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Instrumenting Weick's Seven Properties to Measure Collective Sensemaking in Engineering Teams

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Abstract. As engineering systems become more complex, there is a growing need for interdisciplinary collaboration to achieve design and business objectives. Individuals with hetergoenous mental models are under pressure to optimize and make trades across performance, quality, cost and time. Engineering of complex systems requires these teams to work together effectively, which in turn necessitates collective sensemaking. Collective sensemaking is defined as an ability to gain sufficient shared understanding of a system so that taking effective action is possible. Current research has focused on qualitative approaches to capture sensemaking over time and to evaluate that data after the fact. Accordingly, research of sensemaking processes in real-time remains a challenge, with underlying operating mechanisms of collective sensemaking not yet well understood. This research proposes and prototypes measurements that map sensemaking concepts to sensemaking phenomena during systems work by cross-functional teams. An experimental approach is proposed. An initial study deploys a questionnaire that correlates instances of teamwork sensemaking to team-level observable practices. Next steps are described for integration of these measures into engineering team workshops for non-intrusive detection of sensemaking in real time.

Keywords. Transdisciplinary engineering, Sensemaking, Teamwork experiments

Introduction

Sensemaking, first defined by Karl Weick [1] to explain the process by which people engage with the environment so they can act in it, is currently used in fields ranging from leadership, strategy, organizational development, pedagogical sciences and project management. While these fields have adapted approaches to improve people's and organization's capability at engaging in sensemaking, there is less research on the methods to adequately measure sensemaking in real-time and in a non-invasive way.

By establishing a validated method to measure sensemaking, a set of opportunities becomes available to detect patterns across disciplines [2], characterize intermediate and multi-level processes [3] and to validate many of the good practices currently proposed by the research corpus. However, sensemaking is often abstracted as a concept and dissociated from the context at hand, in particular separate from the nature of the problem and solutions in the moment. In part, this gap in the research literature yields a challenge of properly instrumenting the way people work in today's distributed environment. With teams being rarely co-located and rarely engaging in synchronous and simple problems

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as studied in artificial experimental constructs, the challenges to observe sensemaking compound.

For this research, teams are the relevant and meaningful unit of organization. Currently there remains a need for theory on collective sensemaking informed by understanding about sensemaking as a shared emotional and distributed process [4]. The instruments and signals that are associated with the sensemaking-features must be able to work for groups of people as well as individuals.

Given that a well-accepted property of sensemaking is that it relies heavily on the use of language and reflection, much research has focused on (micro-) ethnographic studies [5] or embedded-observer approaches [6]. These approaches have the shared strength of analyzing a group's narratives and their patterns [7].

The relationship between the composition of design teams and the complex problem being worked on has been identified as an influencing factor in how a team engages with a system [8]. The previous two perspectives will be referred to in this paper as *Social Space* and *Problem Space*. Meanwhile, the Context in which the problem is worked on will be referred to as Solution Space. This paper assumes that in order to have a full picture of sensemaking, measurements across all three spaces are necessary. The influence of a dynamic Solutions Space is what makes sensemaking necessary most of the time, as it creates uncertainty and ambiguity in the system [9]; thus, making the Spaces-triad a socio-technical system.

Given the relevance of the intrinsic qualities of the problem being worked on, a formal approach to defining and quantifying its level of complexity is also needed. The interaction between the actors/agents and the environment is an important part of the process by which knowledge is constructed by taking action and seeing its effects. Finally, even though a great deal of literature focuses on the theory of sensemaking, there are concrete ideas of instrumental processes that indicate sensemaking is being carried out, such as pattern identification, labeling and categorization of new information, use of physical artifacts and generation of hypotheses [10].

In this paper, we establish a method to catalog sensemaking signals that can be used to measure sensemaking in complex engineering projects.

1. Research Framework

1.1. Definitions

The theoretical basis for the definition of sensemaking properties is based on the work from Weick [11]. This framework allows for a characterization of measurable events during the work of a team and relates those events to sensemaking properties. Thus, providing a catalog of events to be used in *Collaborative Workshop* environments. Our goal is that this approach to measure sensemaking is non-invasive.

