A New Mixed-methods Study of Learning-at-disturbance in Experienced Designers

Xiao Ge, Stanford University, xiaog@stanford.edu
Larry Leifer, Stanford University, leifer@stanford.edu
Linlin Shui, Communication University of China, cucsll@cuc.edu.cn

Abstract: We propose and validate a new mixed-methods approach that enables micro-level analysis of knowledge construction as well as high-level understanding of learning dynamics across person, space and time. The learners being examined here are experienced designers who exhibit adaptive expertise of reconstructing knowledge and adjusting behaviors in situation. To study this learning process of designers, first, we draw on theories of disturbance-based learning and identify high-arousal moments, or high-learning potentials, by capitalizing on unobtrusive emotional arousal measures of vocal pitch and electrodermal activity. Next, designers' learning at disturbance is characterized and understood through contextualization and triangulation with video observation and retrospective self-report using distributed views of learning. Together, our work shows how physiological measures such as voice could be integrated into the study of situated knowledge construction in the wild, and how the current mixed-methods approach offer new and more comprehensive ways of seeing and understanding knowledge in action.

keywords: knowledge-in-action, emotion, distributed cognition, multimodal learning analytics

Coming from the field of engineering design, our research is concerned with understanding the learning process in experienced designers' social practices. The focus on experienced designers and the stance of situated learning at disturbance is a confluence of multiple forces.

First, at the practical end, we want to unpack the expertise shown by adaptive expert designers, as compared to routine experts. Adaptive experts (Schön, 1983; Schwarz, Bransford & Sears, 2005) are able to reflect in action, adjust assumptions and modify behaviors during the process of product design in order to create new and meaningful product outcomes for peculiar problems at hand. A real-world example is elegantly described by Schön (1983). In a project of treating children malnutrition in rural Colombia in the 1960s, an unusual engineer Dean H. Wilson unlearned his convictions of system engineering through trial and error, and in turn, created successful educational interventions by grasping opportunities that lied in the intelligence of the local community. The pedagogical question of how to enable our engineering students and novice designers, to build up such adaptive ability has incubated the current research. Second, at the theoretical end, we are influenced by the interconnected streams of thoughts that, in Dewey's words, "thinking starts with felt difficulty" (Dewey, 1910). Our work is built upon this notion that surprise, confusion and discomfort have pivotal effects on learners' performance (Kapur & Bielaczyc, 2012) and knowledge development (Kegan, 1983; Bamberger, 2014; D'Mello, et al., 2014). For participants of social communities in our changing world, disturbance is ubiquitous, instead of rare, psychological phenomena (Berlyne, 1960; Moscovici, 1984).

As a result, we have come to see engineers and designers as dynamic learners who are often disturbed in their work, regardless of their expertise level and social-interaction context. In making this conscious choice of research perspective, we are aware that the teacher-student, parent-child, and master-apprentice paradigms are the basic building blocks of most educational research and have greatly driven the advance of learning sciences. On the other hand, change, the process of developing new beliefs and behaviors, is a process that would also occur for experienced professionals at work. In Schön's account, Dean H. Wilson's learning at work happened when he was a professor and expert engineer.

We join the emerging efforts of multimodal learning analytics (Blikstein & Worsley, 2016) and integrate technological tools with qualitative research to study the scarcely investigated learning process of experienced designers in the wild. Our work is a synergy and reflection of knowledge-construction-in-situ research as well as a methodological probing of how to study the interrelation of emotion and learning in the future.

Theoretical stance grounded in distributed views of learning

The views that situate learning in social and physical engagement have a long history in learning sciences since Piaget time. A leap of its development was seen in the 1980s and early 1990s (Bamberger & Schön, 1983; Brown, Collins & Duguid, 1989; Lave & Wenger, 1991; Pea, 1993). Despite different takes, the distributed views unanimously challenge the traditional view that knowledge is "a property of the minds of individuals" (Pea, 1993). We highlight a few influential theories below.

