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Affective problem solving: emotion in research practice

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Abstract This paper presents an analysis of emotional and affectively toned discourse in biomedical engineering researchers' accounts of their problem solving practices. Drawing from our interviews with scientists in two laboratories, we examine three classes of expression: explicit, figurative and metaphorical, and attributions of emotion to objects and artifacts important to laboratory practice. We consider the overall function of expressions in the particular problem solving contexts described. We argue that affective processes are engaged in problem solving, not as simply tacked onto reasoning but as integral to it. The examples we present illustrate the close relation of emotion to problem solving and experimentation; they also implicate social and cultural dimensions of emotion expression. The analysis underscores a need to consider emotional expression to be intimately and importantly tied to the cognitive achievements and social negotiations of laboratory practices.

Keywords Emotion · Affect · Cognition · Science practice · Motivation · Metaphor · Problem solving

1 Introduction

In recent decades, analyses of both the cognitive basis of emotion and the emotional basis of cognition have led to new questions concerning the clarity with which these processes can be distinguished meaningfully. Theories emphasizing the basis of

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emotion in (cognitive) appraisal of events and situations began in earnest in mid-century and have been influential for decades (Arnold 1960; Lazarus et al. 1970; Roseman 1991). More recently, the profound impact of emotion on cognitive tasks and processes has been argued compellingly, prompting the appearance of the rather intriguing term "emotional cognition" (Moore and Oaksford 2002; Thagard 2008). Because even cognitive theories of emotion acknowledge a somatic or bodily feeling component to emotional experience, the literature on emotional cognition is more broadly situated within the extensive recent literature on embodied mind and embodied cognition (Johnson 2008; Lakoff and Johnson 1999; Varela et al. 1991). Interest in emotion and its role in cognitive processes has prompted appeal to an "affective revolution" comparable in some respects to the "cognitive revolution" of the twentieth century (Haidt 2007: 998).

But against the mounting evidence pointing to intimate connections between emotion and cognition, there is comparatively little analysis of the role of emotion in scientific practice. One notable historical example is Polanyi's *Personal Knowledge,* a chapter of which concerns "Intellectual Passions." Polanyi argues compellingly for the "manifest emotional force" of scientific process most obvious in the discovery phase, including the delight attending acts of ingenuity and the joy of contemplating natural mysteries, the intellectual beauty of mathematics, or the appreciation of elegance (Polanyi 1958/1973: 133). Maslow's *Psychology of Science* (1966) draws from Polanyi's insights in similarly arguing for the importance of the scientists' passionate engagement with ideas and problems, in contrast to the stereotype of the detached and coldly rational observer. The aesthetic experience of scientific theories is likewise acknowledged by a wide range of theorists, historic and contemporary, within the general parameters of scientific values (Kuhn 1977; McAllister 1996). Similarly, Mitroff (1974) and Mahoney (1976) include emotion in their analyses of the contribution of subjectivity to scientific process. In contemporary science studies, however, emotion principally emerges as an important consideration in biographical studies of particular scientists, as implicated in studies of scientific creativity, or analysis of the personality traits of scientists in the collective (Feist 2006; Simonton 2004).

One of the obstacles to analyzing emotion in science lies in the great variety of terms used in reference to this class of experiences and functions. Feelings, desires, emotions, moods, passions, pathos, and being "affected" by objects can be conceptually and historically distinguished; emotions are used in reference to both fleeting states and dispositions. Moreover the conceptual relations between emotion and other psychological categories—notably motivation and personality—vary broadly over decade and academic perspective. The rather convoluted route by which psychologists have related the categories of emotion and motivation over the decades is documented in many textbooks on motivation, whereby motivation has been distinguished from emotion and theorized in terms of drive (e.g. Franken 2006). Similarly, motivation is sometimes linked to personality, notably by Maslow who relates the former to the dispositional tendencies and potential capacities of any person (1954/1987). Personality, in turn, links back to emotion, through long-term and characteristic patterns of emotional responding.

In contemporary cognitive science, Paul Thagard's chapters on scientific cognition in his recent *Hot Thought* (2008) provide one of the few extensions of the recent emotional cognition literature to the domain of science. Thagard uses historical case data: Watson and Crick's discovery of DNA structure and Dr. Patrick Lee's discovery that the retrovirus has the potential to kill cancer cells, to analyze the role of emotion in all phases of inquiry. His analysis, detailed most clearly in relation to Watson, offers "a rich set of examples of possible emotional concomitants of scientific thinking" (2008: 173). Thagard began by identifying "emotion words" across the 143 pages of *The Double Helix*, Watson's "personal account" of his famous discovery with Crick (Watson 1969). Thagard found a total of 235 emotion words: 125 attributed to Watson's own experience, 35 to Crick, and 13 in reference Watson and Crick in combination, and 60 in relation to other researchers. Thagard also coded the emotion words identified as having positive or negative valence, and he found more than half to have positive valence. He then coded in terms of "basic" emotions assumed to be universal: happiness, sadness, anger, fear, disgust, and surprise, but identified additional words that had emotional tone but did not fit these basic categories: interest, hope, and beauty. Finally, Thagard evaluated the place of each emotion word in the context of different phases of inquiry. He began with Reichenbach's (1938) basic distinction between the contexts of discovery and justification, and then drew a further division between investigation and discovery to account for the extensive work that frequently precedes discovery. Thagard analyzed most of Watson's emotion words as taking place in the context of investigation, but identified emotion in all three phases, including justification.

In this paper we extend the analysis of emotion as expressed in historical records to expressions in interview data we collected in engineering research laboratories, where lab members were asked to discuss their on-going research.

2 Field sites and methods

We have conducted a 5-year ethnographic investigation of cognitive and learning practices in two research laboratories in the interdisciplinary field of biomedical engineering; one conducting research in tissue engineering, the other in neural engineering. These laboratories are populated by "engineering scientists," a breed of researcher who aims to make fundamental contributions to basic science as well as to create novel artifacts and technologies. The labs are cutting-edge research environments located at a Research I institution.

