teachers alike.
Keywords: inquiry, emotion, beginning teachers, physics

> I went to a training course from the Science Teachers Association. It was an evening seminar… They talked about EEIs and how horrible they are and how much management they require. And I just went "Right; I'm going to make this as easy as possible for myself and the kids because if it's not, it's going to be a horrible experience." (Tabatha, Interview)

This was a comment made by one beginning physics teacher about how she prepared to implement the mandatory requirement for an extended experimental investigation (EEI) in her class. EEIs are research projects that typically engage the class for about 10 weeks. Tabatha's comment was typical of the comments made by three of the four new physics teachers we observed in the course of their first year of teaching. These teachers entered the profession at a time when the curriculum required them to implement EEIs. According to Tabatha, the experienced teachers who delivered the professional development course organized by the Science Teachers Association highlighted the difficulties teachers might face when implementing EEIs.

There are three interesting and related issues that emerge from Tabatha's comment. First, it is unsurprising that experienced colleagues would express concerns about EEIs. Although exceptional cases have been reported (e.g., Roth, 1995, 1998), barriers to the implementation of inquiry in science classes by experienced teachers have attained prominence in the international literature (e.g., Blanchard, Southerland, & Granger, 2009; Zion, Cohen, & Amir, 2007). Many experienced teachers have difficulty creating inquiry-based classroom environments (Crawford, 2007), which causes them to avoid and resist curriculum reforms that require inquiry.

Second, when beginning teachers take up their teaching careers alongside colleagues with negative stances to inquiry it is reasonable to anticipate that planning to teach science as inquiry is daunting to them (Crawford, 2007; Roth, McGinn, & Bowen, 1998). Coupled with the stresses of teaching fulltime for the first time, implementing EEIs is likely to reduce beginning teachers' expectations of success and lead to classrooms characterized by negative emotions (cf. Ritchie, Tobin, Hudson, Roth, & Mergard, 2011).

After all, the professional development course attended by Tabatha appears to have been shrouded in a discourse of fear.

Third, as we show later in this article, Tabatha set out to achieve a successful outcome for both herself and students against a rhetoric of fear expressed by her senior colleagues. She was determined for her EEI to be well planned such that its implementation was straightforward – she wanted to succeed against the odds.

Following Tabatha's comments, we became interested in the extent to which beginning physics teachers might struggle to implement EEIs and the emotions they experienced. We were aware of the research almost two decades earlier into the successful completion of a research project by two high school students in a university chemical engineering laboratory as part of a school extension project in which the students conducted original research under the supervision of a scientist in much the same way that higher degree research projects are supervised (Ritchie & Rigano, 1996). In this case, the research question was identified by the supervisor, for which the solution was unknown, yet the students became increasingly responsible for data gathering procedures and interpretation of results over the course of the project. This was a research project that would now satisfy the conditions for an EEI, as specified in the physics syllabus (Queensland Studies Authority, 2007). In an EEI, the teacher may assign the research question or the student may identify it. Importantly, the teacher must provide scaffolding. Examining this through the lens of Schwab's (1962) classification system of inquiry, an EEI could be classified as level 2 (guided inquiry) or level 3 (open-ended inquiry). A mediating step to open inquiry occurs for those EEIs where a solution is unknown and teacher scaffolding is provided (see Sadeh & Zion, 2009). When an EEI is undertaken for the first time, as was the case in Tabatha's class,

> [t]he scaffolding should help students complete the assessment by modelling the extended experimental investigation process and familiarising students with the expectations for the written scientific report. However, the scaffolding provided should not specify the physics, or lead the student through a series of steps dictating a solution. Scaffolding should be reduced from Year 11 to Year 12 to allow the student to better demonstrate independence in the research process. (Queensland Studies Authority, 2007, p. 22)

Ritchie and Rigano cautioned widespread advocacy of similar inquiry projects in schools due to the limited research experience of most practicing teachers at that time, as echoed by other science educators and critics of inquiry-based activities for different reasons (see van Rens, Pilot, & van der Schee, 2010). Collectively, these concerns question whether high school teachers are ready for supervising inquiry projects without ongoing support. Even experienced teachers tend to need extended professional support, as well as a curriculum in which inquiry activities are integrated across grade levels, for the successful implementation of scientific inquiry projects (Lederman & Lederman, 2012). Yet, as we highlight below, beginning teachers may have different professional experiences and expectations prior to teaching, and we do not know how they will respond to stances to inquiry expressed by their more experienced colleagues. There is therefore a need to study closely how beginning teachers experience the implementation of EEIs in their physics classes (cf. Blanchard et al., 2009). A research program that focuses on beginning teachers' implementation of EEIs is important work because the literature "does not provide a clear picture of just how difficult it is to teach science as

inquiry" (Crawford, 2007, p. 614). Furthermore, even though studies of inquiry have focused on prospective science teachers (Crawford, 2007; Eick & Dias, 2005; Meyer, Meyer, Nabb, Connell, & Avery, 2011; Yoon, Joung, & Kim, 2012), intern teachers (Blanchard et al., 2009), and in-service teachers (Wallace & Kang, 2004; Zion et al., 2007), with the exception of one phenomenographic study (i.e., Demir & Abell, 2010), beginning teachers have not been the target of recent research.

Another important reason to conduct this study is because

> [r]esearch into . . . teachers' emotions is becoming increasingly important not only because of the growing number of teachers leaving the profession [especially high demand but low supply of physics teachers], but also because unpleasant classroom emotions have considerable implications for student learning, school climate and the quality of education in general. (Schutz, Aultman, & Williams-Johnson, 2009, p. 207)

Implications gleaned from fine-grained studies of beginning science teachers' emotional experiences, especially during demanding EEIs, might assist their transition to fulltime teaching, and lead to greater teacher satisfaction that could enhance their retention in the profession. For this reason, the study of teachers' emotions has become a recent focus in education research (e.g., Ritchie et al., 2011). In fact, recent advances in brain research have shown that emotion permeates virtually everything humans do, and "all brain regions play a role in or are affected by emotion" (Davidson, 2012, p. 89). Unsurprisingly, "affective experiences are intricately woven into the fabric of classroom experiences" (Schutz et al., 2009, p. 195).

In relation to emotions of high school science teachers, Cross and Hong (2009) reported how one teacher experienced negative emotions in the form of stress when he was expected to implement inquiry approaches in his classroom against his beliefs. In contrast, a biology teacher and a physical science teacher who both believed in the value of inquiry-based activities reported an "awesome" experience (p. 285) and "joy and excitement," (p. 286) respectively, when they implemented inquiry activities successfully.

Most studies of teacher emotions rely heavily on teacher interviews (e.g., Cross & Hong, 2009; Day & Lee, 2011; Schutz & Zembylas, 2009). Interview studies afford opportunities for researchers to identify how beginning teachers' capacities to sustain their resilience (or emotional commitment) are mediated by their identities and contexts (e.g., Mayer, 2011). Even though identity studies are important in understanding the emotional lives of teachers (Day, 2011), they tend not to focus on in-the-moment emotional experiences of teachers. For example, several teachers in one study found it difficult to identify specific instances of emotional arousal in their classrooms at interview, suggesting that interview was not fruitful by itself to elicit details of their experienced emotions (Williams-Johnson et al., 2008). Importantly, research in affective neuroscience has shown that an emotional state is a fleeting unit of emotion lasting only a few seconds, typically triggered by an experience (Davidson, 2012). Logically, understanding the events that trigger emotional states should require additional and more fine-grained methods than interview. After all, there are recommendations that future research on teachers' emotions should focus on theoretical discussion, multiple methods, and new ways of representing research to illustrate emotional experiences better (Zembylas, 2011).