Knowledge-in-action is a concept initiated by Bamberger and Schön (1983), defined as "the current state of a person's mental constructions". The concept captures "the sense of movement and instability associated with, even necessary to, learning and change". According to Bamberger (2014) and Schön (1983), knowledge is mobile as a result of constantly interacting with the changing context instead of being stable, abstract and codified, the latter of which are often characteristic of other sociocultural views of knowing, such as cognitive schemas (Crocker, et al., 1984) and social representations (Moscovici, 1984). While knowledge-in-action stresses the continuous mobility of knowledge, as the learner interacts with materials at hand and the social context, distributed intelligence emphasizes the role of materials (e.g., technological tools that support learning) in terms of distributing and empowering intelligence, which is traditionally regarded as "a property of the minds of individuals" (Pea, 1993). This view is echoed in Papert's constructionism, which places significance on the role of different media in children's knowledge (re)construction (Ackermann, 2001). Others (Hutchins, 1995; Suchman, 1987; Lahlou, 2018) have demonstrated how workers' actions, which reflect their knowledge and expertise, are augmented with, controlled by and channeled through physical and social realities.

A designer's knowledge lives and grows through his/her mental, social and physical mediations, and in doing a design task, the designer engages in moment-by-moment construction of knowledge as he/she moves across time and space. This distributed view is contrasted with the traditional view in which to design is to enact a codified body of knowledge and skills. In addition, we take the stance there is not "a single, coherent and non-contradictory account of what happened", and that "real action is often ambiguous and may have multiple determinations" (Lahlou, 2018). However, references to the specific situation and designers' subjective experiences would lead to more complete interpretation and meaningful analysis (Xue & Desmet, 2019).

A new mixed-methods approach

Empirical approaches to study learning at disturbance range (e.g., experimental design in Kapur & Bielaczyc, 2012, inductive analysis in Bamberger, 2014). In works that adopt a situated view of knowledge, however, ecological validity has non-negotiable priority (Bamberger & Schön, 1983; Shaw, et al., 1997; Rahman & Barley, 2017; Parekh & Gee, 2019; Kulikowich & Young, 2001). The situated nature of knowledge favors approaches where real-world phenomena are largely preserved. Where intermediate self-reports are collected to gain access to participants' subjective experiences, ecological validity is compromised, and thus ecological momentary assessment has remained a challenge (Ram, et al., 2017).

Recent years have seen an emergence of new, non-obtrusive technological solutions and analytics (Blikstein & Worsley, 2016; Andrade, et al., 2016; Di Mitri, et al., 2018; Eteläpelto, et al., 2018) to enhance the ethnographic and phenomenological study of learning. Physiological measures, primarily electrodermal activity (EDA), are increasingly used for approximating students' emotional arousal in various learning contexts (Pijeira-Diaz, et al., 2018; Villanueva, et al., 2018). EDA refers to the variation of the electrical conductance of the skin in response to sweat secretion, which is produced by the sympathetic nervous system. Our skin becomes a better conductor of electricity when we receive external or internal stimuli that are physiologically arousing (Boucsein, 2012). And emotional arousal has long been regarded as an indicator for curiosity (Berlyne, 1960) and active participation (Pijeira-Diaz, et al., 2018). In contrast to EDA, Vocal pitch as a proxy for emotional arousal (Mauss & Robinson, 2009) has not found its way into learning sciences research. Vocal pitch is considered in literature as "less controllable and more leaky channels" of high emotional arousals that are not revealed by verbal content or facial expressions associated with the message (Zukerman & Driver, 1985; Dietrich, et al., 2019). The advantage of voice and sweat gland is that they make unobtrusive ecological assessment feasible, but they should also be used with caution. Unlike controlled-lab studies, their instrumentations in the wild would induce a lot of real-world noises which may make speech data difficult to clean up and electrodermal responses hard to interpret. In addition, the mapping between the basic physiological processes of emotion and experiences of emotion (i.e., what is felt) is still poorly understood (Barrett, et al., 2007). Subjective perspective-based video analysis, when triangulated with retrospective self-report, is a powerful qualitative measure (Lahlou, 2011) of experience and behavior, and could complement the bodily measures for validity-driven analysis.

The current research has been conceived to take advantage of aforementioned instrumentations. Our research question is a methodological one: *How to capture, characterize and understand the knowledge-(re)construction process of experienced designers at disturbance*? Considering our goal is to study learning through high-learning-potential moments of disturbances, emotional arousal measures of EDA and vocal pitch make it possible to identify high-arousal moments amongst large amounts of time-series data. To deal with the limitations of physiological measures, multiangle video data and retrospective self-reports are collected for interpreting the objective measures as well as to match our theoretical position.

