Early-career Engineers at the Workplace: Meaningful Highs, Lows, and Innovative Work Efforts

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ABSTRACT

Beyond engineering skills, today's graduates are expected to have a number of professional skills by the time they enter the working world. Increasingly, innovation is one of the arenas where professional engineers should be adept at operating. However, in order to educate our students for contributing to innovation activities in their organizations, we need a better understanding of the knowledge, skills and attitudes that are relevant for early-career engineers in their development efforts. As a starting point to add to this understanding, we start by asking: *what does meaningful engineering work look like in the eyes of early career engineers?* We then go on to consider engineering work that is not only meaningful but also innovative, asking: *What does innovative work look like in the eyes of early career engineers?* Finally, we consider: *How do innovative work and engineering work more generally compare?*

Based on qualitative in-depth semi-structured interviews, this paper analyzes the work experiences of 13 young engineers in their first years of work after graduating from universities in the United States. Interviewee-reported critical incidents of top and bottom moments, as well as experiences in creating, advancing and implementing new ideas in work, were coded into different dimensions of learning experiences according to Mezirow's [1] transformative learning theory in order to understand better what these experiences comprise. Many positively experienced innovation efforts were related to implementing new features or components to products or process improvements, and collaboration and feedback played an important role in these efforts. Negatively experienced innovation efforts, in contrast, were related to a lack in implementation, solutions and resources. Top and bottom moments were strongly tied to the social dimension of work: top moments were typically related to camaraderie with peers or recognition coming from managers, and bottom experiences with an absence of social connections in addition to falling short of one's own expectations.

The results suggest that managers should be cognizant of the importance of social connections and feedback cycles with their young engineers who are looking for guidance and validation

of their efforts. For educators, the results highlight the importance of equipping our graduates with skills suited to navigate this active, social landscape of engineering practice. There are more challenges to tackle in today's educational settings to prepare students for the collaboration, people-coordination, presentation, and community-building skills they will need in their professional lives.

1 Introduction

Shining a light into the early career experiences of recently graduated engineering students is no easy task. Their professionl pathways are varied even in the first 2-3 years after graduation [2] and engineering work itself is so multi-dimensional that one engineering-intensive setting may not map neatly onto another. Ethnographic research within these workplace settings, to observe real-time projects, assignments, interactions, phone calls, and meetings, is not feasible in many cases. In the absence of dedicated and detailed follow-up research with engineering graduates, workplace ethnographies, or even mutually agreed upon definitions of "engineering" among its practitioners, it can be challenging to know who is "doing engineering", in which way, and where.

That said, in order for engineering programs and industry to best support, retain and advance engineers (not to mention develop products and processes that serve society well), these same engineering programs and industry need a strong understanding of how engineering students apply their skills, develop new ones, and strengthen or change their interests and goals in their first jobs. A growing community of scholars has investigated early work experiences of engineers (e.g. [2], [3], [4], [5]), building on and in concert with larger studies of technical work [6] and industry expectations for new engineering hires [7]. One finding across these studies has been the social dimensions of "real-life" engineering practice; that is, despite the image of technical work being at the heart of an engineer's job, and the primacy of technical skill development in most engineering education environments, professional engineers actually engage in strongly communicative and interpersonal work ([4]; see also [8]). Our current research extends this understanding of "real-life" engineering practice by looking at not only the social, but also the action, emotional, cognitive and contextual dimensions of workplace activities, and by focusing specifically at events that the early career engineering professionals have identified as meaningful.

Beyond exploring the engineering work of early career professionals more generally, we also consider the extent to which they are engaged in innovative work. Our focus on innovation within and around the idea of meaningful work stems from efforts not only in the United States, but also in Europe and beyond, to add skills related to innovation as an important part of engineering learning (e.g., [9], [10]). New engineering hires are not only socialized *into* the existing practices of the workplace [11] but can actively *shape* their organizations through creating, championing and implementing new ideas. Building on top of the operationalization of innovative work in a longitudinal survey study [12] tracking engineering students into the work force, we take creating, championing and implementing new ideas as efforts toward *innovative work* that engineers may engage in at the workplace. We conceive these behaviors to be necessary but not sufficient for innovation – innovations require creating, championing and implementing new ideas, but not all such behavior eventually leads to the introduction of an innovation. Innovation has always been a critical factor of a company's success, especially in today's global markets, where product life cycles tend to be much shorter, organizations face greater challenges staying competitive and are even more encouraged to engage in innovative behaviors.

As employers can no longer rely on a few dedicated innovation champions, managers and experienced colleagues can capitalize on the potential of young, newly joined employees by managing and guiding them effectively [13]. Yet we know little about the factors that influence people's engagement with innovative work, especially in the first few years of their career, and in a field-specific way. Both personal factors and contextual factors interact to encourage or inhibit employees to generate, promote, and realize new and useful ideas in the workplace" ([14], [15], [16], [17]). Interestingly, Simonton [18] described an inverted U-shape, with the peak of creativity at the junior years of university. In contrast, Nager, Hart, Ezell and Atkinson [19] showed that people have their most innovative output (not creative anymore) when they are older – in fact when they are more than 40 years old. These specific findings suggest there are (generationally- and rank-based) workplace realities around innovation that new engineering hires must confront. The current study deepens the investigation into innovation by examining it in the context of meaningful work for individuals just beginning their careers.

Our three specific research questions for this study are:

A. What does *meaningful work* look like in the eyes of early career engineers?

B. What does *meaningful innovative work* look like in the eyes of early career engineers?
C. How do the personal experiences of *innovative work* and *engineering work* compare?