Zembylas (2002, 2004a, b, 2005) led a move away from interview studies towards nuanced ethnographic work using multiple methods that included classroom observations, teacher emotion diary, interviews, and classroom artifacts to study the emotional work of one elementary science teacher over a three-year period. Despite these multiple data sources, he did not report on microanalyses of teacher-student interactions, a limitation addressed in the design of our ethnographic case study of a female beginning science teacher (i.e., Ritchie et al., 2011). In that study we identified positive emotional events that transformed the teacher's practices. Successful interactions involve mutual focus of attention, emotional entrainment through bodily synchronization and mutual stimulation, which result in feelings of membership and positive emotional energy (Collins, 2004). Specifically, when the teacher experienced a successful interaction ritual she reproduced it in subsequent interactions and lessons. These subsequent interactions can be likened to a set of related *cascading* events (Sewell, 2005), which collectively transform a teacher's practice. We extend this work in the present study by analyzing the emotional events during the implementation of EEIs in the classrooms of beginning physics teachers.

A Theoretical Perspective on Teacher Emotions

In sociology, numerous theories of emotions have emerged. These may be grouped into seven categories: evolutionary/biological, symbolic interactionist, dramaturgical, ritual, power and status, stratification, and exchange theories (Turner, 2009). For example, Kemper (1978) was one of the first sociologists to theorize how emotions are influenced by power and status. In collaboration with Collins, whose work transcends several categories (e.g., ritual theories, 2004; stratification theories, 1990), they (i.e., Kemper & Collins, 1990) showed that people's expectations for holding, gaining and losing power mediated their experienced emotions when there was a change in status/power (Turner, 2009). Whereas most scholars work within a particular theoretical category, Collins and Turner stand out as exceptions (Turner, 2009). In particular, Turner (2007) embraced features of multiple categories in his development of a comprehensive theory of human emotions that integrates several theories of emotions to form 17 principles. These principles are underpinned by the argument that culture inherent in social organization causes arousal of discrete emotions (i.e., the four primary emotions are: satisfaction-happiness, aversion-fear, assertion-anger, and disappointment-sadness) and, in turn, these emotions affect the dynamics of face-to-face encounters and the larger social structures in which they occur. This argument rests on an assumption that "[e]motions are one of the most critical micro-level [e.g., in face-to-face interactions] social forces because they are what holds all levels of social reality together or, in the end, breach encounters or break mesostructures [e.g., classroom procedures] and macrostructures [e.g., school policy] apart" (p. 208). In our previous research in a beginning science teacher's classroom (Ritchie et al., 2011), for example, we illustrate how the teacher experienced positive emotional arousal (i.e., happiness) when her positive expectations for teaching were realized and when her fears for negative outcomes were not realized. Importantly, the study provides evidence from a new teacher's classroom to reinforce the first principle of the sociology of emotions (Turner, 2007):

> [w]hen expectations for self, other, and situation are met in an encounter, individuals will experience mild positive emotional arousal and will be more likely to give off positive sanctions to others. . . . and if they had some fear about expectations being met, they will experience more intense variants and elaborations of positive emotions. (p. 200)

The four primary emotions identified may be expressed at different levels of intensity. High intensity happiness can be expressed as elation, joy, or delight; medium happiness can manifest as cheerfulness and enjoyment; whereas a teacher experiencing low-level happiness might express contentment or gratification. Interestingly, there is no adequate English label for the emotion that exceeds happiness or pride (i.e., a first-order elaboration of happiness with fear) after accomplishing a particular challenge, such as the successful implementation of an EEI. The label given to this emotion is fiero, a word derived from Italian but with a root common to Romanic languages meaning pride mixed with joy and satisfaction. When someone experiences fiero,

> the person has stretched to accomplish something difficult and the feeling about having done so and succeeded is very enjoyable and quite unique. . . . Fiero requires a difficult challenge, and a very good feeling one has about oneself at the moment of accomplishment. (Ekman, 2003, pp. 196–197)

Of course, teachers also will experience negative emotions in classrooms (Tobin & Llena, in press). A teacher might typically express low intensity fear in the form of concern, but experience medium intensity fear in the forms of anxiety or trepidation less frequently, and hopefully, rarely express terror. Just as it would be unlikely for a teacher to experience terror in a classroom (i.e., high intensity fear), teachers seldom experience high intensity anger (e.g., outrage, incense, fury) and sadness (e.g., sorrow, despondency). They are more likely to experience medium (anger=frustration, displeasure; sadness=gloominess, dismay) and low (anger=irritation, annoyance; sadness=discourage, dispirit) levels of these primary emotions (see Turner, 2007).

An important source of arousal of negative emotions is failure to live up to expectations of self and others (Turner, 2007). Consistent with Turner's theory, Hargreaves (1998) argued that because society expects too much of teachers, these professionals will be "prone to fall short emotionally" (p. 836) adding to feelings of guilt, eroding professional identity, and leading to burnout. This relates to Turner's third principle that "When expectations for self, other, and situation are not met in an encounter, individuals will experience one or more negative emotions" (p. 201). This was illustrated in one self-study of a teacher educator who returned to teach an elementary class for one year while on sabbatical leave (Winograd, 2003). The teacher educator became despondent after experiencing persistent negative emotions associated with his lack of success in realizing his own expectations for teaching.

Against a background of the relevant literature on inquiry-based activities and teacher emotions, our theoretical framework focused our attention to ask: "How do beginning teachers' expectations of implementing EEIs impact on their practice?" and "What are the trajectories of their emotional arousal during implementation of EEIs?"

Exploring Emotional Events in Physics Classes: Methods

In this multicase study (Stake, 2006) we tracked four Australian beginning physics teachers over a 10-week period as they implemented EEIs in their grade 11 physics

classes where the students typically were aged between 15 and 16 years. We focus on salient events identified by these teachers that illustrate how their interactions with students during EEIs evoke their discrete in-the-moment emotions, and how these experiences transform their practices, a position advocated by Maskiewicz and Winters (2012) who argue an exclusive focus on the teacher overlooks the importance of teacher-student interactions in inquiry activities. Epistemologically, practices are considered as knowledge in action. Transformations in practice are thereby considered changes of knowledge in action. Narratives linking events within and between classes are generated from the interpretation of observation and interview data at the meso level. Events are then explored at the micro level using such analytical techniques as prosody analysis, analysis of facial expressions, and use of emotive words, where possible. Integrating these analyses across cases strengthens our claims.

Context: Introducing Teachers and Their Teacher Preparation, Schools and EEIs

Two of the teachers were male and two were female. Bevan was a middle-aged former consultant civil engineer and David was a graduate of education in his first career. Tabatha was a graduate of aerospace engineering, but had a 10-year career post graduation in various corporate jobs before completing her teaching diploma. Catherine gained a master's degree in biomedical engineering before taking up a six-year career in product development for engineering companies in Australia and Europe. She turned to teaching after becoming cynical with her role of designing products that would simply sell or deliver more drugs for clients from the pharmaceutical industry.