The study of learning-at-disturbance in experienced designers

Participants and a half-day design task in the wild

Experienced designers were recruited based on accomplishments. They all started as engineers and went through rigorous human-centered design programs (from 1970s to 2019) from an engineering department at a U.S. university. The designers were randomly paired to work on a task in a naturalistic setting for three hours. None of them collaborated before. With a previously established measure (Atman, et al., 2010), we assessed their confidence, frequency of engagement in design activities, as well as how supportive their work environment is towards different types of design activities. The designers had on average 14 years of design work experience. Despite large variance of experience (sd: 15.28 years), they were on average highly confident (avg: 86.31 out of 100 with ad: 4.78), receive positive work-context support. We will focus on designer Diver (anonymous label) for qualitative analysis, Diver regarded himself as a design innovator, product designer, consultant, educator, researcher as well as magician. He was frequently engaged in the early front-end of product design, and these years only occasionally worked on the later stages of product realization. Diver had 40 years of design experience.

An ill-defined design problem was introduced. Given a set of videos and written materials, the participants were asked to create solutions to radically improve the dining experiences of families with small children. Video materials contain pre-collected data of eating scenarios from several families. To realize "in the field" experience, we crafted a temporary design studio situated at a place with easy access to children's facility, kitchen and residences of families with small children. The designers were physically unconstrained from the design studio. Two hours into the study, two families with their children came in for user testing. We suggested the users not make compliments only, but provide honest, critical and helpful feedback to the designers. By the end of the three hours, each team delivered a pitch as if to their client with some prototypes in hand.

Data collection and analysis

We used multiple observational channels to account for uncontrolled variables in the wild. Video cameras were mounted at the four corners of the studio. Each designer wore a miniature eye-level video camera, AXON Flex 2, to capture how situations are lived from the perspective of the participant (Lahlou, 2011) and keep track of design activity wherever the participant is, and it also provides audio data for speech acoustics analysis. Each participant also wore an Empatica E4 wristband on the dominant hand. The device acquires time-series data of EDA, movement, skin temperature, heart rate variability. Only EDA is used in the current study. Within a week after the study, participants shared subject experiences in a 2-hour one-on-one interview. Large prints of snapshots of the participants' own views, artifacts produced during the project, video clips of their subjective view, and other tools were used when appropriate to facilitate the unfolding of internal experiences.

Designers' engagement level is approximated by vocal pitch and skin conductance response (SCR) frequency, interpreted through triangulation. Audio data for each participant is extracted, manually cleaned up for speaker diarization and partitioned into utterances with ELAN software and analyzed with PRAAT software. Laughing, whistling and other sounds are separated from vocal speech. Creaky voices are identified with the Covarep program in Matlab and cleared from the dataset. To understand intraindividual change, each designers' utterances are segmented by design phase and social situation to calculate average and standard deviations of each phase and changes across phases. To allow for between-subject comparison, the baseline was acquired by rescaling vocal pitch to standard deviations above and below each designer's average vocal pitch (Detrich, et al., 2014). Utterances that are 1.5 standard deviations or more than the local average (i.e., z-score) are regarded as pointers to pronounced episodes of "felt difficulties", and thus high-learning potentials. These deviates are analyzed qualitatively through triangulation with EDA, self-report and video analysis. EDA retrieved from Empatica E4 was processed with Continuous Decomposition Analysis (CDA) as implemented in Ledalab program with Matlab. SCR is exported using a minimum amplitude criterion, which is a threshold that the rise in skin conductance value must reach or surpass to qualify as SCR. Since the current study took place in an uncontrolled environment, a score of 0.05 mS is used (Boucsein, 2012). We use SCR frequency to categorize the data into different levels. 1–3 peaks/min (ppm) is marked low (Dawson, et al., 2017), values higher than 20 ppm are interpreted as high arousal (Boucsein, 2012), while anything in between is medium. Signals less than 1 ppm are discarded for the purpose of data cleanup. Each designer's SCR frequency is also segmented by design phase and social situation. Lastly, retrospective self-reports are transcribed to provide a window into the subjective experiences of designers to support the data analysis.