Lab A[1] is a tissue engineering laboratory. During our study, the main members included a director, one laboratory manager, one postdoctoral researcher, seven PhD graduate students (three graduated while we were there, the other four, after we concluded formal collection), two MS graduate students, and four long-term undergraduates (two semesters or more). Additional undergraduates from around the country participated in summer internships, and international graduate students

[1] The designations "Lab A" and "Lab D" are arbitrary.

and postdoctoral fellows visited for short periods. All of the researchers came from engineering backgrounds, mainly mechanical or chemical engineering, and some were currently students in a biomedical engineering program. Some had spent time in industry prior to joining the lab. The lab manager had an MS in biochemistry. The tissue engineering laboratory, as an institution, had been in existence nearly twenty years when we entered.

Lab A's overarching research problems are to understand mechanical dimensions of cell biology, such as gene expression in endothelial cells, and to engineer living substitute blood vessels for implantation in the human cardiovascular system. The dual objectives of this lab explicate further the notion of an engineering scientist as having both traditional engineering and scientific research goals. Examples of intermediate problems that contributed to the daily work during our investigation included: designing and building living tissue—"constructs"—that mimic properties of natural vessels; creating endothelial cells (highly immune-sensitive) from adult stem cells and progenitor cells; designing and building environments for mechanically conditioning constructs; and designing means for testing their mechanical strength.

Lab D is a neural engineering laboratory. During our study the main members included a director, one laboratory manager, one postdoctoral researcher, four PhD graduate students in residence (one left after two years, three graduated after we concluded formal collection), one PhD student at another institution who periodically visited and was available via video link, one MS student, six long-term undergraduates, and one volunteer, not pursing a degree (with a BS), who helped out with breeding mice. When we began our study, the laboratory director ("D6") was a new tenure-track assistant professor. His background was in chemistry and biochemistry, with his engineering experience largely self-taught, though highly sophisticated. The backgrounds of the researchers in Lab D were more diverse than Lab A and included mechanical engineering, electrical engineering, physics, life sciences, chemistry, microbiology, and some were currently students in a biomedical engineering program. As an institution, the neural engineering laboratory was in existence for a few months and still very much in the process of forming when we entered.

Lab D's overarching research problems are to understand the mechanisms through which neurons learn in the brain and, potentially, to use this knowledge to develop aids for neurological deficits and "to make people smarter" (PI). Examples of intermediate problems that contributed to the daily work included: developing ways to culture, stimulate, control, record, and image neuron arrays; designing and constructing feedback environments (robotic and simulated) in which the "dish" of cultured neurons could learn; and using electro-physiology and optical imaging to study "plasticity." Here, again, the researchers have dual scientific and engineering agendas.

Collectively, our research group conducted over 800 h of in situ field observations and 148 unstructured interviews. We collected various other data, which we do not detail because our focus here is on the interview data. Our framing assumption in approaching data collection and analysis is that the cognitive practices of the laboratory are both *situated* in the laboratory and *distributed* across systems of interacting persons, artifacts, instruments, and traditions. The situated approach to cognition construes intelligent behavior as arising among interactions within particular settings. The position holds that "problem solving is carried out *in conjunction with the environment*" (Brown et al. 1989: 36, emphasis added). By *distributed*, we mean that we regard brain and environment as co-constituting a single complex system, in as much as the forms of sense-making and problem solving that occur would not be possible in isolation from that environment, including the social environment. In so framing our study of the laboratories as situated and distributed, we connect it to other investigations of real-world problem solving that implicate the environment in cognition in important ways (e.g. Greeno 1998; Hutchins 1995a, b; Resnick et al. 1997). Consistent with this tradition, we rely upon interpretive methodologies to unpack the rich complexities of science in its natural habitats (in this case, laboratories). Although we approach our study of these laboratories with the assumption that cognitive and social processes constitute a whole, the use of individual interviews with researchers at different levels of expertise and from different disciplinary backgrounds enables us to analyze how the particular learning history and affective style of the researcher might contribute to the rich mélange of social and cognitive practices that constitute science.

Broadly consistent with the aims of grounded theory, we have been approaching interpretive coding analytically and inductively (Glaser and Strauss 1967; Strauss and Corbin 1998), enabling core categories (and eventually "theory"[2]) to emerge from the data and remain grounded in it, while being guided by our initial research questions. To date we have coded approximately 16% of the interviews. The focus of our analysis was cognitive practices; however, in the process of coding we found there to be numerous expressions of emotion. We therefore distinguished a class of expressions we have coded and analyzed as implicating *emotion*, *affect*, or *motivation*. Our interviews were with undergraduates, graduate students, postdocs, and PIs. Importantly, emotional expressions appear to be independent of ages and research projects/roles in labs.

Our analysis of emotion and motivation in science practice bears some similarities and some important differences from the analysis undertaken by Thagard (2008). Similarities include identification of "emotion text," in our case, passages of interview text that we interpret as expressions of emotional experience. We also examine the valence, positive or negative, and the target of the attribution, that is, to whom (or what) the emotion is attributed. Unlike Thagard, however, our focus on the presence of emotion expressions in the context of open-ended *interviews* with researchers enabled us to analyze the function of emotion expressions in a more immediate, on-line account of science practice rather than an edited, published account. Secondly, we include attributions we found of emotions to *objects and artifacts* important to laboratory practice. Thirdly, we did not take assumed universal categories of emotion as a guide. We coded in an unrestricted fashion, attempting to describe emotional or motivational themes of the passages as seemed most fitting. Finally, we examined not only emotion words, but

[2] We place the word "theory" in quotation marks here because what grounded theory advocates mean by that term better approximates what Tweney 1989, has called a "framework.".

also longer passages of text suggestive of emotional or motivational states, as well as figurative language that appears to have an emotional tone or function when interpreted in context. Because our interviews have different foci, we do not analyze the expressions coded in terms of the stage of problem solving in which they occur (as did Thagard); rather, we consider the overall function of the expression in the particular problem solving context as recorded in the interview. Our analysis of emotion is still in comparatively early stages, but we provide examples of different forms of what we consider expressions of emotion or motivation, and consider how they relate to more explicitly cognitive practices indicated in the interview.