The first author (Ritchie) taught all four teachers science curriculum studies at university before they qualified as physics teachers. This was the first of three curriculum courses that dealt with theoretical principles of learning and teaching general science (grades 7–10) and their practical applications. Students demonstrated their understanding of these principles and practices through microteaching centered on such inquiry activities as discrepant events and POE (i.e., Prediction, Observation, Explanation; see White & Gunstone, 1992). Additional courses focused on teaching physics and curriculum design, and other teacher educators taught these courses, which also afforded additional opportunities for students to engage in microteaching, and demonstrate their capacity to design and conduct contextually situated activities, including EEIs.

All schools were situated in neighboring suburbs and within a 15-minute drive from the university. Each class contained 18–25 students. Most students were achievement oriented and aspired to compete for entry into university programs in science and engineering, including such highly competitive courses as medicine and optometry. This was most evident in Catherine's school, which was a prestigious independent school.

In one school the EEI was specified. The task read: "You are to develop a series of experiments which will test your hypothesis in relation to factors affecting the electrical resistance of pencil 'lead' (graphite). The experiments should be designed to test different variables separately, and a range of different pencils are to be used (different lengths, lead thickness, hardness etc.)." Additional information about the different phases of an EEI, milestones, report structure, assessment criteria, and standards were provided. In contrast to this single-focused EEI, multiple possibilities were offered in other schools. For example, the students in Bevan's class could select an EEI from a manageable list of nine thermodynamic topics (e.g., Make and calibrate a thermocouple before investigating

factors that influence resistivity; Investigate the effects of paint color and cabin volume of interior temperature of cars), and the students in the three classes at Catherine's school could choose from a list of seven topics that were elaborated on the International Young Physicists Tournament website (e.g., Rising bubble: A vertical tube is filled with a viscous fluid. On the bottom of the tube there is a large air bubble. Study the bubble rising from the bottom to the surface). Again, details of expectations for presentation and assessment were provided to students.

Lesson Observations and Interviews: Meso-level Analyses

Except in Catherine's class, five one-hour lessons for each teacher were observed and video-recorded. We recorded a sequence of 16 lessons in Catherine's class, several of which were double lessons (i.e., two hours rather than one hour), because the first two observed lessons were characterized by less scaffolding than the other classes. We saw this as an opportunity to explore whether this would affect subsequent classroom transactions and outcomes. Post-lesson interviews were conducted following each lesson to help identify events for more detailed analysis of video recordings. During the interviews the teachers were asked to identify events of salience to them from the lesson. Their responses were probed to elicit reasons why the teachers identified the events, and to establish how they perceived these events impacted on their teaching. An additional interview was conducted after the school year when one of the teachers (i.e., Bevan) returned to his previous career as an engineer upon completion of his teaching contract.

Even though we discuss particular events that were analyzed in detail for the purpose of this study, all teachers identified other events during the interviews, as indeed we did following several replays of the video-recordings. We selected those events identified by teachers as salient for them, and for which we had multiple data sources, where the teachers' emotional expression was of a higher level of intensity than typical expressions, and where transformation of practices or structures could be identified.

Selected events from these recordings were analyzed at the intermediate (meso) level (i.e., ethnographic descriptions drew on multiple data sources that included interviews and other post-lesson analyses at the micro level). After identifying the events, each video clip was played and replayed at both natural speed and then frame-by-frame. Transcripts were made of the interactions, and where relevant, overlapping speech and pauses were measured and noted. Observations of the participants' facial expressions, gestures, and other body movements were noted alongside the associated speech.

In the first instance, utterances were scrutinized in terms of the semiotic resources each speaker made available to other participants, whether these were non-verbal (e.g., gestures) or verbal (e.g., laughs and utterances). In our transcriptions, we apply the conventions of conversation analysis (Roth & Hsu, 2010; Selting, Auer, Barden, Bergmann, Couper-Kuhlen, & Günthner, et al., 1998), where relevant, to the analysis of our data (Table 1).

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Micro-level Methods and Analyses

The video clips of the identified events were analyzed at the micro level for prosody (i.e., vocalized expression of emotion through such parameters as pitch, intensity, speech rate) using PRAAT software (http://www.praat.org), facial expressions (i.e., Ekman's

Facial Action Coding System, as well as eMotion software), and body movements and gestures or proxemics (see Harrigan, Rosenthal, & Scherer, 2008).

We used such prosodic parameters[1] as pitch or F_0 mean and standard deviation (in Hz), Formant F_1 and F_2 mean and bandwidth (in Hz), intensity mean (in dB), and speech rate (syllables per second), where relevant, to support claims about the discrete emotions aroused during interactions as determined from other verbal and non-verbal indicators. These data were used to reinforce or triangulate results from multiple methods. Because "emotional and relational states are not conveyed by a single indicator but rather by a set of cues" (Burgoon, Jensen, Meservy, Kruse, & Nunamaker, 2005, p. 3), dialog features such as the use of emotionally salient words and direct one-sided speech also were used to help overcome limitations with prosody analysis (Nomoto, Tamoto, Masataki, Yoshioka, & Takahashi, 2011) and adopt a multi method design in which another technique used to identify discrete emotions of participants is the facial expression of emotions.

Facial expressions of teachers were analyzed qualitatively using the categories of neutral, happy, surprise, anger, disgust, fear, and sadness. These categories of emotion are used in eMotion (Sebe et al., 2007), a facial emotion software that provides sophisticated analyses of frontal images of faces from video files to obtain measures of the emotions of the participant for each frame in a video clip where possible. This technique is unsatisfactory, however, for side images and when the angle of tilt of the head exceeds 15 degrees. In these exceptional cases we referred to the Facial Action Coding System (FACS) for manual assessment of the teacher's emotions (e.g., Ekman & Rosenberg, 2005).

Emotional Events Implementing Extended Experimental Investigations

In this study we set out to explore the classroom emotional events that transformed beginning physics teachers' practices in activities related to EEIs. The two research questions addressed were: 1) How do beginning teachers' expectations of implementing EEIs impact on their practice? 2) What are the trajectories of their emotional arousal during implementation of EEIs? Our nuanced approach to the analyses of multiple data sources helped us to understand better these teachers' preparation for implementing EEIs, their different approaches to supervising students' EEIs, and most importantly, the relationship between their expectation states and their realized emotions during events. Our discussion of these themes provides insights into how these new physics teachers implemented EEI tasks successfully, and explicates how teachers' emotional states are explained by a sociological theory of human emotions (Turner, 2007). Importantly, one teacher's (Catherine) teaching experiences and context differed from the other teachers. We account for these differences in terms of context, expectations (both personal and colleagues), and prior experience.

Preparing for Inquiry

[1] Any sound signal S can be decomposed and expressed as the sum of dominant frequencies $S = \sum a_i F_i$, a decomposition called Fourier analysis. F_0 or pitch is the base frequency that characterizes a voice; F_1 and F_2 are the next higher frequencies that make dominant contributions to an articulation. Only the frequencies are relevant in the social psychology of emotions but not the constants a_i. Bandwidth is the width of the range of frequencies around each formant frequency.

As we indicate above, Tabatha became aware of the difficulties associated with implementing extended experimental investigation tasks from the fears expressed by senior colleagues during a workshop. Bevan too witnessed his senior colleague "having a little nervous breakdown at the time" when he implemented EEIs in the grade 12 class during the second term of the school year. "He was going berserk," Bevan recalled. These early observations by Bevan, David, and Tabatha were reinforced by their own experiences managing relatively straightforward experiments scheduled in Terms 1–3[2] that preceded the commencement of the EEIs. David was "exhausted after every lesson" when individual students undertook their own part to each assigned group experiment. The students too, "panicked the week before" their reports were due: "They all had mini meltdowns" (Tabatha).