To address these questions, we interviewed 13 new engineering graduates within 1-2 years of completing their bachelors degree, analyzing participant-produced critical work-related incident narratives against a framework of transformative learning [20]. As one of the prominent theories of adult learning, transformative learning describes learning as "the process of using prior interpretation to construe a new or revised interpretation of the meaning of one's experience in order to guide future action" [20]. It offers a useful framework for examining events that have been meaningful for the participants themselves [21] distinguishing between five different dimensions in these experiences:

1) meaningful events in *actions*, reflected in the behavior of the participants (such as trying something new)
2) *socially* meaningful events, where the behavior of others has been experienced as meaningful (such as feedback from peers or examples set by managers)
3) *cognitively* meaningful events, where meaningfulness is derived from one's interpretation of the events (such as surprises or realizations)
4) *emotionally* meaningful events, where meaningfulness in experienced emotionally (such as disappointment or satisfaction in an event), and finally
5) *contextually* meaningful events, where contextual factors are experienced to shape the nature and interpretation of meaningful events (such as organizational policies).

Although the majority of research on transformative learning has focused on formal learning settings such as courses or workshops [21], Clavert and colleagues [22] used the five-dimension framework for making sense of engineering educators' experiences in developing as teachers. We extend this line of research in a workplace context by examining newly graduated engineers' experiences of meaningful work. As a result, we are able to paint a fuller picture on how early career engineers participate at the workplace, with what potential implications for longer-term career pathways and engineering education.

2 Research method

To investigate the experiences of new graduates, a narrative research approach was adopted ([23], [24], [25]), building on critical incidents [26]. Evidence suggests that personally important incidents are more likely to be remembered than less significant ones, reducing retrospective bias ([25], [26]). Furthermore, they allow the participants to select and focus on what they have experienced as meaningful, rather than the interviewers imposing their judgment and interpretation of what is relevant or not in the situation. As such, the approach is well suited for studying experiences from the perceptive of those who experience them – in our case, work experience as experienced by early-career engineers themselves.

2.1 Participants

The wider scope of this study comes from a larger research project, called "Engineering Major Survey", of Epicenter and the Designing Education Lab of Stanford University [12]. This research larger project is being conducted at 27 engineering schools in the United States, with an annual survey deployed since 2015. Among all 27 participating universities, four universities were selected for the sample of this paper based on the size of the subsample of respondents that reported having graduated and started in a full-time job in their 2016 survey response. This paper is based on the interviews of 13 such graduates, with bachelor degrees from computer science, computer engineering or electrical engineering. Three participants were female and the remaining 10 males. See Table 1 for an overview of the participants.

Table 1. Overview of study participants

Name	Degree	Current work position
Alan	Electrical/Electronics /Communications Engineering	Rotational Program in Communications Engineering
Alex	Computer Science	Software Engineer
Andrew	Electrical/Electronics /Communications Engineering	Product Line Engineer / Sales Engineer
Bob	Computer Engineering	Software Engineer in Networking
Daniel	Computer Science	Software Engineer
Julian	Computer Science	Deployment Engineer
Katie	Computer Science	Starts as Product Manager, previously Software Engineer
Matthew	Computer Engineering	Embedded System Engineer
Pamela	Electrical/Electronics /Communications Engineering	Project Manager in Engineering
Paul	Computer Engineering	Currently looking for job, before Sales Engineer

Rosie	Computer Science	Kernel Developer, previously Performance Analyst
Tim	Computer Science	Web Application Engineer
Victor	Computer Science	Software Engineer

2.2 Data collection and analysis

The interviews were conducted through Skype or - if possible - in person. Most of the interviews lasted between 30-40 minutes. The interview structure was built around the critical incident method [26], which makes it possible to explore participant-selected meaningful events in an interviewee's experience. The majority of the interview was devoted to going through the top and bottom three moments of the participants in their employment so far, and a positive and negative example of innovative work efforts. Innovative work efforts were operationalized as experiences in "creating, championing or implementing new ideas", building on top of the survey items utilized in the wider EMS study [1]. In addition to prompting for critical incidents in these three types of experiences, the participants were asked whether they considered their position as innovative, whether their views on innovation had changed, their future plans and reflections on their education. The questions from the interview protocol were tested in three pilot interviews with graduate students from a private university prior to data collection.

The interviews were analyzed in three ways. First, the top, and bottom experiences as well as innovative work efforts reported in the interviews were segmented and coded into five different dimensions: cognitive, emotional, social, contextual, and action-related dimensions based on the types of significant events in transformative learning [1]. The experiences were broken down into sufficient detail to allow each segment to be coded into only one dimension, as typically these experiences comprised multiple dimensions. These segments were then categorized according to thematic similarity [27] within each dimension of an experience type. The categories and the segment distributions are shown below in Table 2.

Second, the top and bottom experiences and innovative work efforts were categorized according to thematic similarity [27]. The resulting categories, as related to Innovation Experiences are shown in the Results section in Tables 3A and 3B.

Finally, in the third step, distributions of dimension sub-categories within innovative work efforts were compared to the dimension subcategories within top and bottom moments.

3 Results

Among the 13 interviews, over 650 meaningful elements/components of the reported experiences were identified. These events were previously categorized into the five different dimensions of significant events in transformative learning [1] : social (n=206), action (n=192), cognitive (n=121), emotional (n=82) and contextual (n=50) segments in meaningful events at the workplace. Furthermore, data-driven subcategories were defined based on thematic similarities. Table 2, below, shows these distributions.

Of the five transformative dimensions, more than half the codes are situated in the social (n=206) and action (n=192) dimensions. In the next section (3.1) we focus on illustrating the dimensions in terms of top and bottom moments. Then in section 3.2 we consider what our interviewees told us about their self-identified innovative experiences where they were involved in creating, championing implementing new ideas, and how the dimensions come into play here.