Because we have conducted fine-grain coding on only a small subset of our large collection of interviews, our emphasis is not on counting the presence of emotion words or expressions, but on characterizing the variety of ways emotion expressions appear and on the functions these expressions play in the context of the interviews analyzed. Where possible we attempt to provide examples both from different researchers and from across laboratories. We organize our examples into three categories of emotion related expression evident in our transcripts: I. Overt expressions; II. Figurative or metaphorical expressions; III. Anthropomorphizing expressions. Our examples illustrate not merely the close relation of emotion to problem solving and dedication to the work of the laboratory, but similarly implicate social and cultural dimensions of emotion expression.

The following convention was used to label and catalog interviews: year-month-date-Lab (A or D)-I (for interview)-participant # (e.g. [2006-10-20-A-i-A22]). Of note in relation to interview segments appearing in this text, pauses in speech or a marked change in direction as indicated by a dash (–). Authors' condensation of interview text is indicated by (…). Quotations marked with "tour" are not from the interviews, but from a tour of Lab D conducted by the lab director for us and some other guests. We did ask questions during the tour.

3 Overt expressions of emotion or motivation

3.1 Excitement

We begin with a general look at the place of excitement in our transcripts. Here in an interview focused on research progress, a student working in Lab D says that:

> *Right now* ***it's not too exciting****. (I'm) taking courses and I haven't been able to do as much as I like as far as research or anything like that* (2002-03-25-Di-D2).

Note that in this example, "not too exciting" is equated with not doing much research. An interview nine months later finds this same student still expressing motivation in terms of the chance to participate in research:

> *And I've developed a lot of theory but I haven't had the chance to do anything yet…* ***I am really anxious to do experiments.****…I've never really done*

experiments before, so I'm really curious to see how good I'm at it. I'm just kind of delaying picking up more and more theory (2002-12-05-D-i-D2).

For D2, excitement and motivation are connected to his own "doing", his own participation in experimental science. The second passage implies a contrast between the active research participation D2 imagines as exciting and the accumulation of theory abstracted from hands-on practice.

But the focus of excitement is quite different for D6, who in giving the interviewer a laboratory tour expresses excitement over both a new microscope and the use of "real robots:"

So the latest addition to the lab ***I'm very excited*** *about, the new microscope… One of the* ***exciting*** *things that we've gotten involved in is using real robots instead of simulated creatures* [12-02-2002-D-D6 (Tour)].

After identifying the use of real robots as exciting, D6 links his excitement to the *theoretical* import of the robot for the researchers in developing an understanding of creativity:

And, so this year we had this thing [robotic arm] *being controlled by neurons in our lab here right here, so we had a link, a real-time feedback link going halfway across the world to Z35… and the neurons would continue drawing some drawing…, I think this is important for a number of reasons. One of them, is that* **it gets people to think about what is the minimum necessary for a creative process to happen.** *You know, what is the process of creativity, and the whole process of artistic creation. Another thing is the integration of human made artifacts and biological tissues* [12-02-2002-D-D6 (Tour)].

The use of robots is exciting precisely because of its theoretical significance, which includes reflection on the minimum requirements of creativity.

D6 also expresses excitement in the context of a narrative about his entry into the field of neuroscience:

So, so uh, when I went to college, I didn't know what kind of scientist I wanted to be. My roommate said: "you ought to come to this class that I'm taking. It's about cognition. …I accompanied him to class and sure enough ***everything he said was absolutely fascinating to me****, and I went into go, to go chat with him in his office hour. …* ***In that half an hour it was fantastic, what he said was just wonderful, it sucked me in****. …So, that was* ***extremely exciting to me*** *and he was at Z12 at that time, and I made a road trip up from Z10 to Z12 to go and hear him give a talk and got even more inspired. And at that point I had decided, ok, neuroscience is what I want to do, and I wonna be a neuroscientist.*

This passage clearly relates the excitement D6 remembers experiencing in first exposure to a set of ideas about cognition to his decision to pursue neuroscience as a career.

Other expressions of excitement include their attribution to other researchers. For example, in a progress interview, A22 can't remember the details of A10's experiment, but she remembers that A10 was very excited about it:

I So have you learned any new procedures this week?
A22 *No, not really. Um, I've gotten to see the results of some new stuff that, that um, that A10 did. I don't—can't tell you much about it because I didn't have a chance to learn.*
I What did A10 do?
A22 *Um, he—see, this is what I'm going to have to try to remember—um, he made tissue—some tissue engineered……I don't even remember what it is. It has something to do with the heart valve that he was working on. …. **But he was very excited*** [laughs]. (2002-11-13-A-i-A22).

3.2 Frustration

We additionally found many references to frustration, both overt and implied, attributed by researchers to themselves and others:

A31 repeatedly expresses unpleasant emotion in relation to the task of graphing the data in Lab A: "*I'm **still struggling** with the issue of graphing the data*." This impacts his work by limiting the amount of time he can bring himself to devote to the project: "*I get **real frustrated**, so I only work in increments*." He elaborates with the interviewer's prompting:

*You have to set your array size and then initialize it. So I figured out how to do that, but then I can't figure out how if, if I have a 1 by 10,000 element array, it's empty, um, I can't figure out how to append to the end…So I got **pissed off** about that, and I started working on the linear encoder.* (A31 2005-02-02-A-i-A31)

In other words, A31's frustration has resulted in a change of task-working on the linear encoder. Several weeks later he tells another interviewer that he has

"*taken enough time off from this thing that I'm not pissed off at it anymore…*"
"*There was a period there where I was working on it everyday and I was just like…really…you know… 'Im going to lose it if I can't get this to work…*"
(2005-02-22-A-i-A31)

3.3 Connections between emotion and motivation

Emotions also enter narratives researchers provided concerning their entry into biomedical engineering and their career paths. For example, negatively charged expressions color the account D6 provides of his graduate school experience: He describes his relation with his own academic advisor as "***hell***," explaining that when he was merely learning techniques he and the advisor got along well, but that "*at some point when I, when I learned enough to start coming up with my own ideas of how we should do things, we really butted heads. …And when I have ideas I* *expect that he should at least consider them but often he did not even consider them and I was* ***really grinding my teeth****…* (2002-12-11-D-i-D6).