These early experiences with colleagues and students alerted the teachers we observed to the necessity of thorough preparation for managing the implementation of the EEIs in Term 4. Their interviews were marked by emotion as they accounted for the need to be well organized and to structure the EEIs so that their students would not only cope, but also succeed. As Tabatha commented:

> It's horrible to watch a student just feel like they're drowning. So, it's these sorts of instances where you see a student and you go, "I need to fix you somehow." Step in and go, "you need help. How do we fix this problem?" I think that's what's instigated this EEI this way.

David recalled his first experience with managing student experiments:

> That was the first one I ever did and getting materials was a bit of a hassle because you didn't really know what was going to happen, and kids would change their experiments after the due date. So there was lots of running around. We had it nice and organized this time. We knew what to expect.

Knowing what to expect, these three teachers implemented their EEIs in a much more structured manner than their previous practical activities. As David explained: "This one we need to have set dates for when this is due and that's due. I know where they are all up to." For Tabatha, this involved articulating four milestones that she signed off: (a) designing and assessing risk, (b) completing research question and trial of experiment/apparatus/skills, (c) preparing and submitting a draft report (i.e., "they all had to have method, aim, hypothesis done like a week ago"), and (d) submitting the final report. These milestones not only structured the EEI process for both teacher and students, but also afforded students opportunities for the teacher to scaffold the development of essential skills. David earmarked practice lessons of particular skills (e.g., such as using a multimeter) that students would need to demonstrate to complete the EEI successfully. During these preparatory lessons, David moved between groups checking that students had connected multimeters correctly and were able to read the various scales, for example.

In contrast to these three teachers, Catherine taught both grade 12 and grade 11 physics classes alongside two very experienced and well-qualified teachers who were optimistic and supportive of engaging students in open-ended inquiry through EEIs.

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[2] The academic year is structured in two semesters, each with two terms of about 10 weeks. In each class, the EEIs were implemented in Term 4.

Students at this school were actively encouraged to enter national and international physics tournaments, and EEIs afforded valuable opportunities for students to gain first-hand experience at investigating open-ended inquiries. Even though grade 11 students tended to "work up" or become anxious prior to undertaking EEIs, the staff downplayed the task. As Catherine explained, "none of us feed into it." From her experience in the second term supervising grade 12 EEIs, Catherine even acknowledged the workload supervising EEIs was less than teaching as usual because "it's helping as things occur." Yet, Catherine expected she would need to do "a lot more scaffolding" with the grade 11 students as they commenced their EEIs. This shows how the relations with experienced teachers and having done EEIs before prepared Catherine to supervise EEIs. The other teachers, too, identified events that led to better preparedness to supervise EEIs. The following classroom event from Bevan's class illustrates how these events mediated their teaching practice.

A Transformational Event for Bevan. In one of the preliminary lessons in Bevan's class a significant emotional event occurred after he assigned the task. Requesting the students refer to the directions for a laboratory activity involving series circuits in their textbook, and identifying where they could find the appropriate apparatus, he announced:

> Okay, we've got one and a bit lessons to do this particular exercise and we'll be doing another one, and hopefully that should have enough in there for you to understand what to do for the EEI. EEI will be done first up in Term 4. By then you should know how to do an experiment . . . I'll be checking as you go, it's all self-motivated, self-paced. I'll be seeing how well you do. So, you've got a lesson and a half to do it. (Bevan, Lesson 2)

As promised, Bevan moved between groups checking their circuits and, later, their logbook annotations (students in this class needed to maintain logbooks of their work from each laboratory session). As he was checking the polarity of the ammeter and voltmeter before students turned on the power in one group in the center of the classroom, another group assembled at the backbench had begun to explore parallel combinations of the available light bulbs rather than set up a series circuit as indicated in the text. Prior to approaching this group, Bevan glanced at them briefly twice during his interactions with the center group. Analysis of the video recordings from the previous lesson indicated that Bevan referred to these students by name on 15 out of the 20 occasions during interaction breaches by students throughout his whole-class exposition. In this context, along with Bevan's action of bypassing a student who called for assistance as he approached this group, Bevan exhibited in his demeanor signs that he was concerned with what was happening. After the lesson, Bevan reflected on his interactions with this group during interview: "[I felt] a fear as I was walking up to them. It was fear that they were really just cocking about and not doing what I hoped they would be doing."

Bevan opened his 6 minute 39 seconds interaction with this group with the following series of unanswered questions directed to the group: "Boys (1.7) Have you got? What the hell have you done? Have you written down (1.5) the information enough to start doing your results?" This speech is indicative of low-medium intensity anger (i.e., irritation) in content and prosody. He utters these questions when he realizes this group had not set up the circuit as required in the text. It is unidirectional, and the use of "hell"

in particular is characteristic of anger (cf. Nomoto et al., 2011). The prosody analysis of Bevan's utterance of "Have you" in the last question compared with neutral utterances of these words in earlier questions shows that, on all the major speech parameters, Bevan's vocalization was consistent with the emotion of irritation (Scherer, 2003). For example, the mean of the fundamental frequency (i.e., F_0) increased from 127 Hz to 176 Hz and the intensity increased from 62 dB to 70 dB, which, because the measure is logarithmic, means about an eightfold increase. As he uttered these words, Bevan's arms and legs were crossed, which is a demeanor frequently displayed when a person is unimpressed. The crossed arms and legs in this context are consistent with low intensity anger (e.g., Burgoon et al., 2005) and even constrained hostility (Pease & Pease, 2004).

Bevan engaged with the students to determine what they had found from their exploration. The concluding interactions represented as Extract 1 below demonstrate Bevan's satisfaction with the students' achievements.

Extract 1: Bevan's satisfaction

01	Bevan	We've got 10 minutes. See, now you have got rid of the parallel ((component))
02	Marty	They are about the same ((referring to the light intensity seen in the light bulbs))
03	Bevan	About the same. Now you've got rid of that one ((points to the circuit drawn in the notebook, specifically the parallel node that Marty had removed from the circuit)) and it looks exactly the same (5.9) see what the see what potential difference is (0.1) 'now
04	Marty	((Reads the potential difference from the voltmeter)) 'five [point eight]
05	Bevan	[Five point eight] check that one ((points at the other light bulb))
06	Marty	((Checks potential difference across the other series light bulb)) S[ix]
07	Bevan	[Six] near enough the same
08	Marty	Yeah
09	Bevan	Hey? ((Looks at the other 2 boys in the group while walking slowly away from the group))
10	Ben	((Nods twice)) Thank you sir
11	Bevan	That's good (0.5) keep (0.8) don't play for too long (1.9) I want to see something in writing (0.3) but that's not bad

Throughout this episode, there was mutual focus on the circuit and notebook. In turns 03 and 05 Bevan repeats Marty's answers from each of the preceding turns (i.e., "same" and "five point eight") that shows a degree of synchrony between Bevan and at least one student (i.e., Marty), indicative of successful interactions (Collins, 2004). Prosodic analyses of these utterances suggest positive emotional energy that would be associated with a successful interaction. Specifically, when compared with other utterances of these expressions in earlier neutral interactions, all acoustic parameters aligned with elated joy (Scherer, 2005). That is, there was an increase in F_0 mean and standard deviation, an increase in F_1 mean but a decrease in F_1 bandwidth. Furthermore, the content of Bevan's parting comment in turn 10 is suggestive of a positive outcome with Bevan's use of the emotive expression "that's good." In response to the post-lesson interview question, "So you went from fear?" Bevan replied:

> Fear to anger, to basically happiness and around there. This is the first time I've really gone down this road as well. . . . Approaching this with a little bit of trepidation. . . . I

> think, certainly in the end, happiness, fairly happy in the end. Getting something out of it and I hope they're getting something out of it as well.