A descriptive approach to defining sensemaking properties has already been started by Weick [12], phrasing the characteristics of sensemaking in a way that allows for characterization:

1. *Sensemaking Organizes Flux* – where humans face chaotic situations in need for understanding.
2. *Sensemaking Starts with Noticing and Bracketing* – where perception, language and synthesis play a role in enacting a list of actionable options.

3. *Sensemaking is About Labeling* – where, in the face of novel challenges, humans name abstract groups of experiences to ease processing the information acquiered by experience.
4. *Sensemaking is Retrospective* – where the relationship of disaggregate pieces of information is given meaning as new information and context are discovered.
5. *Sensemaking is About Presumption and Action* – where people create an expectation of future results aimed at taking action on the system.
6. *Sensemaking is Social and Systemic* – where people are not relying exclusively in their individual logic capabilities but in other people's expertise and *interaction* with the system.
7. *Sensemaking is About Organizing Through Communication* – where groups of individuals are needed to engaged effectively with a system challenge.

Despite of these clear definitions, there is need for an additional step to create a library of observable actions and bahviors associated to the process of sensemaking.

What role does sensemaking play in engineering projects? Today's complex systems and how they are built and operated have been characterized as sociotechnical systems [13], with the engineering of these systems as transdisciplinary [14]. The need to understand the role of *collective sensemaking* in engineering teams comes precisely from the reliance of complex systems' existence on collaborations among experts from multiple disciplines [15]. Specifically on knowing whether engineering teams tasked with critical design responsibilities have the tools and methods they need to understand how to better interact with their system. It is this relationship between the *social* aspect of engineering teamwork and the *nature of the problem* that we believe will require different *sensemaking* approaches.

For the observation and analysis of engineering workshops, our recent work at the Global Teamwork Lab [16][17][18][19] decomposes the phenomena during teamwork into three categories:

- **Problem Space**, defined by needs and how they relate to one another, including often surprising and nonlinear values in how they are traded and satisfied. Also known as the "-ilities" or "figures of merit". It is useful to think about it in "solution-neutral" terms, or similarly in *what* need is being satisfied, rather than *how* the need is satisfied.
- **Solution Space** is defined by design decisions leading to function and form. Complexity comes from how the function and form of the system are dependent on each other. System complexity (behavioral and topological), interfaces, information and energy are characterized in the solution space.
- **Social Space**, which is a mapping of how people relate to one another, their utility (of value in different dimensions), their position, power and so on. The ABC model (affective, behavioral, cognitive evidence) [20]. We observe their attention, actions, interactions and so on.

The relationship between socio-technical systems and Weick's sensemaking properties is clear (see Figure 1). Given that in a controlled environment, such as an instrumented workshop, it is possible to create an artificial yet realistic Solution and Problem Space, the detection of sensemaking properties ought to be possible. Note that the diagram shown in Figure 1 indicates the sensemaking properties in red.

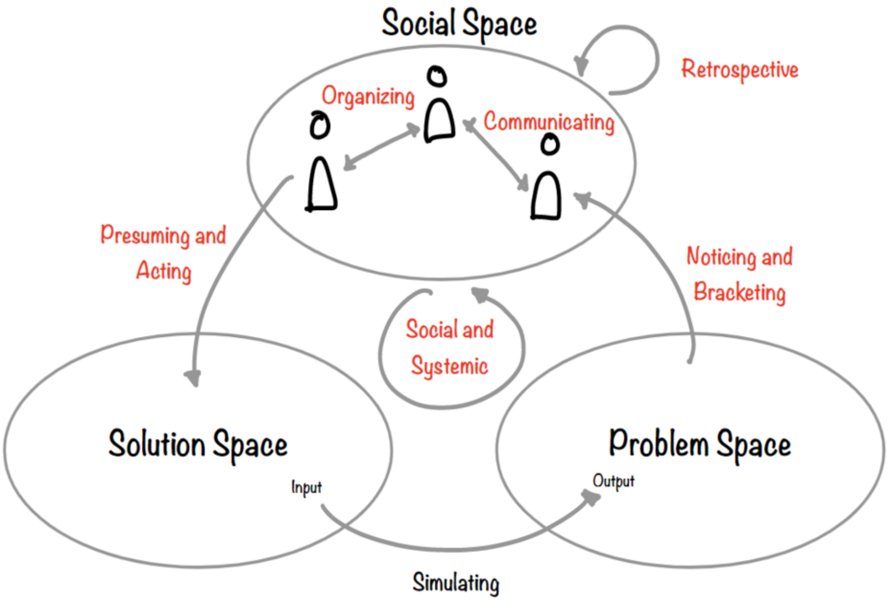

Figure 1. Overlap of the socio-technical systems abstraction and Weick's sensemaking properties. This diagram has been created as an illustration of how sensemaking properties form part of an engineering solution and problem spaces.