Results

With the proposed measures, how to capture, characterize and understand the knowledge-construction process of experienced designers? We highlight case examples from designer Diver and show some micro-level analysis of "felt difficulties" which trigger designers' learning in action. Additionally, the mixed-methods approach allows comparative analysis of learning dynamics across person and time.

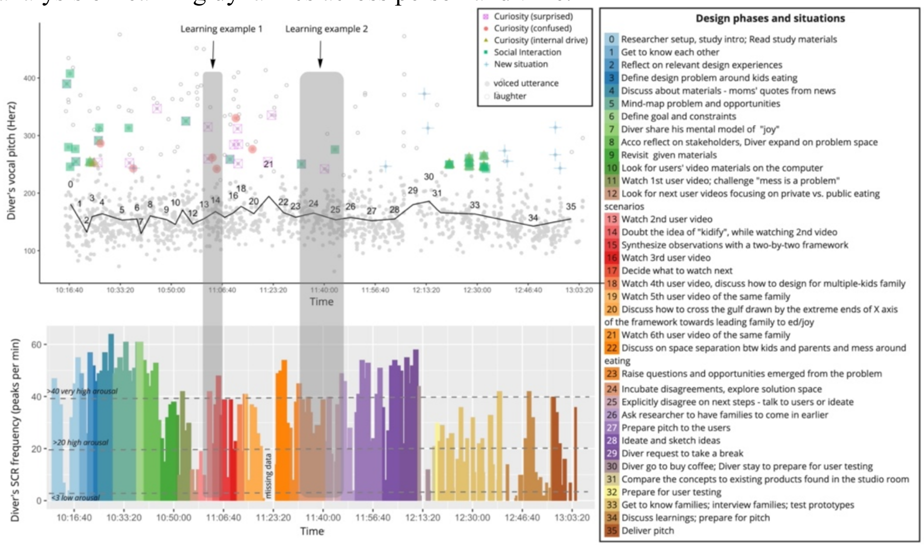

Figure 1. Designer Diver's engagement map; Top-left: Average vocal pitch over time (error bars not shown for simplicity) and types of high-pitch utterances; Bottom-left: SCR frequency, where arousal levels are based on standards (Boucsein, 2012; Dawson et al., 2017). The identification of high-learning-potential episodes (as indicated by colored shapes in top-left graph) is based on 1.5 z-score rule, and subsequently qualitatively coded through triangulation with SCR, retrospective self-report and video analysis. Grey bars highlight case examples.

Zoom-in: Characterizing and sensemaking knowledge reconstruction at disturbance

Learning example 1

Consider designer Diver's 2-minute experience here as he responds to a video material about a child interacting with food and utensils (Figure 2). Within the short time, Diver is channeled to speak in a distinctively high voice (1.5 z-score) a few times. In the quotes below, Diver's high vocal pitches are marked in *italic*.

After silently watching the video for a while, Diver turns to his partner Acco to offer his observation that adult products are scaled down for kids in softer materials, "*but it isn't clear*" (z-score: 1.89), he pauses, and does not finish the sentence before continuing, "we've seen these modifications in adult world of plates and utensils. So within the culture we are trying to kidify it enough that (unfinished)... It isn't clear it's helping the kids. And I think the parents go, this looks like it is for kids". He continues with a related observation from past experiences that some adult bottle designs are actually influenced by baby products and that "it literally went the other way around!" As the video plays along, he turns his attention back and forth between the TV screen and his partner. "*But I'm realizing it's a baby bottle!"* (z-score: 1.53), he excitedly points to the screen (as shown in Figure 2), "*But that…",* Diver quickly brings his hand back to hold his chin, and then stretches out to gesture, contradicting his earlier comment: "*and it works for her! It works perfectly. She had no problem with that*." (z-score: 1.66). While Acco acknowledges Diver's observation, Diver keeps watching the video, holding a fist by his chin, asking in a deeper and lower voice: "So are we looking at this the wrong way, that we wanted to have", he briefly pauses and turns to Acco, taking a lighter voice, "kids become adults versus learn from the kids and modify our adult world (with laughter)? That might not be hard to sell!"