"Trepidation" constitutes medium intensity fear (Turner, 2007). This was the word Bevan used to describe his recollection of his emotional experience at the time he approached this playful group. The use of this emotionally salient word (Nomoto et al., 2011) underscores the existence of a trajectory in Bevan's emotional arousal from fear to anger to happiness during the event. In this single event Bevan reported he experienced fear, anger, and eventually happiness – all changes supported by analysis of multiple data sources. These changes are produced by the activity itself so that even though an action is completed in fear the very enactment leads to anger, and an angry action allows happiness to emerge. Even though the teacher experiences the emotions at an individual level, they are also manifestations of the activity itself (cf. Roth & Radford, 2011). The positive emotional outcome led to a series of cascading events that transformed the classroom practices for this and subsequent lessons (e.g., Sewell, 2005). More specifically, as Bevan visited the other groups, he suggested that they, too, should begin to explore parallel circuits rather than simply following the cookbook style instructions in the text. For example, in the cartoon representation depicted in Figure 1, Bevan points to the group at the backbench as he remarks, "See, these guys got it so that they can change a lot because voltage drop across all those ((pointing at the light bulbs in the circuit with his pen)) being different." This compelling evidence of transformation is far more significant than results obtained by analyses of prosody, proxemics, and interview data because it is an observable change in practice. Collectively, these results strengthen our claim that the event led to a positive outcome for students and teacher; it was a transformational event.

«««««« Insert Figure 1 about here »»»»»»

Supervising EEIs

As students prepared their EEI reports David responded to questions as required. This meant that for those students who had not kept to the specified milestones on time, they did not complete a full draft for his review. In contrast, Tabatha scheduled one-to-one consultations with each student in the class prior to both the scheduled draft and final submission milestones. For Tabatha, the report-writing process was "so important to real life" it was a crucial part of doing an EEI. Her resolve for students to develop strong report-writing skills was based on her own personal and transformative experience in a former corporate role. As she explained: "I learned it through a life lesson but I don't want kids to have to learn it that way. They can turn around and start those skills now. I think this is one of the most important life skills you'll get, writing reports."

Even though David had established and publicized milestones for students to complete the EEIs in a reasonable time, one group was still completing the data component for their EEI in the final week before the due date, leaving no time at all for him to review a draft report. Yet, Tabatha was "really strict with time lines and made sure [she had] seen everyone's." In fact, as Tabatha continued, "I've seen most of them about three times just because, I don't want them to drop their marks purely because they don't understand how it's going to be written, or the language I expect." In contrast with her earlier experiences with student reports, this time Tabatha reported an "amazing" outcome from her transformed practice in supervising students' report writing. Reporting that she had seen

three drafts from her A students before the due date for submission of the EEIs, Tabatha elaborated:

> I didn't get that with my A students in term one so I think they've all lifted. I think the fear of, "I'm not going to look at your draft if you haven't given me anything by Friday" worked really well because it made them all go, "you know, we want to do well." And they've worked really well and really hard.

However, Tabatha acknowledged that her students did not universally welcome her unrelenting approach to supervision. When one student questioned the need for her work to be signed off, for example, Tabatha retorted, "because of your poor effort with the [Term 1 report]. These are the consequences of your actions."

Like Tabatha, Bevan emphasized the importance of writing. This can be seen from his interactions with the playful group described previously in Extract 1 when he reminded them: "I want to see something in writing." This was a continuing process rather than any specific action that weighted the final report as highly as Tabatha had done. Bevan insisted that for each lesson students were required to enter outcomes from their activities in their logbooks. Logbooks were used across subjects at his school, but few that he had seen matched the detail that was evident in his students' logbooks: "I really, really made them understand that right from the start the logbook had to have in it information, I wanted to see progress. . . . I just kept hammering them and hammering them." Apart from persistent announcements and reminders to enter information in their logbooks during lessons, Bevan's characterization of "hammering" also involved him checking regularly students' logbooks during lessons before he would "sign off," or positively sanction their productivity. Without emphasizing the importance of writing, Catherine, like Bevan, checked student work each lesson by "stamping student journals." Journals were the ongoing records of the students' refinement of ideas, and "stamping" constituted the same practice as Bevan's signing off.

In contrast to a constant emphasis on writing through the EEI project for three of the teachers, and the escalation of Tabatha's scrutiny of written work towards the end of the process in particular, these teachers' supervision of their students' investigative work eased as the students demonstrated increased competence and confidence with the design and associated procedures of their EEIs. In other words, the teachers' scaffolding faded as the EEIs progressed. In Bevan's case, he attributed the experience students gained in the preliminary investigations that he supervised closely as the major contributing factor to a successful outcome:

> Without those experiments the EEI would have been pandemonium. . . . They gained more confidence than they had at the beginning of the year. Without having to ask many questions, the problems they encountered, they've been able to do it themselves. Students are able to solve problems and seek solutions themselves. (Interview)

The transition in the teachers' supervision was observable in the classroom too. As in other classes, Bevan typically manipulated apparatus with groups of students during the preliminary experiments. Yet, towards the end of the project, Bevan stood back and observed students at work – in a hands-off stance. During the class shortly after one instant Bevan was observed to stand back from the activity of a student with little confidence before, Bevan commented: "The confidence shows in the kids as well," as he tilted his head towards the same student who was now demonstrating competent practice.

Even though Catherine interacted with individual and small groups of students every lesson, she was less directive and demonstrative than the other teachers. The following extract shows a fairly typical pattern or sets of interactions between Catherine and a pair of students midway through the EEI project. In this extract, Catherine uses subtle gestures and smiles while Roxy made decisions about determining the mass of the oil used in the rising bubble EEI. As the student's (i.e., Roxy) actions show, the gestures and smiles become resources for developing confidence and independence.

Extract 2: Gestures and smiles support student decision-making

01	Roxy	Okay, umm, I got this the weight of this to one decimal place but Ah::: the measurement is in two
02	Catherine	Hmm ((Catherine nods))
03	Roxy	(.8) Should I go up and try to get a scale that gives it to two decimal places ((Catherine shrugs her shoulders while maintaining eye contact with one eyebrow raised slightly)) 'cause the other one gives it to four? (2.3) ((Catherine maintains eye contact and smiles gently)) Yeah probably I go and get scale to the two decimal places ((Roxy walks away towards the door))
04	Catherine	(1.1) ((Catherine gestures with both palms facing upwards in a balancing manner that conveys the meaning of comme-ci comme-ça as she shakes her head)) It's your experiment and your (.7)
05	Roxy	Yeah the [uncertainties]
06	Catherine	[Uncertainties] (.1) and
07	Roxy	Yeah (1.9) I probably go and get some materials from upstairs (.2) ((smiles as she turns to leave))
08	Catherine	(1.5) Little concerned about the bubbles in there. How much does that affect the volume?
09	Roxy	U:mm, volume of it not much
10	Catherine	And did you find the mass of your measuring cylinder?
11	Roxy	Sorry?
12	Catherine	What's the mass of your measuring cylinder?
13	Roxy	U:mm::::::
14	Sasha	((Roxy's partner approaches to provide answer)) two one nine point six three
15	Roxy	Two decimal places, so I probably get the mass of this to two decimal places. Okay I go right back upstairs.
16	Catherine	((nods and smiles))

Catherine provokes doubt in Roxy's searching expression of her proposed action in turn 07 through a series of targeted questions (turns 08, 10, 12). It is not until Roxy's partner, Sasha, interjects with the number 219.63 (turn 14) that Roxy expresses a confident decision in turn 15 by emphasizing "Okay" before declaring her action. This response is greeted with a reassuring nod and smile from Catherine (turn 16) upon which Roxy proceeds to carry out her next step. It is Catherine's questioning rather than answering or telling that appears to be associated with Roxy's ownership of the procedure, albeit with a contribution from Sasha.