Table 2. Frequencies of dimensions and their subcategories in meaningful events in different types of experiences

Dimension (n)	**Subcategories (n)**	**Type of experience**		
		Top moment	**Bottom moment**	**Innovative work efforts**
Social (206)	Collaboration (101)	27	14	60
	Communication (35)		5	30
	Getting feedback (35)	7	4	24
	Social context (32)	12	14	6
	Other role-related (3)		3	
	Total	*46*	*40*	*120*
Action (192)	Development action (individual & collaborative) (87)	10	6	71
	Preparing and exploring (27)	3		24
	Communication (13)	5	4	4
	Challenges (25)		11	14
	Changing role (19)	7	7	5
	Other (time, help & advising, interaction with clients, completing project/task) (21)	11	2	8
	Total	*36*	*30*	*126*
Cognitive (121)	Realizing problems, needs & solutions (40)	2	9	29

	Learning (16)	9	1	6
	Motivation: interest and value (15)	8	7	
	Development attitudes (19)	2	9	8
	Planning (7)			7
	Perceived space to act (13)	4		9
	Understanding users/clients (7)			7
	Surprises (4)			4
	Total	*25*	*26*	*70*
Emotional (82)	Enjoyment (positive emotions) (16)	13	1	2
	Lack of enjoyment (negative emotions) (13)	1	8	4
	Positive emotions resulting from effectiveness (28)	15	2	11
	Negative emotions resulting from (potential) lack of effectiveness (25)	2	14	9
	Total	*31*	*25*	*26*
Contextual (50)	Available technology (23)			23
	Available time (10)	1	1	8
	Opportunities to act (or lack thereof) (7)	1		6
	Inspiring training (2)	2		
	Other (8)	1	1	6
	Total	*5*	*2*	*43*
Total		**143**	**123**	**385**

3.1 Meaningful work interpreted in terms of transformative dimensions of adult learning

Some 36 top moments and 29 bottom moments were recorded in the interviews. Top moments fell under the broad themes of Community and Camaraderie (n=10), Management Recognition and Social Validation (n=9), Completing Work and Implementing Changes (n=7), Expanding and Renegotiating Responsibilities (n=5), and Seeing the Impact and Implementation of Improvements (n=5). Bottom moments fell under the broad themes of Mistakes and Falling Short of Own Expectations (n=10), Lacking Social Connection (n=8), Efforts Blocked/Stalled (n=5), Uninteresting or Unpleasant Tasks (n=4), and Negative Feedback (n=2).

We now look at these moments in terms of Mezirow's [1] five dimensions of transformative learning. To include more contextual information, the quotes presented are longer than individual segments, and may thus include elements from several dimensions.

3.1.1 Social Dimension of Top and Bottom Moments

Social Elements in Top Moments: Considering the **social dimension**, the subcategory of *collaboration* makes up more than half (27) of the 46 segments found in socially-related top moments, as seen in Table 3. Collaboration examples found in top moments include positive interactions, leading a team, networking, attending conference together, customer interaction, and feeling heard and needed. On this latter point, Tim describes for example that he became the go-to-guy for a certain area: *"So, now I'm kind of the "go-to" person for Cloud architecture advice. And it's kind of nice to [unclear] feel needed in that regard, to be the person people go to, so I like that."*

Positive feedback (7 reported instances in top moments) included reports of management recognition, social validation and receiving promotions. Tim also described another project where he got great feedback after showing it to the rest of the team: *"High moments being like when our optimizer project worked, and we were like, "Holy crap, it works!" And then, we got to show it to people and be excited about it. Because this thing that only two or three people really knew about was actually working, and it was like kind of our little secret, and now everybody got to know about it."*

Social Elements in Bottom Moments: Based on the 40 socially-related instances found in personal bottom moments, over a quarter of them were associated with the social context of the situation and included changes in team make-up or poorly managed disagreements. This subcategory also includes making mistakes that had an adverse effect on other' ability to complete their work in the organization. Daniel described for example others having to wait while he was trying to bring the site he had crashed back to operating: *"There's been several times where changes of mine have directly affected our production website in a negative way. […] I was also up all night trying to fix it. So, that was a particularly low moment."*).

A significant number of the bottom moments were associated with collaboration, where interviewees mentioned moments related to losing or lacking good social connections within the company or experiencing trouble in interpersonal relationships. For example, Alex describes his positive relationship with some coworkers even in the midst of a moment that was negative overall: *"And the people I was working with were super, super smart, and that was awesome. But it also felt like I was kind of only using one part of my brain, like the*

highly mathematical and technical side, and not really the social part or the creative part as much.“

Some reported about communication problems or challenges with managers or coworkers, for example when a manager pulled Bob from a project he said: *“And I’ve gone to my manager and I’m like, “Hey, if you do not give me the opportunity to stay with the project long enough to learn it well […] the next time you need me for something like this, I’m not going to know how to do it again.”*

Further social instances in bottom moments were when their efforts were somehow blocked or stalled by others in the organization. Tim described his frustration from the negative reaction of his manager: *“A low point to me is that I did spend a good portion of this year working on the charting library that I was very happy with, come the end of spring. And now he wants me to completely rewrite it.”*).

A few interviewees reported getting negative feedback as one of their bottom moments. For example, Matthew lamented a product launch: *“We finished it, and we actually certified it, and we got our software through the FAA. And on that same day, we had somebody that they wanted to…they had a defect against it that came out. The day we finished it, they said, “Something doesn’t work” as they wanted it to. And it’s not that it’s…it’s not unsafe or not functional in any capacity.”*

3.1.2 Action Dimension of Top and Bottom Moments

Now we consider the **action dimension** of top and bottom moments, and the associated subcategories that are shown in Table 2.