Frustration is also attributed to other researchers, as in this passage:

> A22: "*A54—I don't even know his last name… I was talking with him yesterday, and I know* ***he's frustrated*** *because he can't understand all the jargon"* (2002-10-10-A-i-A22).

Anger is also attributed to a computer, in the context of the researcher not being able to demonstrate a point to the interviewer by pointing to a display on its screen:

> "*It's alright. It's buggy sometimes. It* ***gets angry*** *when it has too much stuff*" (2005-02-02-A-i-A31).

Most frequently, however, expressions of frustration occurred in conjunction with accounts of failed experiments or work not progressing as planned. Given the cutting-edge nature of their research, failure is a daily fact of life in these labs. In this example, D4 frames her current paper writing effort in the context of her overarching motivation to perform plasticity experiment:

> *We're writing an experimental paper about how to suppress bursts. …Straight forward…But my whole motivation for ever getting into suppressing bursts is plasticity experiment, ok? I spent March to August last year trying to get this work – plasticity experiment- working. OF COURSE it didn't* (2003-04-09-D-i-D4).

Although frustration is not expressed directly in this passage it is suggested by what seems to be an ironic "*of course* it didn't" (work) at the end of the passage. Following up, the interviewer merely repeats, "It didn't?" to which D4 gives a lengthy and seemingly emotionally charged reply:

> I: It didn't?
> D4: *It did NOT. Very good, so I said why is it not working? And I thought, ahhh! The bursts! Ok, then I spend the rest of the year trying to do, till this March, trying to do burst suppression. Succeeded, so called. Succeeded…and now, this March, I'm back again, to plasticity experiment [starts laughing]. So it's pretty interesting, I've spent an entire year doing something else, and I've come, it's around the* ***same damn time*** *that I'm doing* ***the same damn plasticity experiment****. But, now I feel that this should work.* ***If it doesn't, then it's very bad. It's very bad****. So, every time I go and start this plasticity experiment, I say, "****my god, if this doesn't work****"* [pumping fist], ***my whole hypothesis, one and a half years of work can go into the dustbin*** *and it's just, fine, so, ok; I'll have to try a totally new line of thought* (2003-04-09-D-i-D4).

This passage vividly illustrates the unpleasant aspects of science practice that counteract the thrill of innovation or the vigor accompanying theoretical challenge. Despite identifying plasticity experiment as her "whole motivation," D4 now marks it and the time she devotes to it with the expression "same damn." The pressure she appears to feel to obtain her desired result is indicated in her statement that her hypothesis and eighteen months of effort will be wasted ("can go into the dustbin").

Of interest is that the interviewer noted D4's pumping fist even though the interview was conducted during the early stage of our investigation when we had given no indication that we would be looking at the function of affect or emotional expression in the laboratories.

Despite her frustration, however, D4's account also underscores what is increasingly emphasized in recent analyses of the role of failure in innovation, including scientific discovery (e.g. Fetzer 2003; Petroski 2008). If her hypothesis goes into the dustbin, D4 will embark on a new direction of thought and experimentation. The unpleasant experience of frustration in relation to failing experiments may be a necessary impetus to innovation or heightened efficiency. This idea is also expressed by a Lab A researcher in relation to his effort to obtain desired results:

> *So I tried to do all this stuff like build array. You know and you use, set your whatever element array…But for some reason it just wouldn't work. …**It seems like it should work. And that's what really frustrated me,** and so I started messing with this auto-indexing thing* (2005-02-02-A-i-A31).

Note that A31 expresses frustration in part because the results of his manipulations do not accord with what he thinks is logical, what makes sense to him. He begins to discuss a new course of action, "messing with this auto-indexing thing" immediately after acknowledging his frustration. In other words, there appears to be a relation between the frustration through failure to obtain the expected result and the new action taken to remedy the problems.

This view of frustration as an unpleasant but important spur to new action accords with an interesting finding emerging from our coding in relation to what we have framed as the agentive learning environment of the laboratories—that is, environments in which graduate and undergraduate students are empowered to be agents of their own learning—as well as to their status as innovation communities. These features of the laboratory communities are associated with both positive and negatively charged emotions. Here A7 and D7 acknowledge the pleasant aspects of working independently, but the tone of the passage from an interview with D4 is decidedly more negative.

In an interview ostensibly devoted to a description of a physical simulation models they design and construct, locally called "devices," A7 calls working in Lab A

> "***a fun adventure"**…**"you fumble along**, and hopefully you're better off you know for having taken time to really think through what you're doing… so I mean **you totally have ownership of this**… **you know at the end of the day that would feel good***" (2004-07-01-A-i-A7).

D7 acknowledges the potential for some of Lab D's "big ideas" to fail, yet calls the research "fun" and speaks of his love of being part of the lab:

> D7: *And these are very, very big ideas…A few of them might, um, might fail. You know.*
>
> I: But that's research as you said.

D7: *So like, I **take it as fun, I love, I love to do, I love to think like this**. And that's why I'm here. Because, here I know that I'm interacting with [PI] for a long time, and I know that I can get, get good opportunity here, like, this will be mutual. If I, I'm able to join in this lab, they will also benefit, I will also get satisfaction* (2002-10-24-D-i-D7).

On the other hand, the knowledge-at-the-frontier status of research in Lab D is associated with "trouble" in this interview with D4, and the affective tone of this description of her experience is at least mildly negative:

D4: *But there are a lot of questions and nobody knows how to answer them. Nor does [the PI]…Yeah, I don't know what's happening! How much do I know what's happening? Very little. There's, there's a lot that I just don't know. …So, the deal is there are too many questions and very few answers, and **that's where the trouble is*** (2003-04-09-D-i-D4).