This excerpt was typical of Catherine's classroom encounters, even those with two students who, independently, were experiencing "real problems with where they're at and where they're going to get to." That they were not satisfying Catherine's expectations caused her some (mild) frustration, and led to her decision to target them for additional support in subsequent lessons. In one of these cases (i.e., Janet), Catherine commented: "Janet's not getting anywhere. She'd like to just play with something and that would be enough." Catherine spent 38% of her time in small groups with Janet over four separate

transactions in the next lesson. Yet, Catherine's part in the interactions did not vary. More time interacting in the same way did not lead to Janet's successful completion of the EEI, which left Catherine with a mild sense of disappointment and a desire to adopt a more direct scaffolding approach next time she teaches grade 11 physics. Despite this single case of disappointment, Catherine rated her overall experience with EEIs as successful.

Success!

All four teachers were pleased with the outcomes from their students' EEIs. During an interview, David expressed satisfaction with the implementation of EEIs in his class: "very well compared to previous experiments that I've done. . . . I was pretty happy with how it went." Similarly, Tabatha expressed pride with her students' achievements: "I'm proud of how they have done. I'm really proud of how they've got into this and they've taken it seriously." Catherine quantified her satisfaction as "three quarters…seven or eight out of ten." Finally, referring to the student outcomes from their EEIs, Bevan also remarked proudly: "It's probably my crowning glory of the year."

Apart from these affirming post EEI comments recorded at interview, there were two in-class events in which Tabatha and Bevan, separately, expressed high-intensity emotional satisfaction with the students' achievements from EEIs. The first event was recorded as Tabatha was reviewing students' draft copies of their EEI reports. She had booked the computer room for students to complete their individual reports and had positioned herself seated behind the front desk. Tabatha nominated individual students to join her at the desk whereupon she reviewed their progress.

As she was reading one report written by Darryl, Tabatha expressed appreciation of his work, as shown in turn 01 from Extract 3 below, before asking how he determined the resistance of the pencil lead. Darryl referred to his potential difference (volts) versus current (amperes) graph as he answered, "rise over run" (turn 02). With this response Tabatha instantly thrust back her head in surprise as shown in Figure 2a (i.e., eMotion software reads this as 100% surprise).

Extract 3: Tabatha's experience of fiero

01	Tabatha	Oh you're a good boy. Do you know why you're a good boy? You are the only person who has used volts versus current to calculate resistance. How did you get resistance?
02	Darryl	Ah: (1.2) rise over run
03	Tabatha	.´hhhhhh °The only person who's done that ((Head is thrust back with both clenched fists raised together – Figure 2a)). Someone who has done that ((Broad smile breaks out over face with eye engagement with student, fists pumped down and raised again – Figure 2b)) <u>Thank you</u>° ((Fists are sharply pushed down for emphasis and her head is lowered in synchrony)). Somebody got that! I'm stoked about that, that's very good, that's very good. You're the only person who did that. Thank gosh.

«««««« Insert Figure 2 about here »»»»»»

In less than 1 second, Tabatha completes a backward head thrust with elevated clenched fists as she gasps for 0.6 s, whispers a comment to Darryl with eye engagement (turn 03) before breaking out into a Duchene smile as she pumps her fists down and up again, lowering her head in synchrony with her fists pushed down to emphasize "Thank you" (Figure 2b). A Duchene smile is evident when there is intensification of the naso-

labial folds and elevated cheeks, the corner of the lips are drawn back and up, and the skin below the eyelids is pushed up and lines are formed below the eye (Ekman & Rosenberg, 2005). The backward thrust of Tabatha's head associated with opening and closing of the hands in a highly dynamic fashion (Figure 2a) is characteristic of elated joy and possibly pride (Walbott, 1998). It is a typical expression of fiero (Ekman, 2003).

Prosody and content analysis of Tabatha's interaction with the student Darryl in Extract 3 are also consistent with fiero. In particular, Darryl's answer in turn 02 evokes a more intensive vocalized emotional response from Tabatha (turn 03), suggesting not only happiness but also pride with this unique achievement. Prosodic analysis of the 0.6 s gasp (turn 03) shows a rapid escalation in F_0 from 155 Hz to 598 Hz with a mean pitch of 456 Hz, consistent with the expression of elated joy (Banse & Scherer, 1996). Other parameters for elated joy (Scherer, 2003) are satisfied by this analysis. This experience of fiero coincides with the pride Tabatha felt about her students' achievements with their EEIs at interview. The EEI task was a challenge for both teacher and students, and they succeeded together.

The second high-intensity emotional event was recorded in Bevan's class. At the 48-minute mark towards the end of the fifth recorded lesson Bevan approaches the researcher (SR) to disconnect the Bluetooth microphone as he comments with surprise: "It was a good day. Emotionally, I was not worried. ((Bevan begins to step away but corrects his previous statement instantly)) No, hang on, no ((Bevan steps back towards Ritchie))." As Bevan again resumes eye contact with Ritchie, he is asked inquisitively, "What were you emotionally?" Bevan now elaborates as shown in Extract 4.

Extract 4: Bevan's exhilaration

01	Bevan	Emotionally I was (0.9) scared to the shit house this weekend ((right open hand raised and lowered, laughing)). "What are we going to do ((right hand repeated gesture))?" "How are we going to organize all this?" 'Today ((closed right hand, with index and middle fingers pursed against the thumb, is raised and lowered for emphasis)) has gone (0.5) ((2 Nods)) really ((right hand raised and lowered)) well
02	Ritchie	Good. So, you are really happy?
03	Bevan	Oh yeah, oh yeah, ((Figure 3a: eMotion reads this expression as 99% surprise and 1% happiness)) big ((Bevan's right hand is raised to the top of his forehead level with palm facing the floor as a smile begins to break across his face, Figure 3b)). Endorphins coming in. ((both hands raised to ear level and rotated in small circles with right index finger pointing inward to ear, head nodding, eyes wide open, Figure 3c))
04	Ritchie	Is that right?
05	Bevan	Yeah (0.4). If you gave me a shot of cocaine ((shakes head and waves his right hand away from his body as he strides away)) (0.7) it wouldn't make no difference.