Action Elements in Top Moments: In instances relating to action, development action stands out. These were instances of creating, championing and implementing new ideas, such as making improvement suggestions or working on a new product design. As these experiences were specifically prompted for in the interviews, their prevalence was to be expected in the data overall, however, they were also spontaneously reported in the top (and bottom) moments. Examples included releasing a big product feature, or successfully chain-loading software

through multiple storage devices. Innovative work efforts are described in more detail in Section 3.2.

There were also seven instances related to changing roles, while gaining responsibility. Katie for example took the project over during a leave of absence of here coworker: "*So, one of my teammates was supposed to be working on that, but then she took a leave of absence for like three months, so then, I took over everything that she was doing."*

Action Elements in Bottom Moments: Many interviewees listed changing roles or responsibilities in doing uninteresting/unpleasant work among their bottom moments. Additionally, some bottom moments included elements of the interviewees communicating to others in the organizations (overlapping with social elements). For example, Bob confronted his manager after being pulled from a project: *"And I've gone to my manager and I'm like, "Hey, if you do not give me the opportunity to stay with the project long enough to learn it well […] the next time you need me for something like this, I'm not going to know how to do it again."*

3.1.3 Cognitive Dimension of Top and Bottom Moments

Some 51 instances related to top and bottom moments fall under the **cognitive** dimension. Its subcategories created for this work that are shown in Table 3, and include realizing problems, learning and motivation.

Cognitive Elements in Top Moments: Among the top moments, the largest groups of coded cognitive elements came from learning (n=9) and motivation: interest & value (n=8). An example related to learning is when Tim was continuously challenged with new tasks and through that learned new things: *"They're constantly challenging me, which is good. I'm constantly learning from that."*. Examples related to motivation included elements such as seeing the value and impact of one's own efforts and getting confirmation. Daniel described his excitement of also interviewing candidates: *"It is part of my job but I always thought of this job as just writing code, but there's this other side to it that involves recruiting and interviewing candidates and stuff "*.

Cognitive Elements in Bottom Moments: In the personal bottom moments, there were equal numbers of instances related to realizing problems, and outlooks on development (both n = 9).

Examples include Alan describing the problems of his company: *"I guess just like bureaucracy and politics of a huge company operating in a huge city, and stuff like that. It's frustrating, because sometimes I'm like, "Well, why can't we just do this?"* Also mentioned was development outlook; again in Alan's case he reported perceiving refactoring code as useless: *"[…] So, just the extra time and effort it would take to really make things more efficient, sometimes you're just like, "Eh, why bother, really?".*

3.1.4 Other Dimensions of Top and Bottom Moments

We also see instances within top and bottom moments that fall in the dimensions of **emotional** and **contextual** dimensions. Interestingly, the combined number of emotion top moments falling in enjoyment and positive emotion (combined n=28) is just slightly more than the comparable number of emotion bottom moments that fall in lack of enjoyment and negative emotion (combined n=22). The positive emotions included emotions such as being proud, satisfied or inspired by successful efforts, and more general enjoyment in their roles, such as having fun and enjoying their work. Alex reported about a camping trip he organized: *"I think, was like two or three weeks after I joined I organized a little camping trip for everybody, like for the six of us who worked there. And it was really fun*.".

Interviewees also reported negative emotions resulting from a lack of effectiveness or unchallenging work. Julian, for example, reported the following: *"And at the time, I was asked to do a role where it is less intellectually fulfilling and more oriented towards like the "grunt work," I guess you might say of making like a large IT infrastructure. Which is not something that I was interested in doing, but I sort of begrudgingly took it on because I was still very young at the company".*

3.2 Meaningful Innovative Work Efforts

In the prior section we talked about how early career engineers described top and bottom work experiences, and how those experiences could be broken down in terms of Mezirow's five dimensions of learning. Now we consider what these same engineers talked about experiences that were focused specifically on innovative work efforts, asking them to identify both positive and negative experiences in creating, championing and implementing new ideas. We first describe the general topics of their positive and negative innovative work efforts and include specific examples. Then we consider how these experiences represent the

five dimensions of learning, including how innovative instances compare with those present in top and bottom moments.

3.2.1 Reported Innovative Work Efforts

We found that 13 interviewees reported a total of 16 positive examples of experiences in innovative work efforts, as shown in Table 3A (some interviewees reported two). The reported innovation experiences show a focus on experiences where the interviewees were directly working on the implementation of a new or improved product or process (10 out of 16 good innovation experiences in total). Innovation experiences reported as "good" were, for example, when a company pursued the development of something based on the suggestions of an employee or an employee was allowed to pursue an improvement (e.g. Alex: *"And people were receptive, so we made a mobile app, and that was fun, and that felt like a moment when I kind of had an idea and we talked about it and decided that it was a good idea and rolled with it."*).

Table 3A. Overview of Positive Innovative Work Experiences

Name	**Positive experiences in innovative work**
	Efforts Description
Coming up with and implementing product improvements	
Alex	Collaboratively building a mobile app on his idea. Implemented a new way for hiring people.
Pamela	Came up with an idea, which is being patented now
Paul	Developing a new product feature at a new company
Matthew	Came up with a new solution after a problem occurred.
Tim	Developed an idea which will launch soon as an individual product.
Coming up with and helping to implement process improvements	
Alan	Helped to automate reports; Implemented a new way to deliver his service
Andrew	Saw more process improvements
Daniel	Proposing sampling the phone testing with own cell phones; proposed to upgrade to a new software development kit. Rewrote code to make it work.
Victor	Dividing work into smaller teams to make development smoother
Social appreciation for well-executed improvements	
Bob	Developed a new training manual and got great feedback
Rosie	Took over a project and was well accepted
Seeing the end results and usefulness of own process and product improvements.	
Julian	Development project for a company in Asia went great.

Katie	Rolling out a new tool in organization, figuring out why people weren't using it and managing to increase usage.