Let us go through the thin slice again with our theoretical and analytical tools. A designer's knowledge lives and grows through their mental, social and physical mediations. And here, designer Diver curiously *saw* "kidification" as channeled by the video of child interaction with utensils. Diver's design knowledge around children's products is manifested in his ability to see kidification; In comparison, two less experienced designers in the study found this specific video material uninteresting. Moreover, instead of simply acknowledging kidification, Diver questioned it, and spent time on it, making it a rather intriguing issue. In addition to high voices, his body language suggests excitement, and his verbal expressions suggest confusion ("*but it isn't clear*") and curiosity (repetitive and contradictory statements). As he navigated the video, Diver broke down his assumption again and again, to further his understanding about kidification, from "*It isn't clear it's helping the kids*" to "*…it works for her! It works perfectly. She had no problem with that*" to questioning "are we looking at this the wrong way". The disturbance and elicited curiosity are also evident from the perspective of SCR frequency, where a steep rise occurs in the local proximity of the video-watching activity (Figure 1, bottom-left).

Example 1 not only shows the "mobile continuity" (Bamberger & Schön, 1983) of situated knowledge which is distributed in the physical (TV), mental (Diver's embodied expertise) and social (cultural practices associated with the child's dining) spaces, it is also a high-learning episode. Diver is grabbed by the visually colorful and soft utensils, curiously stuck on why designers should assume baby products are scaled downs of adult products. This question drives Diver, as a seasoned children's product designer, to unlearn the default assumption and reconstruct his knowledge in the space. It is notable that kidification might not be an entirely new concept to Diver. He may have developed this concept of kidification in his previous experiences. However, this alternative view is not made obvious and questionable until this disturbing moment as he engages with the video material, which allows Diver to adjust and expand his situated knowledge.

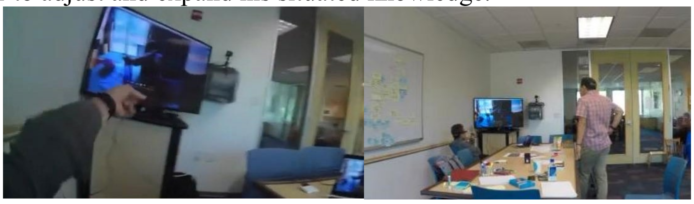

Figure 2. Designer Diver's subjective view (left) and a third-person camera view (right) of a high-learning moment for Diver, located at phase 14 in Figure 1. Left: Diver extends his left arm and points at the TV, saying "*But I'm realizing it's a baby bottle!"*. Right: Acco (standing) observing user behaviors as Diver (sitting) talks.

Learning example 2

At a later point of time, Diver has a tense disagreement with Acco. After the user-behavior observations, Diver indicates a few times of his interest to talk to actual users. As Acco does not respond, Diver makes it an explicit request. But instead of supporting Diver's suggestion as Acco always does until this point, Acco proposes to design some sacrificial concepts first. Hearing that, a high-pitch voice leaks from Diver before Acco finishes his sentence. "*Hmm! um-hum!*" (z-score: 1.68). Diver is verbally positive, but his vocal pitch suggests surprise and discomfort. As an experienced designer, Diver is able to regulate his emotions and make conscious balance between maintaining teamwork and making the right pathway. He opens up to go with Acco's thinking process to ideate. After a few minutes of exploring the solution space, Diver is channeled back to think of talking to users, because one of their concepts is hinged on the question "when do kids transition from baby food [to family food]?" "That", Diver points to the TV, "looks like my plate, only it's not working!... And we literally had to separate ourselves from the kids because it doesn't work…Ah, I, I would love to ask about when you eat together, when you don't". In response, Acco insists on spending the limited time on coming up with some concepts and preparing for user-testing. Diver attempts to persuade Acco again — "We've thrown some ideas out around this stuff, and I'd love to see — are we even close to be on track", and he adds, "and our hypothesis is that they (parents and kids) are struggling eating together. I just, I want to validate that". But Acco also persists in his thinking. "*Okay"* (z-score: 2.14), responds Diver in an abnormally high voice.