«««««« Insert Figure 3 about here »»»»»»

In the context of his admission of apprehension with the unknown (turn 01), Bevan's colloquial expression along with relaxed gesture and laugh suggests relief and happiness with the outcome of the lesson. Then, in the last two lines of turn 01 Bevan nods twice after a 0.5 s pause as he utters "really well." The coupled effect of nodding for emphasis along with the added superlative indicates the lived experience of positive emotion. Prosodic analysis supports the claim that this was a positive emotional experience for Bevan. That is, analysis of the emphasized word of "Today" demonstrates happiness

(Scherer, 2005) on all parameters compared with a similar two-syllable utterance under more typical conditions. Bevan escalates his degree of happiness in exaggerated utterance, hand gestures, and facial expressions (turn 03). In particular, Bevan begins by showing a surprised facial expression (Figure 3a) before demonstrating how his experience placed him in such a high positive emotional state as he uttered "big" by gesturing maximum height with his hand (Figure 3b). He then refers to the high pleasure derived from the release of endorphins (Figure 3c). Furthermore, he continues to escalate the positive expression of his positive emotional experience with his final analogy as he strides away with associated hand gestures to indicate that this positive experience could not be topped, no matter what (turn 05). Prosodically, all pitch parameters for the expression of "you gave" in turn 05 align with the prediction for the vocalization of happiness and joy (Scherer, 2005). For Bevan, this was exhilaration – the best emotion he could experience in a classroom, or, as he said in the final interview, his "crowning glory."

Positive Emotional Arousal Through the Achievement of Success

Our account presented here provides much needed insight into how four beginning physics teachers implemented inquiry activities in the form of extended experimental investigations (EEIs). In relation to our first research question, three of the four teachers expected the implementation of EEIs to provide them with professional challenges, especially in the context of fearful discourse from their more senior colleagues. This expectation led to their realization of the need for thorough preparation of EEIs by scaffolding preliminary activities, emphasizing writing activities, and monitoring student achievement of skills. Their early experiences scaffolding laboratory activities prepared them for the successful supervision of students' EEIs. In Bevan's case, for example, we illustrated how he scaffolded students' work in a hands-on way initially, but as the students became more competent, his scaffolding faded to a hands-off approach also found in research supervision of high school students working in a university laboratory context as the students became independent researchers who were confident and competent in their own skills and decision making (see Ritchie & Rigano, 1996). Even though fading was observed in three of the four cases, these teachers exhibited different supervisory styles throughout the duration of the EEIs. Bevan insisted that students enter daily records of their work in logbooks that he checked regularly. This meant that towards the end of the term, students had effectively compiled their reports for submission. In contrast, Tabatha and David set up student milestones with different levels of monitoring. Tabatha built into her program milestones for draft reports that she reviewed up to three times for each of her students towards the end of term whereas David invited students to submit drafts for his review, which meant that fewer of his students availed themselves of this opportunity.

Catherine's style of supervision was very different again. Teaching alongside very experienced and talented colleagues in a more privileged school context afforded Catherine the opportunity to create an atmosphere conducive to open inquiry, where the teacher engaged with her students in such a way that they took responsibility for the design and procedures of that inquiry in the way previous research had shown (Roth, 1995). Her subtle hints through questioning during interactions led most of her students to successful outcomes. These classroom experiences accorded well with Catherine's

expectations, gleaned from her experience with a grade 12 class during the previous semester and possibly from her research and design experience in industry. Unlike the other teachers, Catherine did not fear her supervision of EEIs and she expected the students would succeed with the level of her supervision we observed. Yet there were two students who did not meet Catherine's expectations and these caused the arousal of minor frustration during lessons and disappointment for one of these students (i.e., Janet) at the conclusion of the EEI.

Despite the different styles of supervision observed in this study, all teachers were satisfied with the work completed by their students. Unlike Catherine's circumstances the three other teachers were somewhat surprised by the successful outcomes because they began their careers in a climate of fear without the privilege of teaching alongside experienced colleagues who were proactive in promoting open-ended inquiry.

Surprise was shown in two high intensity emotional events towards the end of the term. Bevan experienced exhilaration as his students demonstrated increased competence and confidence with independent research towards the end of term (Extract 4). The evidence presented was triangulated from multiple sources, as was the case for Tabatha who exhibited fiero in one remarkable event as she reviewed a student's draft report (Extract 3). These emotions were intense because the teachers achieved a very positive outcome against low expectations they developed from their initial experiences with inquiry activities and their interactions with their more experienced colleagues who unsurprisingly were overwhelmed by EEIs. In the context of fearful expectations for their upcoming implementation of EEIs, taking action to prepare for and implement EEIs involved the transformation of practice (cf. Roth & Radford, 2011), which, in the present situation, generated high intensity positive emotions. That is, "if they had some fear about expectations being met, they will experience more intense variants and elaborations of positive emotions" (Turner, 2007, p. 200). These intensive emotional events were significant learning opportunities for these new teachers, each reassuring them that their practice was worth reproducing – practice that is likely to become part of their explicit knowledge of teaching physics. More generally, a teacher is more likely "to develop commitments to the structure and culture" (p. 206) of these practices when they experience more encounters that consistently lead to positive emotional arousal among the participants, including themselves.

Less intense emotional events still led to transformation of practice. Even though the evidence from prosody and facial expressions might be less reliable than high intensity displays, compelling evidence of transformation was shown in Bevan's actions, for example, as one learning event triggered a set of related cascading events, demonstrating the immediate impact on his learning to become a physics teacher who was competent with the implementation of inquiry activities – learning in-the-moment and in the course of interacting with students, who, in their turn, also learn and develop (e.g., Roth & Radford, 2010, 2011). This event could have far reaching implications for further research and theory development, especially in terms of how teachers learn in practice and while interacting with their students (cf. Maskiewicz & Winters, 2012).

A unique contribution of our research to the field is that we have documented the arousal of teachers' discrete emotions during extended experimental investigations as they interact with, and in relation to the achievements of, their students. Just as Moll (2011) argued that emotionally evocative activities are more likely to be memorable and

be used by physics students for later reflection and learning, in relation to our findings, we believe this argument applies equally to teacher professional development. In other words, purposeful reflection on emotionally charged events, even low intensity ones, could help physics teachers develop better supervisory practices for students engaged in inquiry activities. After all, Alsop (2011) argued, that even though embodied displays of emotion may be short lived, they are highly memorable and, as we have found, can shape teacher practices. Affording practicing teachers opportunities to identify, reflect on, and respond to emotional events would seem a worthwhile professional development activity (cf. Maskiewicz & Winters, 2012). Engaging teachers in collaborative research about their emotional practices would be one way of creating an engaging opportunity for teacher professional development (see Ritchie et al., 2011).

In relation to our second research question, Table 2 summarizes the trajectory of classroom activities with associated emotional states experienced by the teachers along with their students' achievements. Most teachers experienced fear, frustration, and anger to a limited extent, during the scaffolding activities. Yet, as the students' skills, confidence and independence grew over the ten weeks, the teachers adopted more of a hands-off approach, leading to satisfaction and even two high intensity positive emotional events following the successful achievement by students. Whereas all four teachers were satisfied with the outcomes of the EEIs, only Catherine experienced disappointment when one of her students did not succeed. She acknowledged that for this student, additional scaffolding might have led to a different outcome – as it did in the other classes.