For some interviewees, social appreciation (e.g., getting recognized for the work) seemed to be important and was considered a positive innovation experience (Rosie, Bob, Alan). Three of the innovation experiences mentioned were in a social context and involved for example customer or colleague feedback (e.g. Rosie: *"So, in my previous team, we were a data analysis team, and I […] came up with an idea to analyze individual events during a test. […] So, I took on that project myself, and I implemented it myself. […] And it had really good acceptance. Like, one of my variations is currently being used by one of the performance analysts.")*.

Sixteen reported "less than ideal" innovative work efforts were reported by the interviewees (Table 3B). Nine of these were related to the end result or lack thereof of the efforts: five negative innovation experiences were about improvements did not get implemented (Andrew, Bob, Julian, Paul and Rosie), and a further four negative innovation experiences were a result of participants being unhappy with the end results of their own work (Alex, Daniel, Pamela and Tim). For example, Daniel described: *"We thought that the product was fundamentally better with that improvement, but we really never reached out to anybody to check. And so, it wasn't until they had it in their hands that we realized that they did not want it, but at that point, we had already done all the work."*.

Table 3B. Overview of Negative or Neutral Innovative Work Experiences

Name	**Negative or neutral experiences in innovative work**
	Efforts Description
Discontinued projects and improvements not getting implemented	
Andrew	Started something that was discontinued because priorities changed.
Bob	Had technical problems and couldn't immediately start working on a project, ultimately got pulled off project
Julian	Developed solution did not get applied at the client in the end
Paul	Project was been left incomplete.
Rosie	Intern project was an experiment which was not used later; worked on a project and there were bugs in the script.
Less-than-hoped-for results	
Alex	Made a bad engineering decision
Daniel	Developed a feature for the users which wasn't received well.
Pamela	Idea did not end up technically working.

Tim	Wrote bad code and had to do a lot of hacky fixes which were less than ideal.
Operating under constraints and limitations	
Alan	Having to implement non-ideal solutions, difficult to change processes or a large corporation
Katie	Too tight schedule and unrealistic management expectations; when started, had lot of ideas but quickly learned that they outside team's "jurisdiction"; tools/programs constraints what can be done and what cannot.
Technical difficulties	
Matthew	Had a problem that couldn't be solved until somehow else with a deeper knowledge came up with the solution.

Two "less than ideal" efforts in innovative work involved a realization of the constraints on one's own work (Alan and Katie). Katie for example said: *"I think when I first started I had more ideas about things we could do and things we could change, but after kind of seeing how they couldn't be implemented and just kind of learning more about the constraints of my team and how limited we were, as the more and more time I spent there, it kind of became like, "Oh, I know we can't do that."* Finally, one experience (Matthew) was related to frustration with difficulties in locating the source of problems in a development project.

3.2.2 Innovative Work Efforts Dissected in Terms of the Five Dimensions---Initial Analysis

Revisiting Table 2, we can see that the two most numerous dimensions (social and action elements in the experiences), meaningful events were more likely to be associated with involvement in innovative work efforts, than the top and bottom moments combined (120 social segments in innovative work efforts vs 86 in top and bottom moments combined; 126 action segments in innovative work efforts vs 66 in top and bottom moments combined).

Noteworthy is that many of the **social instances** within innovative work efforts were connected to collaboration (n=60); such as ideating together with one's team or coworkers, developing solutions together, having a good team, or getting help (Rosie, Daniel, Pamela, Julian). Many of the **action instances** within innovative work efforts fell into developing actions (n=71), and include bringing ideas to managers, suggesting ideas (e.g. Daniel, Rosie, Alan, Julian, Bob Tim, Alex), or developing and changing ideas (Bob, Daniel, Rosie, Julian, Pamela, Tim, Matthew, Paul, Katie, Alex, Andrew).

There are clearly fewer cognitive and contextual instances within innovative work efforts, as compared to the social and action dimensions. Within the **cognitive instances** within

innovative work efforts the largest subcategory was realizing problems, needs and solutions (n=29). Victor for example described his experiences related to professional skills: *"I think in terms of people, one thing that I really…I realized when I started working here is that people skills are a lot more important than most people think for engineering jobs, especially computer science."* Participants also reported for example learning specific technical skills or learning the limits of one's "turf" in development efforts.

The **contextual instances** were found almost exclusively within innovative work efforts (n=43), rather than in the described top and bottom moments (n=7). Most of these cognitive instances were related to available technology and technical resources (n=23), such as having to deal with "crappy code" or technically challenging assignments (Tim, Paul, Matthew, Andrew). Eight interviewees described lacking time. Matthew for example described a project with tight time constraints.

Within innovative work efforts, **emotional instances** were the least numerous of the five dimensions (n=26). The largest category within this dimension was positive emotions resulting from effectiveness (n=11). For example, Julian described getting his improvement working as *incredible*, Rosie reported being *proud* of her work, and Matthew described feeling *confident* of his input. On the other hand, the interviewees also reported being *frustrated* with a lack of effectiveness and *nervous* about potential effects of their efforts (n=9). We note that over twice as many emotional instances were present in top and bottom moments (n=56), as in innovative work efforts – likely due to the differences in the prompts through which these experiences were obtained in the interviews (asking for salient top and bottom experiences).

3.2.3 Innovative Work Efforts Dissected in Terms of the Five Dimensions---A Closer Look at Connections Within a Single Example Experience

The analysis of the innovative work efforts presented in the prior section involved dissecting each reported experience into its dimensional parts, then taking counts of how those parts sum over all of the identified experiences. This allowed us to see that the social and action dimensions of learning are most present in the reported innovative work efforts (relative to the other three dimensions), and these experiences are filled with many more instances in four of the five dimensions than were top and bottom moments (the exception was the

emotional dimension). What that initial analysis fails to show is how these dimensions are present and interact within a *single* experience of innovative work efforts. A complete analysis of this sort on is beyond the scope of this paper; however, we present an illustrative example to show that the instances of the five dimensions do happen within an innovative work experience.