As Diver reflected in the retrospective interview, he regarded the division with Acco as "the high point of perplexity". In Diver's view, the project ended in "anticlimax" partly because of that, even though they receive positive and encouraging feedback from the users during the user-testing phase. Diver was deeply convinced, based on his experience, that it is not wise to go too deep in concept generation without validating their underlying assumptions with users first. Intriguingly, Diver started navigating this "felt difficulty" with a positive attitude and open mind. During this process, there is no doubt that Diver was guided to shape understanding about the design project at hand, as new questions surfaced (e.g., when do kids transition from baby food to family food?). By cooperating on ideation, Diver built a new mental container that would accommodate product ideas while not stretching his own convictions too much. But that only led to building up tension in the conflict. At the moment when Acco expressed strong interest to work on concepts, Diver realized they had different conceptions of "concept" and "ideation" — while for Diver they already had some high-level ideas, to Acco these were not concrete concepts ready to be tested with users. As shown in the analysis, Diver's knowledge about Acco and how to work with Acco was being reconstructed moment by moment as well.

This experience also had a pivotal effect on Diver's subsequent performance. He was less curious about the task and less engaged behaviorally as well. Diver laughed much less (Figure 1, top-left) and showed fewer learning behaviors as indicated by the high-pitch criteria. Shifting lens to EDA, Diver's arousal does not make obvious sense as in example 1, since phase 24 and 25 are actually lower than the local proximity, despite the high baseline. This could be better understood through contextualization. In Diver's reflection, he described design progress as "going along where your energy is" and emphasized how important it is to "keep the energy up". For

Diver, the splitting point with Acco was a deflation of energy he gained from earlier activities. This is observable in his physical activation as well. Diver changed from the active posture of standing up and working by the whiteboard at phase 22 and 23 back to sitting down, as he tried to resolve the conflict. In comparison to example 1 in which Diver's high-pitch utterances suggest stimulation, excitement and curiosity, the high-pitch utterances of example 2 are briefer in length and suggest undesirable tensions.

The two examples here are complicated and pronounced ones, whereas in some other cases, the situated experience is rather brief. For instance, earlier in the process, hearing Acco's joke about their shared design training, Diver jokes as well: "*Okay, checked! Extra credit! We are done, we are out of here!*" (z-score: 1.83) It is clearly a team bonding interaction, where Diver is positively surprised and channeled to build his knowledge about his unfamiliar partner and how to work with him.

It is worth noting that not all high-pitch utterances suggest disturbance-based learning. Some of them are not elicited by disturbing stimuli but are due to uncertainty and curiosity to learn. For instance, in the user-testing phase, Diver asks one parent: "*Do you guys ever eat together at that table or do you eat separately*?" (z-score: 1.67). According to Diver's retrospective self-report, the answer to this question was very critical to validating his assumption behind the product idea. There are also exceptional arousal rises due to entering or expecting new situations, for instance, Diver raises his voice to say "*Okay!*", suggesting moving on to the next design phase. Fluctuation of pitch as associated with situation change has less to do with the kind of disturbance in our theoretical framing and can be distinguished by triangulation with qualitative analysis.

Zoom-out: Learning dynamics across time, between people

Designers' arousal level, as measured by EDA and vocal pitch, has notable changes across design phases and social situations. For instance, as shown in Figure 3, Designer Diver is situated in a much more highly aroused state in the early exploration than in user-testing, reflection and pitch delivery. More specifically, in the beginning phases, Diver is physically and socially more stimulated, as shown in his dense laughter and high-pitched verbal expressions. In addition, clusters of disturbing moments within a person would emerge from the mapping over time. For designer Diver, the beginning phases of the design task are filled with positive disturbances as he interacts with the unfamiliar partner. The bodily signal graphs also show that Diver's disturbance-based learning peaks during the time of observing user behaviors through video materials.

In comparison to Diver, the video materials are less stimulating for some other designers with much fewer disturbing incidents. This observation allows us to revisit Diver to understand his knowledge and expertise, acknowledging his ability to see problems from what is otherwise perceived normal for other people. Figure 3 gives another example comparing Diver and Analyte, who was from another design team. Interestingly, Analyte's arousal stays low to medium throughout except for a few salient phases, such as the user-testing stage. Notably, Diver's arousal in the user-testing phase is low, whereas in the same phase it is highest for Analyte. In addition to possible individual differences in EDA, the differences can be better understood from analyzing their retrospective reflection. While Diver cares for keeping the energy up by immersing himself into the work, Analyte tends to detach himself from the design work as for him, "it was professional" and it was about applying "the process" and "rules of engagement".