These examples provide rich, contextual illustrations of the close relation between overt emotional expression and either advancement or disruption in problem-solving.

4 Figurative and metaphorical expressions

However, as interesting as the clear expressions of emotion and motivation in the interview transcripts prove to be, there is a need to look beyond them to fully appreciate the implication of emotion in laboratory practices directed toward the production and dissemination of knowledge. This is best understood by considering theories that emphasize the social nature and function of emotion. Kövecses (2000), for example, argues against the strong biological position on emotions whereby brain states rather than linguistic distinctions are principally implicated in the evolution and experience of emotion (LeDoux 1996). In contrast, Kövecses considers conscious feelings to be vitally involved in emotion, and notes that these feelings "are often expressed in or, indeed, are shaped by language" (1996: ix). What is required to understand this connection deeply is an abandonment of what he considers "simplistic views of emotion language:"(xii), whereupon…"emotion language will be not be seen as a collection of literal words that categorize and refer to a preexisting emotional reality, but as a language that can be figurative and that can define and even create emotional experiences for us" (xii).

In our data set, then, as a second class of emotion expressions we consider the function in context of what we call *affectively toned metaphorical expressions.* These are sprinkled throughout the interviews and are more subtle forms of emotional expression than are the overt examples already discussed.

4.1 Little beasts and violent methods

In this interview about laboratory equipment, D1 refers to a vibrator as a "little beast" for no obvious reason related to the interview context other than that the vibration is of high frequency. Calling a piece of equipment a “little beast,” however, suggests a feeling that it is wild and uncontrollable—and possibly a sense of danger.

I: “So I noticed the hood was cleaned out, from stuff. Just wondering what was going on there.”
D1: “*What they’re doing with this right is platinzing MEAs… And this* ***little beast*** *is a, um, it’s a high frequency vibrator is essentially what it is, and it produces a high frequency vibration (*2002-12-05-D-i-D1)

In the same interview, D1’s offers this appraisal of Lab D’s methodology:

I: So how do the methods change with the technology?
D1: *The technology seems to be racing forward dramatically, and, um, the methods are slowly beginning to catch up. But, you know, from what I’ve seen, cause I come from the cognitive learning and memory area, and we have a long history of experimental method… with lots of different types of controls you can do for different types of phenomena…. From what I’ve seen in this field so far, the method seems to be very simple; it’s a typical A-B-A type of preparation …*
I: *Y*ou think the methods in this field are too deeply rooted and maybe need to grow?
D1: *They will over time, because they’ll make the same sorts of mistakes that we did using those types of methods. I mean, it’s bound to happen and make the mistakes that will take you down the wrong path, and you’ll get better and doing what you do. My advantage is that I know about all this stuff already. So I know how* ***I can be killed*** *by this type of procedure (*2002-12-05-D-i-D1).

It is not in any way obvious how A-B-A (sic) research design is in and of itself a lethal procedure, thus we can assume the metaphoric expression signals some frustration or disappointment D1 suffered through a prior experimental procedure. “Being killed” expresses a sense of victimization. In contrast, here A31’s language is suggestive of more violent impulses toward a measurement tool:

I: The measurement you are getting off there… I guess the red line… it is independent of what you are trying to produce? Independent of the voltage you are sending out to control it?
A31: *Yes I think so. When it was set up incorrectly and I command it to move 5000 counts that way, right? A lot of times it would do something like this and shoot the wrong direction and oscillate out of control … it was nuts… it sounded like a jack hammer… [both laugh] and* ***I had to press kill, kill, kill!*** *It needs a big red button to control the damage.* (2005-02-22-A-i-A31).

What we are claiming is that such figurative or metaphorical language provides subtle indication of affect that is easy to overlook. Yet the affective coloring is significant in that it is integrated with the cognitive practices also in evidence (e.g. describing equipment or methodology). That they have affective coloring is underscored by comparing them to other metaphorical expressions appearing in the transcripts that call upon metaphor principally for the purposes of explication and clearly lack such coloring:

I: And so what other things might you look at on—what else to see the results of the bioreactor?
A16: "*…And so the elastic,* ***the elastic part is similar to- you think about a rubber band****, a rubber band can recover if you just stretch it back and forth, and back and forth, and it doesn't seem to change in any way* (2002-07-15-A-i-A16).
…
A10: *So like, a blood vessel, the matrix is collagen. Cells sit in there. So you have these*—***it's like it's putting rocks in jello****. So the Jello's the matrix and the rock's the cell* (2002-07-05-A-i-A10).
…
A10: ***Basically turbulent flow is like in the back of a canoe paddle with the eddies***. (2002-07-09-A-i-A10).

In these examples, the use of use metaphor and analogy appears to be used deliberately and for the purpose of enhancing the interviewer's understanding through visualization. Thus our claim is not that all metaphorical or analogical expressions are affective in tone, but that in some cases metaphor seems to signal affectively toned expressions. More broadly, metaphorical expressions might be a source for identifying subtle contributions of the affective dimension to sense-making practices in science: "There is very little about the emotions that is not metaphorically conceived" (Kövecses 2000: 85).

4.2 "Cool" science

Also easily overlooked as an affective marker is the multivalent term 'cool,' which makes frequent appearances in our interview transcripts. Its meaning, though figurative, is largely indeterminate and used in a wide range of circumstances in ordinary discourse. It certainly not one of the basic categories of emotion and might be disregarded in an analysis focusing on these categories. Indeed, it is tempting to dismiss the frequency with which various aspects of laboratory practice are called "cool" by our researchers as reflective of the ubiquity and banality of "cool" in casual American discourse. However, read in the context of the discussion recorded in interview transcripts, "cool" marks emotionally laden and motivationally relevant expressions of several varieties. Note that in these examples the use of 'cool' flags particular interest or involvement in relation to what are clearly cognitive practices.