Consider the positive experience of Alex in innovative work efforts, as summarized in Table 4A. All five dimensions are present, and in the case of, for example, the social dimension, multiple aspects with a social element happen. When we look at the narrative around Alex's positive experience, we can see, for example, that he was involved in collaboratively building a mobile app. During this experience, which he worked on together with his coworkers, he experienced many instances of collaboration, communication or getting feedback within the social dimension. At the same time, since he was actively involved in the innovation effort, we saw a strong representation of the action dimension, especially development actions and preparing and exploring. Overall this innovation experience seemed to really make him happy and we saw how he reported having enjoyed working on this project.

Table 4A. Overview of Positive Experience of Innovative Work Efforts by Alex with Dimensional Details

Innovation Description	**Dimensions of meaningful events within the experiences and their sub-categories**
Collaboratively building a mobile app on his idea.	Social: collaboration, communication, getting feedback; Action: development actions, preparing and exploring, other; Cognitive: perceived space to act; Emotional: enjoyment; Contextual: available technology, opportunity to act, available time

Table 4B. Overview of Negative Experience of Innovative Work Efforts by Daniel with Dimensional Details

Innovation Description	**Dimensions of meaningful events within the experience and their sub-categories**
Developed a feature for the users which wasn't received well.	Social: collaboration, getting feedback; Action: development actions, preparing and exploring; Cognitive: understanding users/clients; Contextual: available time

The case of Daniel's not-so-positive experience is summarized in Table 4B, and again shows that multiple dimensions are present. When we look at the narrative around Daniel's negative experience we see that he showed also, like Alex above, indicators of social collaboration or getting feedback. Furthermore, he was also involved in development actions and preparing and exploring. This is due to the nature of the innovation experience, that he also was actively involved in the development of a feature which wasn't received well.

These examples start to illustrate the interaction of the dimensions in making up a meaningful (in this case innovative work effort) event. While offering limited information on what triggers moving from one dimension to another, what we see is evidence that these dimensions somehow make-up an experience. We come back to this point in the final section the paper.

4 Discussion and Implications

Aiming to gain more knowledge about how early career engineers are engaged in meaningful work and innovation activities, we analyzed the experiences of 13 newly graduated software and computer engineers. All of the interviewees shared some of their top and bottom moments so far, and could also name examples of creating, championing or implementing something new at their workplace. Many of the positive experiences within innovative work efforts that the early career engineers described were related to implementing new features or components to products or process improvements. Some interviewees valued seeing the impact of one's efforts and the good feedback they had received, and valued management recognition and social validation as top moments. Half of the negative experiences in innovative work efforts, in contrast, were related to self-assessed shortcomings in the end result. The other half were related to stalling efforts or realizing constraints in the scope of one's work.

The work these early career engineers described contained all five of Mezirow's [1] transformative learning dimensions (social, action, cognitive, emotion, and contextual events), regardless of whether they were describing their self-identified top moments, bottom moments, or instances where they were positively or negatively engaged in innovative work efforts, That said, social, action and cognitive were much more present than the emotional and contextual dimensions. The cognitive dimension, made up of such subcategories as

learning and realizing problems, needs and solutions, is not surprising; engineering is considered a profession based on specialized knowledge as well as the need to continue learning beyond schools. This is even seen in the ABET learning outcomes for engineering programs (e.g., 3.k an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice, and 3.i a recognition of the need for, and an ability to engage in life-long learning). The strength of the action dimension is also not surprising, as engineering is commonly characterized being focused on "problem solving"; here again, ABET outcomes reinforce that notion (e.g. 3.e an ability to identify, formulate, and solve engineering problems; 3.b an ability to design and conduct experiments, as well as to analyze and interpret data; 3.a an ability to apply knowledge of mathematics, science, and engineering).

That the social dimension is so prevalent is consistent with prior research (e.g., [4]). What may be surprising is that this social dimension is so multifaceted, ranging from collaboration, to communication, to social context. Here, when we consider ABET learning outcomes, there is only one that directly (or indirectly) refers to engineering being such a social enterprise. We come back to this point when considering implications for our work for engineering education.

The experiences of the graduates highlight the importance of perceiving one's efforts as bearing fruit. Many top moments had to do with expanding one's responsibilities and seeing the impact of one's work, while many bottom moments on the job had to do with discontent with a lack of impact or limited scope of tasks. However, assessing the impact of one's work can be challenging especially with limited previous experience. Managers can thus play a significant role in connecting the dots for their employees. As one interviewee described: *"My manager last year, he was just like, 'So, how do you think you did this year?' And I was like, 'You know, I think I did all right, but I definitely could have been better. I could have done this better, I could have done this better.' And then, having him just be like, 'Well, I think you did an amazing job!' Like just being told that, despite if I think maybe I screwed something up, just being like, 'Well, we understand that you just graduated. We understand that this is your first full-time job, and you did a really good job with it'."*

Hence, we propose that based on our findings from early career engineers' the definition of innovative work experiences, cannot only be limited to creating, championing and

implementing ideas. For the innovation efforts of these young engineers it also involved peer/organizational validation/embeddedness ("social appreciation") and technical blocks/false starts (the bottom aspects).