As shown by these brief examples, meaningful interpersonal and intraindividual comparisons are made possible with the multimodal data of vocal pitch and EDA through contextualization and triangulation.

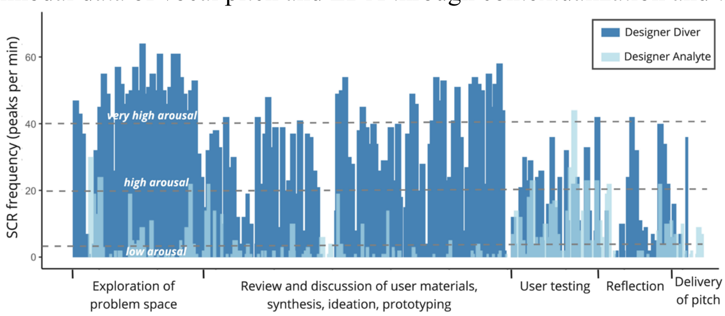

Figure 3. Comparison of designer Diver and Analyte who had distinctively different arousal profiles.

Discussion

How to capture, characterize and understand the knowledge-(re)construction process of experienced designers at disturbance? In pursuit of a methodologically rigorous approach, we integrate vocal pitch and electrodermal activity into the qualitative analysis of knowledge construction in situ. Such a mixed-methods approach enables researchers to study experienced designers' momentary emotional disturbances and situated knowledge work in the wild. As demonstrated so far, on the one hand, we are able to do micro analysis of how designers curiously chew on disturbances and adapt their assumptions in the moment and in context. On the other hand, it also gives a broader view of designers' learning dynamics across person and time.

Reflecting on the different measures of experience, we find electrodermal activity is sensitive to energy level and stress level, which is otherwise regulated in vocal expressions. In comparison, vocal pitch captures well involuntarily leaked momentary surprises (Detrich, et al., 2014), despite that most talking was well regulated with vocal pitches gravitating towards the mean. Meaningful phase-based segmentations of time-series data enable comparison of arousal level using mean and standard deviations. These objective measures have unique advantages and are complementary to traditional observational and self-report measures. It is otherwise difficult to see internal disturbances that are regulated in external behavior. Practically, participants in retrospect would not remember or voluntarily report exhaustively their swift disturbing experiences during a long activity, despite that the two given examples of knowledge construction process are quite emotional in situ. On the other hand, first-person perspective camera is promising for its unique advantage of approximating real-life observation and gives meaning to the lifeless physiological numbers.

We have applied some instrumentation and analytical tools from affective science. In affective science, however, scientists tend to avoid applying different measures due to poor concordance, as any one measure has its biases that are associated with variance unique to it (Mauss & Robinson, 2009). As a result, construct validity of arousal or stress is often unaddressed. In addition, EDA is sensitive to real-world noises when instrumented in the wild. Our study addresses the validity problem by approaching emotion arousal with contextualization and triangulation through multiple measures. This complexity-embracing approach, combined with basic bodily signal analytics, enables us to see discordance between different measures as opportunities to trigger new questions and new ways of data interpretation. Taken together, the current approach offers new and more comprehensive ways of seeing and understanding knowledge in action. Important questions going forward include how to capitalize on the technical conveniences for remote research given the challenges presented by the pandemic, and based on the current research insight, how to design coaching interventions to guide learners to navigate disturbances.

Conclusion

Designers, in the process of creative design, constantly construct their design thinking, feeling, behaving and learning. Adaptive design experts in particular exhibit extraordinary ability of reshaping knowledge and adjusting behaviors in situ — they learn as they design, in order to create new and meaningful products to solve peculiar problems at hand. In this paper we reflect on the past research of distributed learning in situ and propose new ways to advance this body of knowledge. We hope our research will open up fruitful discussions on how to advance learning sciences in the future. At the practical end, engineering educators are deeply concerned about bringing up next-generation designers to effectively, collaboratively and creatively deal with the complexities and uncertainties of the peculiar problems at hand. We hope the study will inspire educators to think about how to guide their students to curiously get disturbed, work on it and learn through it.

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