D4 calls Lab D's robot "really, really cool" because of its affordances for problem solving and innovation:

I don't know whether you've heard of [the PI's] animat thing which is basically this simulated animal… The point is to have an embodiment for these cultures which is basically a robot…If we get some recording patterns of this dish that we will be able to do something with…So… ***that robot is really, really cool.*** *It has sonar systems.* (2003-3-30-D-i-D4)

The excitement D6 expresses in relation to the acquisition of the new microscope is framed in terms of the aesthetic appeal of the products it affords. Here "cool" is also paired with "exciting":

after a year or so this thing was ready, and it just worked the very first time we tried it out to put a post-it note under the microscope it, it made this [emphasized:] ***gorgeous picture*** *of paper fibers…* ***Wow, this is so cool…very exciting***. "(2002-12-11-D-i-D6)

'Cool' also implicates value in science practice, as it's presence in an interview passage serves to demarcate worthy from unworthy things. For example, D4 contrasts 'cool' with 'not clever' in the following passage: "So, my cluster may be actually accounts for the slant so, it's basically an expectation maximization kind of algorithm. ***It isn't any cool thing*** except ***the clever thing*** I did is with this, put some parameter which accounts for the slant for the shift in latencies" (2003-02-27-D-i-D4). "*Really, really cool*" in reference to the robot marks something with conceptual clout, as indicated when D6 reflects on the potential of the robot's "creations" for helping scientists to think through the minimal requirements for creativity. By contrast, in this example, "cool" is closely identified with the potential *social* relevance of scientific practice:

I: What do you think you'll do when you finish (graduate school)?
A7: *Industry is what I've always kind of had on the top of the list…I think some of the* ***cool*** *aspects I idealize about industry, whether it's true or not, is being hopefully close to the clinic (sic)… in other words, hopefully working on things that are very close to moving into um* ***aiding human health****… I mean you think um a lot of basic science is* ***really, really cool*** *in terms of what we're learning and* ***how we can apply it*** (2004-07-01-A-i-A7).

The connotation of 'cool' in interview context is invariably positive, associated with something desirable. It is used in relation to several different kinds of situations/events: career prospects, research problem, an engineered product (robot), an experimental outcome ("*so that would be really cool if that happened*"; 2003-04-09-D-i-D4)

The frequent appearance of "cool" in our interview transcripts is reflective of the interplay of cultural influence on emotional expression. The term, firmly rooted in the twentieth century and adapted by a new generation of young people who find it useful for a wide variety of purposes, can only be clearly interpreted by analyzing the discursive context in which it appears. It is not merely students who keep it in play; "cool" and "really cool" made frequent appearances in transcripts from at least one of the principal investigators. One speculative possibility is that cool might serve to generalize and diffuse emotional experience for the speaker; it is perhaps a convenient and socially sanctioned stand-in for more precise emotional expression.

As a class of motivation, "cool" aspects of practice might be seen to contrast with what we have coded as a pragmatic focus in science practice. We found multiple examples of this pragmatic focus as well, so our claim is not that researchers were *merely* motivated by what is cool or exciting, only that "cool" science is one seemingly important source of motivation. Further "cool" and "exciting" for the engineering scientist often goes hand in hand with a potential for applications, as in the account the PI of Lab D gives of his entry into neuroengineering. It is at once the fact that the material is theoretically exciting and affords useful applications that seems most closely associated with the affective tone of the narrative:

> *So that was the first time I've ever been exposed to, even though it is fairly abstract, a model of the brain and it being* ***useful for something other than for something just to understand how brains work****, um, to actually use it for engineering tasks or pattern recognition or whatever. So* ***that was extremely exciting to me****….and I made a road trip up to go and hear him give a talk and got even more inspired. And at that point I had decided, ok, neuroscience is what I want to do. I want to be a neuroscientist*" (2002-12-11-D-i-D6)

This same researcher also projects his anticipated life satisfaction on practical *accomplishment:*

> *the thing that will make me happy when I go to my grave… having done… would to have accomplished tangible improvements in the happiness of people you know…*(2002-12-11-D-i-D6).

5 Anthropomorphizing expressions: happy cells

The class of emotional expression we found especially interesting in interview transcripts is the attribution of emotional states to the objects and artifacts central to the sense-making practices in the laboratories. The most striking and theoretically important example of this practice is the attribution of happiness to cells in Lab D:

> I: You mentioned "cell density." Why is that important?
> D4: *Cell density is important, because for one cells survive more if they, if they're connected to each other.* ***A lone cell by itself is not very happy*** (2003-03-20-D-i-D4).
> …
> D6: *So we also have microscopes in here that as you can see, they're always closed up in these boxes that we can keep warm in there, and we can modulate the atmosphere* ***so the cells are staying happy*** (2007-02-14-D-i-D6).
> …
> D24: *This is problem solving on a whole new level because it's like how do we build a device that you put the microscope in that's gonna keep the humidity and the temperature in and we can deliver this to it and* ***keep our cells happy*** (2003-09-16-D-i-D24).
> …
> D24: *There's neurons in a dish and* ***just count them and keep them happy*** *and hope they don't get sick and die.*
> I: So these MEAs, did you know anything about them before you came in the lab?
> D24: *Um, not like specifics. I knew neurons were in them and i knew electrodes monitored them and that sort of thing* (2003-09-16-D-i-D24).
> …

D28: *Imaging with cells is also non-trivial because there is, you know they're not happy being zapped with laser beams* (2005-03-15-D-i-D28).

Happiness is occasionally extended to the dish as a collective:

D4: *So yeah there're, there are a couple of noise sources in there…So yeah, that's the deal, it's pretty good, works very well;* ***today the dish is happy*** (2003-09-15-D-i-D4).

And to the cell culture:

I: So uh… I don't think I understand conditioning.
D15: *So conditioning basically means… You'd basically culture an entire flask with brain cells…and put the media in there and let them grow in there for a week and then take the media off and use that media to feed other cells.*
I: OK, and what does that gain you?
D15: *Because the glia in the culture…maybe the neurons too…they're producing factors that* ***keep the culture happy*** (2004-10-28-D-i-D15).