4.1 The Importance of Feedback & Camaraderie

As the above quote illustrates, feedback can be an important part of the social-fabric of engineering work. In fact, one particularly salient, and somewhat unexpected, finding from our research was just how important feedback is to the social aspect of meaningful moments. For example, management recognition and social validation (two types of feedback) were consistently reported as top moments. Previous research suggests that such managerial actions can improve an employee's creative performance significantly, which in turn supports both better implementation of new ideas, as well as better idea generation and experimentation ([13], [28], [29]). This points to the importance of feedback cycles of management with their early career engineers who are looking for guidance and validation of their own work. Early career employees are typically open to feedback [30], compared to more experienced colleagues who might be less willing or find it more difficult to change already ingrained ways of doing things [31]. Indeed, many interviewees in this study reported feedback among their top and bottom moments, particularly from their managers. Feedback is a critical part of the social aspects of innovative and meaningful work, and must be attended to when we think about how early career engineers do or do not engage in assigned roles, responsibilities, and new ideas and opportunities.

It should be noted, however, that it is not only the manager employee-relationship that is important; colleagues can also have an immense influence on the social development of a early career employee if they are well integrated into a team inside the company. Some of those interviewed highlighted camaraderie rather than positive feedback among their top moments, (potentially due to a lack of such feedback).-Similarly, many bottom moments were related to missing good social connections at work, interpersonal difficulties or falling short of others' expectations. This is in line with previous argument [32] for a strong connection between an employee's technical engineering skills as well as their ability to collaborate as a team player, which could be taught already in undergraduate engineering programs. One practical implication should therefore be that managers should put effort on a good working culture for these young employees like e.g. company or team building events.

For example, Alex described organizing a camping trip with his team as one of his top moments so far: "*I think, was like two or three weeks after I joined I organized a little camping trip for everybody, like for the six of us who worked there. And it was really fun.*"

4.2 Implications for Engineering Education

The results of the study focus on engagement in meaningful work and the importance of feedback and camaraderie to early career engineers, the roles of managers and peers in providing constructive feedback, building working environments of trust and collaboration, and seeing one's work efforts bear fruit. One could substitute "research supervisor" for any instance of manager in these results and have the implications extend to an engineering educator supervising the work of undergraduate and graduate students alike.

A further implication for engineering education relates to the significant role that social interaction plays in getting engineering work done, as illustrated in this study and by others before us. Engineering education could do more to help graduates learn to, for example, successfully collaborate with a variety of people, how to be part of building a work environment that fosters and values innovative ideas, and how ask for, receive and implement feedback. The social dimension of engineering work is complex, and many engineering programs focus only on a small piece of it in design project work. *How might we think about helping our students learn more about social engagement, even in more traditional problem-set courses, with strategies such as active learning?* A main implication for engineering education is that we can do more to help our students thrive in the "social soup" that is engineering.

4.3 Implications for Future Engineering Research

The small sample size of 13 software-related graduates of U.S. institutions working primarily in the United States means that the current results cannot freely be generalized into all young engineers. For example, graduates from only four universities were interviewed in this study. All of these universities had large innovation and entrepreneurship programs in place, and their graduates might have been more interested in innovation or have different expectations of their work than students from universities without such programs, or for example community colleges. Furthermore, our 13 graduates were allowed to self-identify what constituted "creating, championing or implementing new ideas" to them (which we, by extension, called "innovative work efforts"). Some implications for future research are:

- Consideration of more types of engineering majors and universities (inside and outside of the United States) in relation to meaningful work and innovation engagement;
- Comparison of the self-identified innovative work efforts of these 13 individuals with innovation activities and behaviors where the degree of novelty and creativity is taken into consideration.
- Evaluation of how the perceptions of these 13 individuals as to what constitutes innovative work changes with time.
- More detailed study of how the five dimensions of meaningful events within potential transformational learning [1] experiences interact, and which type of instances are likely to lead to subsequent learning.

In addition, the prominent role of feedback in the current study suggests that it warrants further examination in understanding how it works for newly graduated engineers in the workplace, especially for engineers who come from diverse backgrounds and do not "fit the mold" of people who are typically promoted to leadership positions within an organization. Bias in performance evaluations and feedback mechanisms could reinforce larger patterns of underrepresentation in engineering and demand closer attention at the earliest career stages (see [33], [34], [35]) for windows into this type of bias in technical work settings). Future research also could explore the effectiveness of various feedback constructs and opportunities, such as different forms of personal development discussions, mentoring systems or team building practices within a company, in encouraging innovative work behavior.

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6. References

[1] Mezirow, J. (1991). *Transformative dimensions of adult learning*: ERIC.
Mezirow, J. (1996) Contemporary Paradigms of Learning. Adult Education Quarterly, 46, 158–172.

[2] Sheppard, S. D., Antonio, A. L., Brunhaver, S. R. and Gilmartin, S. K. (2014). Studying the career pathways of engineers: An illustration with two datasets. In A. Johri and B. M. Olds (Eds.), Cambridge Handbook of Engineering Education Research (pp. 283-309). New York, NY: Cambridge University Press.

[3] Brunhaver, S. (2015). Early Career Outcomes of Engineering Alumni: Exploring Their Connection to the Undergraduate Experience (Doctoral dissertation). Stanford, CA: Stanford University.

[4] Brunhaver, S. R., Korte, R. F., Barley, S. R. and Sheppard, S. D. (forthcoming). Bridging the gaps between engineering education and practice. In R. Freedman and H. Salzman (Eds.), U.S. Engineering in a Global Economy. National Bureau of Economic Research.

[5] Korte, R., Sheppard, S., and Jordan, W. (2008). A Qualitative Study of the Early Work Experiences of Recent Graduates in Engineering. In Proceedings of the American Society for Engineering Education Annual Conference, Pittsburgh, Pennsylvania, June 22–25.

[6] Barley, S. R. (2005). What we know (and mostly don't know) about technical work. In S. Ackroyd, R. Batt, P. Thompson, and P.S. Tolbert (Eds.), The Oxford Handbook of Work and Organization (pp. 376-403). Oxford: Oxford University Press.