«««««« Insert Table 2 about here »»»»»»

One of the strengths of this study was its focus on analysis of recorded events with the four teachers. They all experienced positive emotions through successful interactions with their students, as predicted by current theories in the sociology of emotions (e.g., Collins, 2004) and as observed in other studies of classroom interactions (e.g., Roth & Radford, 2011). This leads to the achievement of positive outcomes for their students, which can be taken to be positive sanctions for their efforts. Additional case studies with teachers from diverse backgrounds and experience that focus even more heavily on recording and analyzing in-the-moment events would help to generate further evidence supporting or refuting our research-based claims. More specifically, we see value in seeking verification of the principle that:

> When individuals perceive that they have received positive sanctions from others, they will experience positive emotions and be more likely to give off positive sanctions [e.g., Tabatha's sanctions in Extract 3] to others in an escalating cycle that increases . . . heightened mutual flow of positive sanctioning, increased sense of social solidarity. (Turner, 2007, p. 201)

We suspect such escalation of mutual positive sanctions could be at the heart of the production of positive emotional climate. Positive emotional climate is the collective state of emotional communion between classroom participants in which the salience of self for individuals decreases as the collective identity of the class is enhanced with the expression of such positive emotions as joy and contentment by individuals (cf. Tobin et al., in press). This demonstrates the dialectical relationship between the expression of emotions by individuals and the collective expression of emotional arousal of the class. Extending the methods we adopted in this study by introducing new procedures could help us understand the continual reproduction and transformation—even complete

reversal (Roth & Radford, 2011; Roth, Ritchie, Hudson, & Mergard, 2011)—of the emotional climate in classrooms that is a direct consequence of acting. In fact, we have begun research in teacher education classes that explores the mutually responsive relationship between individual expressions of emotions within a class and the collective emotional climate of the class.

Another dialectical relationship that should be studied in more detail in subsequent research is that between teacher and student emotions. In this study, we highlighted student actions that triggered emotional responses by their teachers. Further work also should examine how teacher actions evoke emotional responses from students, and how emotional arousal of both teacher and students interact to produce emotional climate conducive to learning science and successful implementation of inquiry activities.

All four teachers attended a pre-service teacher education program that afforded them opportunities to undertake microteaching of inquiry activities and develop skills in planning context-based programs of work that featured EEIs. Even though we cannot attribute this preparation to the successful outcomes observed, it seems that prior research experience in former careers alone, could not account for their success (i.e., David did not have a scientific career and Tabatha did not practice as an engineer). This finding contrasts with Breslyn and McGinnes's (2012) conclusion based on analyses of teacher portfolios and interviews that the discipline structure is the driving factor in teachers' conceptions and enactment of inquiry, and pre-service teacher education may have little effect on beginning teachers' implementation of inquiry. Methodological differences between the studies make resolution of the contrasting conclusions difficult. At the very least, the design and enactment of the four teachers' pre-service program in the present study, which were consistent with existing recommendations for integrating inquiry, appear to be supportive of the successful implementation of EEIs (Lederman & Lederman, 2012). Yet, closer analysis of the classroom transactions within this and other programs could help to identify what constitutes quality experiences for pre-service teachers. We have begun research that focuses on recording a range of pre-service teachers' emotions during university class work related to inquiry teaching.

It is possible that the reason for the teachers' success in this study was due in part to the fact that their former teacher educator conducted research in their classrooms, possibly ameliorating their negative emotions during EEIs that might otherwise have caused them to abandon actions that led to successful outcomes. Only further work with beginning teachers from different programs will help to resolve whether ongoing contact with and support from teacher educators affords desirable support for beginning teachers' transitions to teaching.

As we indicate above, Bevan returned to engineering at the conclusion of his one-year teaching contract. This decision was made on financial grounds even though his long-term goal is to continue his teaching career. Catherine's one-year contract at her school came to a close and she was appointed at a nearby prestigious independent school on yet another one-year contract. Tabatha elected to specialize in mathematics teaching at her school. Only David continued to teach physics at the same school. Despite their successes in teaching physics and EEIs specifically, only one teacher remained tenured as a physics teacher in the second year of teaching. This suggests that events and circumstances beyond their classrooms impact on their retention as physics teachers (cf. Schutz et al., 2009). Whereas mobility of physics teachers who are qualified in other professions (e.g.,

engineering) will always be higher than those who are constrained by certification in teaching alone, it is worrying that the continued practice of offering short-term teaching contracts fails to recruit and retain highly qualified teachers in short supply. New policy decisions that differentiate between employment conditions for high and low demand discipline teachers are currently under consideration by employers and governments.

Systemic and personal issues will always impact on teacher retention. Yet, this study not only confirms the relevance of the principles for emotional arousal (Turner, 2007) in physics classes, but also provides insights into effective supervision practices that can be used to inform new and experienced teachers alike. The description of the successful practices used by these new teachers goes beyond simply illustrating the difficulties of implementing inquiry-based activities, they show how these challenges can be overcome and how such success leads to positive emotional arousal.

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Table 1: Transcription conventions used in manuscript (adapted from Roth & Hsu, 2010)

Symbol	Use	Example
underline	Indicates the speaker is emphasizing the underlined text	Today (Extract 4)
::	Colons are used to indicate prolonged sound with each colon representing 0.1 s	Ah: rise over run (Extract 1)
°text°	The text bounded by the degree symbol represents whispered speech	˚The only person … Thank you˚ (Extract 1)
(0.9)	Timed pauses between utterances are indicated within parentheses	Emotionally I was (0.9) scared (Extract 2)
.hh	Each "h" represents an audible inhalation of 0.1 s	(.´hhhhhh) – gasp of 0.6 seconds increasing in pitch (Extract 1)
′	This symbol represents the upward movement of pitch	As above
((text))	The text bounded by double parentheses represents non-verbal actions of the speaker	((Head is thrust back with both clenched fists raised together)) (Extract 1)
[text]	The text enclosed in [ ] is uttered simultaneously by two speakers.	[Uncertainties] [Uncertainties] (Extract 2)

Table 2: Trajectory of teacher emotional states associated with classroom activity and student achievement

EEI Phase	Class Activity	Teacher Emotional State	Student Achievement
Preparation	• Scaffolding (lab activities for skill development) (Bevan, Tabatha, David)	Fear, frustration, mild anger	Skill
	• Exploration with apparatus (Bevan)	Satisfaction, joy	Skill, receiving sanctions
	• Student-centered planning (Catherine)	Neutral	Skill, planning, sanctions
Supervision	• Checking logbooks / journals (Bevan, Catherine)	Neutral, low anger	Recording results, preparing draft reports
	• Checking milestones (David, Tabatha)	Frustration, low anger, pride, happiness, fiero, surprise	Planning, recoding results, preparing draft reports
	• Fading / hands-off (Bevan, David, Tabatha)	Pride, satisfaction	Confidence, independence
	• Interacting with students (Bevan, David, Tabatha,	Satisfaction, pride, frustration,	Accomplishment, sanctions

Catherine)	disappointment (Catherine only)

Figure 1: Cascading event: Bevan refers to the achievements of the playful group

Figure 2a: Fiero

Figure 2b: Happiness

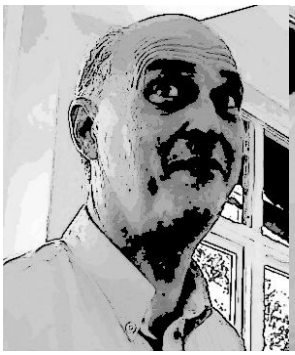

Figure 3a: Surprised

Figure 3b: Satisfied

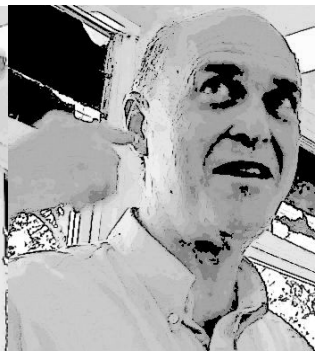

Figure 3c: Exhilarated