Researchers across levels of expertise exhibit this practice of attributing happiness to cells, from the PI to D24, an undergraduate who admits little previous experience with or knowledge of MEAs. Therefore the attribution of happiness seems to indicate a local cultural practice (I.e. local to Lab D, the field of neuroengineering, or possibly biomedical engineering), just as the expression of "cool" reflects wider cultural and perhaps generational patterns.

Even more intriguing is a segment of an interview with D4 which reveals a *normative* component to the concern with happy cells (neurons). This passage is instructive for two related reasons: (1) It provides more clarity on the meaning of "happy" in the context of Lab D (as we shall note, the meaning seems slightly different within Lab A); (2) It reflects an expectation for researchers to keep the cells happy, and even more revealingly, to care about keeping them happy. The context is an early interview with D4, a postdoctoral researcher; it reflects the ethnographer's effort to better understand the basic research practices important to the lab in addition to D4's particular interests.

I: So tell me about these neurons, because you guys are always talking about neurons in the lab.
D4: *What about neurons?*
I: Well, yesterday for example you killed a whole batch of neurons, you know when you were trying to get the MEA to work? And uh, remember Grad A came in and you guys, and um, what was the girl's name? She was so upset when the neurons were killed.
D4: *Right, Grad B.*
I: Yeah, and you guys talk about the neurons with the undergrads all the time because they're culturing the neurons, so, why do you guys care so much about neurons?
D4: *If you don't essentially care about the nodes in the network,…* ***you gotta care about them!***

I: But there's so many of them! D4 *Right there's so many of them, but that doesn't mean that you want to…. So they make up the network,* ***each of them has a part to play****, in the network property, so you want to keep as many as you can. You know, because they make up essentially, as I said, they make some basic rules for the way the network works,* ***so you want to keep them happy.*** (2003-04-09-D-i-D4)

The implication here is that it is not only the happiness of the cells as a collective that is important but even the happiness of individual cells, given that each of them contributes in a particular way to the functioning of the whole. In a later interview with another interviewer, D4 provides more clues as to what is meant by happy cells:

I: So, you know, I see these sparks here [pointing to the monitor], what, can you give me a sense when you see the activity as it flows here, what, how would you describe that?
D4: *So what we see is actually summation of the activity of all the cells around it and-uh so, and this flow of activity is basically because of the connectivity of the network…. But then there are some cells which are always active like this guy here, and that guy there.* ***They are just happy firing all over on their own.***
I: Which one, on the grid 70?
D4: *Yeah, on the grid 70. This* ***seems to be happy all the time,*** *you know,* ***it's happy, it's happy.*** *I can't really say. May be they're two cells connected to each other, they go bing-bing-bing all the time, I don't know. So there are some cells which are very active, most of the time. So, this is a* ***pretty active network*** *because I get activity almost like on 80% of recording, recordable channels, which is, which is very good.* (2003-09-15-D-i-D4)

D4's comments in the context of this interview help to clarify that "happy" cells are not simply alive but that they are actively forming connections—something essential to the researcher's problem-solving activities.

This passage in particular invites analysis in terms of the social dimension of emotion, not merely in terms of the contribution of cultural and linguistic practices to emotional expression, but more strongly to the idea that emotions themselves constitute interactions or *transactions*. Transactional models of emotion emphasize the dynamic interrelations of person and environment or person and situation in the production of an emotional response. A clear account is provided by Lazarus and Folkman:

> What does it mean to speak of relationship or transaction? The essential point is that we cannot understand the emotional life solely from the standpoint of the person *or* the environment per se. We need a language of relationships in which the two basic subsystems, person and environment, are conjoined and considered at a new level of analysis. By this we mean that in their relationship their independent identities are lost in favor of a new condition or state…the terms relationship and transaction are for all intents and purposes interchangeable, although transaction emphasizes more the dynamic interplay

> of the variables, whereas relationship emphasizes their confluence and organic unity (1987: 142–143).

In this account, a range of internal and external factors (variables) interchangeably serve as antecedents, mediators, moderators, or consequences of emotion. As Lazarus (2006) elsewhere more succinctly puts it, "each emotion has a different story to tell about an ongoing relationship with the environment" (2006: 34).

Because of the core emphasis on interrelationship, Lazarus and Folkman (1987) link the transactional theory to earlier systems models that have been gaining momentum in social psychology. Various strands of research provide evidence supporting the view of emotions as forms of transaction. For example, Fridlund (1994) and Fridlund and Russell (2006) analyze the function of facial expressions and argue that they should be regarded as "social tools" that shape social interactions. Parkinson et al. (2005) argue for emotion's function in structuring social interactions in both dyadic and larger group interrelations. More recently, Griffiths and Scarantino (2008) draw from the literature on emotion as transactional in offering what they call a situated theory of emotion, wherein "Behaviors which have traditionally been viewed as involuntary expressions of the organism's psychological state are instead viewed as signals designed to influence the behavior of other organisms, or as strategic 'moves' in an ongoing transaction between organisms" (439–440).

More broadly, contemporary transactional theories of emotion find precedent in Dewey's treatment of emotion in the later period of his work. Within this context, "the situation" is always the focus of analysis; the dynamically integrated nature of the situation is made clear by the participation of the actor's body (including dispositional tendencies) and personal/cultural history with the environment (including the social environment-other people) in constituting and transforming each situation. Emirbayer and Goldberg (2005) provide a helpful summary of Dewey's transactional theory of emotion:

> Actors are always implicated in relations with other actors, and emotions cannot be extricated from those relations or seen as the properties of some disengaged or disembedded subjectivity. Not the subject (or object) alone, but rather, transactions among two or more actors (or other elements of a situation) must be deemed the proper unit of analysis for the study of the emotions. As Dewey puts it, "Emotion in its ordinary sense is something called out by objects, physical and personal; it is response to an objective situation…. Emotion is an indication of *intimate participation*, in a more or less excited way in some scene of nature or life" (Dewey 1988 [1925]: 292, in Emirbayer and Goldberg 2005: 490, emphasis added).