[7] Salzman, H., and Lynn, L. (2010). Engineering and engineering skills: What's really needed for global competitiveness. Paper presented at the Association for Public Policy Analysis and Management Annual Meetings, Boston, MA, November 4.

[8] Trevelyan, J. (2010). Reconstructing engineering from practice. Engineering Studies, 2(3), 175 -195**.**

[9] Byers, T., Seelig, T., Sheppard, S., & Weilerstein, P. (2013). Entrepreneurship: Its role in engineering education. *The Bridge, 43*(2), 35-40.

[10] Epicenter. (2018). About Epicenter. Retrieved March 15, 2018 from http://epicenter.stanford.edu/page/about .

[11] Gilbuena, D.M., Sherrett, B.U., Gummer, E.S., Champagne, A.B. and Koretsky, M.D. (2015) Feedback on professional skills as enculturation into communities of practice. Journal of Engineering Education, 104(1), 7-34.

[12] Gilmartin, S.K., Chen, H.L., Schar, M.F., Jin, Q., Toye, G., Harris, A., Cao, E., Costache, E., Reithmann, M., & Sheppard, S.D. (2017). Designing a Longitudinal Study of Engineering Students' Innovation and Engineering Interests and Plans: The Engineering Majors Survey Project. EMS 1.0 and 2.0 Technical Report. Stanford, CA: Stanford University Designing Education Lab.

[13] Amabile, T. M., Schatzel, E. A., Moneta, G. B., & Kramer, S. J. (2004). Leader behaviors and the work environment for creativity: Perceived leader support. The Leadership Quarterly, 15(1), 5-32.

[14] Ford, C. M. (1996). A theory of individual creative action in multiple social domains. *Academy of management Review, 21*(4), 1112-1142.

[15] Janssen, O. (2005). The joint impact of perceived influence and supervisor supportiveness on employee innovative behaviour. *Journal of occupational and organizational psychology, 78*(4), 573-579.

[16] Oldham, G. R., & Cummings, A. (1996). Employee creativity: Personal and contextual factors at work. *Academy of Management journal, 39*(3), 607-634.

[17] Woodman, R. W., Sawyer, J. E., & Griffin, R. W. (1993). Toward a theory of organizational creativity. *Academy of management Review, 18*(2), 293-321.
[18] Simonton, D. K. (1983). Formal education, eminence and dogmatism: The curvilinear relationship. *The Journal of Creative Behavior, 17*(3), 149-162.

[19] Nager, A., Hart, D. M., Ezell, S., & Atkinson, R. D. (2016). The demographics of innovation in the United States. *ITIF. Web-version:* http://www2/. *itif. org/2016-demographics-of-innovation. pdf*.

[20] Mezirow, J. (2000). Learning to think like an adult: Core concepts of transformation theory. In Mezirow, J. et al. (Eds.) Learning as transformation: Critical perspectives on a theory in
progress. The Jossey-Bass Higher and Adult Education Series. San Francisco: Jossey-Bass Publishers, 3– 33.

[21] Taylor, E.W. (2007). An update of transformative learning theory: A critical review of empirical research (1999-2005). International Journal of Lifelong Education, 26(2), 173-191.

[22] Clavert, M., Björklund, T.A. & Nevgi, A. (2014). Developing as a teacher in the fields of science and technology. Teaching in Higher Education 19(6), 685-696.

[23] Chase, S. (2005). Narrative inquiry: Multiple lenses, approaches, voices. Teoksessa Denzin, NK & Lincoln, YS The Sage handbook of qualitative research: Thousand Oaks, California, Sage Publications.

[24] Connelly, F. M., & Clandinin, D. J. (1990). Stories of Experience and Narrative Inquiry. *Educational Researcher, 19*(5), 2-14. doi:doi:10.3102/0013189X019005002

[25] Webster, L., & Mertova, P. (2007). *Using narrative inquiry as a research method: An introduction to using critical event narrative analysis in research on learning and teaching*: Routledge.

[26] Flanagan, J. C. (1954). The critical incident technique. *Psychological bulletin, 51*(4), 327.

[27] Braun, V. and Clarke, V. (2006), “Using thematic analysis in psychology”, Qualitative

Research in Psychology, Vol. 3 No. 2, pp. 77-101.

[28] Mumford, M. D., Scott, G. M., Gaddis, B., & Strange, J. M. (2002). Leading creative people: Orchestrating expertise and relationships. *The Leadership Quarterly*, 13(6), 705-750.

[29] Shalley, C. E., & Gilson, L. L. (2004). What leaders need to know: A review of social and contextual factors that can foster or hinder creativity. *The Leadership Quarterly*, 15(1), 33-53.

[30] Thompson, C., & Gregory, J. B. (2012). Managing Millennials: A framework for improving attraction, motivation, and retention. *The Psychologist-Manager Journal, 15*(4), 237.

[31] Larson, J. R. (1989). The dynamic interplay between employees' feedback-seeking strategies and supervisors' delivery of performance feedback. *Academy of management Review, 14*(3), 408-422.

[32] Passow, H. J. and Passow, C. H. (2017), What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review. *J. Eng. Educ.*, 106: 475–526.

[33] Correll, S. (2017). Reducing gender biases in modern workplaces: A small wins approach to organizational change. *Gender & Society,* 31(6), 725-750.

[34] Correll, S., & Simard, C. (2016, April 29). Research: Vague feedback is holding women back. *Harvard Business Review.* Retrieved March 17, 2018 at https://hbr.org/2016/04/research-vague-feedback-is-holding-women-back

[35] DiTomaso, N., C. Post, D. Randall Smith, G. F. Farris, R. Cordero. (2007). Effects of Structural Position on Allocation and Evaluation Decisions for Scientists and Engineers in Industrial R&D. *Administrative Science Quarterly*, 52 (2), 175 - 207