We find the view of emotion as dynamic interplay between person and environment and as "intimate participation" with the environment in which practice is situated to be particularly useful in our understanding of anthropomorphizing expressions in our interview transcripts. For example, the intimate participation of researcher with cells reflected in the attribution of happiness to cells is encapsulated powerfully here:

I: So how do you keep them happy?
D4: *Pfft, you keep them happy by feeding them, by taking care of them, hopefully stimulating them* [in a motherly condescending voice-note from transcriber] *and telling them to do something! I don't know what to do to make them happy. I don't know how make them happy, that'll make my neurons happy* [points to head]
I: Hah, to make your neurons happy, your brain neurons happy.
D4: *So, my experiment is very.. so we're writing a paper about, about this burst suppression* (2003-04-09-D-i-D4).

This passage points to the dynamic interplay between the attributed happiness of the cells and the researcher's cognitive goals. D4 directly ties the "happiness" of her own neurons, which we interpret as meaning her own scientific thinking and problem solving, to the well being of the cells, despite the feeling she expresses here that she doesn't know what to do to make the neurons happy. In the interview, this passage immediately follows the researcher's claim that the cells make the rules for the way the network works, thereby requiring researchers to care about their happiness. Earlier, as noted, in the same interview, D4 expresses frustration over not knowing how to proceed in relation to her own research. The connection between the happiness of the cells and her own research progress is striking.

This notion of emotion as an indication of intimate participation nicely complements other concepts with which we have been working to characterize cognitive practices in the laboratories under our investigation. The attribution of happiness to cells in lab D reflects a broader pattern of anthropomorphizing cells and artifacts (simulation devices) evident across both laboratories. This is particularly evident in relation to cells:

A11: *The cells, once they are in the constructs, will* ***reorganize it*** *and secrete a new matrix* (2002-01-14-A-i-A11)
D2: *They (cells) have different functions and they,* ***they talk to each other differently*** (2002-12-05-D-i-D2)
D6: *So* ***they're feeling and touching and probing around in their environment until they find the right partners to form a network with****…They have a lot in common, but* ***each dish definitely has its own personality*** *in terms of what the electrical activity looks like when you plug it in.* (12-02-2002 –D-D6-Tour)

We have elsewhere related the anthropormorphizing practice to what we have termed "cognitive partnering," an expression of working cooperatively with specific artifacts in laboratory practice (Nersessian et al. 2003; Osbeck and Nersessian 2006; Nersessian 2009). We suggested that anthropomorphizing expressions reflect the researchers' attribution of forms of agency to objects and artifacts essential to their research, suggesting that researchers engage sympathetically in transactions with them toward problem solving goals.

How the transactional perspective on emotion might inform the practice of *attributing* emotion is the task we face in trying to understand the practice of describing neurons as happy exhibited so vividly in Lab D. One aspect that is emphasized in some transactional theories of emotion is that an emotional expression constitutes *a demand* for a response. This is one way in which it can be understood as shaping or affecting the future of the relationship, by which it might be understood as a transaction. In projecting onto or attributing the ability to feel happiness to cells, the researcher attaches a demand to those cells, a demand to tend them and care for them in order to keep them alive and active. This implicates the normative dimension noted in relation to the interview with D4: There is a laboratory mandate to care about and for the cells. They could die if they do not receive care. Moreover, as D4 notes, happy neurons are active in forming connections with other neurons. The study of these activity patterns is central to the business of Lab D. Similarly in Lab A, although we found much fewer attributions of happiness to cells, we found frequent references to caring for and "babysitting cells," and one researcher who explicitly called her cells her "children." For both labs, happy cells are vitally important to the cognitive practices, to the construction of knowledge and, thus, the dissemination of knowledge..

Note that the demand associated with the attribution of happiness to cells is context specific (specific to Lab D). In Lab A, cells are also kept "happy", but in this context keeping them happy can sometimes have different implications than it has in Lab D. Indeed, instead of helping cells to proliferate as in Lab D, in Lab A keeping them happy is sometimes associated with controlling or limiting their number:

> I: Um, okay, so, what have you been doing lately?
> A22: *Keeping my cells alive [laughs] and um, and happy…*
> I: So when you say keeping the cells happy—
> A22: Oh, you know, splitting the cells, passaging them so there are not too many and then, things like that. (2002-11-06-A-i-A22).

Despite the differences in the meaning of "happy" cells in the context of Lab A research, we noted frequent references to the need to care for in look after cells, with one researcher going so far as to identify her cells as her children.

We originally coded these statements as indicating identity, specifically identity as a caretaker of cells; however, there is an emotional tone to such statements that appears to serve a similar function to the attribution of happiness to cells in Lab D. In each case the emotional involvement with cells contributes to actively working to promote their well being. It is thus central to the cognitive practices necessary to the success of the laboratory generally and to researcher's individual problem solving.

6 Summary

In this paper we have identified three classes and contexts of expression which we identify as having to do with emotion, motivation, or affect. We examined the function in context of overt expressions, figurative expressions, and expressions attributing emotions to material objects, namely neurons. The analysis, though still in early stages, gives reason to consider emotional expression to be intimately and importantly tied to the cognitive achievements and social negotiations of laboratory practices. Although the qualitative methodology adopted in this study does not afford robust generalizations, our analysis has important illustrative value relevant to the burgeoning trend to recognize the important role of affective cognition in problem solving. In line with the research of Thagard discussed earlier, our analysis demonstrates that another rich source for investigating emotion in science practice lies in open ended interviews which allow examination of natural expression in the context of on-going research. Our study illustrates the creative ways qualitative analysis of the narrative accounts of scientists can complement more traditional psychological methods geared toward prediction and generalization. Moreover, we demonstrate that to identify the role of emotion in scientific discourse, there is a need to look beyond obvious statements to include figural and metaphorical expressions and attributions of emotional states to the objects and artifacts of scientific practice.

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