Sensemaking starts in a state of confusion [11]. This state is characterized by not being certain about the nature of the problem and solution spaces; thus, triggering the need to establish a working hypothesis and taking action to learn more about the system [21]. However, as iterations of action and result occur, it is always possible for the team to purposefully question their assumptions and *go back* to a confused state. This latter strategy could be necessary to avoid locally optimal points and avoid premature convergence of solutions. The point being that in order to set up a situation where a group has no alternative but to engage in intense sensemaking, the state of the *Problem* and *Solution Spaces* ought to be complex and ambiguous, but feel attainable in order to give the team a sense of purpose.

Although dependencies between sensemaking properties have not been elucidated empirically, definitions of each property may be rationally synthesized [12]. Our proposed definitions are listed in Table 1. Zooming out after defining each property revealed that dependencies between certain properties are unmeasurable in isolation and clustering is necessary for detection. For example, the process of effectively categorizing ideas within a team requires creating order and alignment among the thoughts of multiple individuals. These labeling and organizing through communication activities occur concurrently and synergistically. They may also occur independent of interacting with the system as a team. Both of the presence of both of these properties may be required for bracketing, although the dominant sensemaking activity may be interaction with the system. The dependencies between the properties present a challenge for abstraction - however, the added complexity requiring the participant to comparies seven elements justifies the loss of granularity due to the abstraction. The properties clustered into discussion with the team are related to interpersonal interactions, which include social and systemic, labeling, and organizing through communication. Recalling prior experience is relying on experience. And interpretation of the environment, which includes noticing, bracketing, and presuming and acting, are clustered into interacting with the system.

Table 1. Proposed clustering of sensemaking properties.

Cluster	Weick's Properties	Definition
Discussing within the team	Social and systemic	It is recognizing the "why" of them being together. It engages not only the individual but the "larger organization," e.g. a school or a hospital.
	Labeling	Categorizing to stabilize the streaming of experience. Differentiate, allocate, identify.
	Organizing through communication	Questioning or challenging each other. Building on each others' contributions.
Relying on experience	Retrospective	Reflecting on and discussing past events and actions.
Interacting with the system	Noticing	Identifying relevant items or concepts
	Bracketing	Grouping items or concepts
	Presuming and acting	Setting structures and events into action. Coming up with different ideas on how the system could be working.

2. Research Design

The research process followed three steps:

1. Empirical data collection through a survey.
2. Transcription and coding of the survey results and,
3. Mapping of sensemaking properties to sensemaking events.

2.1. Intended group of study

Participants of this survey are selected based on the professional background and the number of years of experience. Complex engineering problems requiring multi-disciplinary teams tend to have engineers with several years of "hands-on" experience, and have a strong technical orientation. The level of maturity of the individuals also helps their reflective capabilities to analyze the way in which they approach problems.

2.2. Survey questions

Participants were asked to provide four pieces of information specified in Table 2.

Table 2. Survey questions.

Number	Question
1	*How many years of experience post-Bsc do you have?*
2	Think about a time when you were working on a complex engineering problem with a multidisciplinary team. How did you make sense of it?
3	*Rank the approach you think you followed in your story.* Options: Discussing within the team, Interacting with the system, Using my previous experiences.
4	*Place in the triad where you would place your story in the triad of sensemaking clusters.*

Given the survey questions, an online form was created and made available to the authors' professional networks. An open call was made for volunteers, where they would find a video of one of the authors with instructions and information about how the data would be used for scientific research. Informed consent was provided by the participants before answering the questions in Table 2.

3. Preliminary findings

The study collected 23 responses from professional engineers. This number of answers is too low to make significant conclusions but it does indicate the expected pattern of responses that become available with the proposed methodology.

One of the answers did not provide any data for number of years of experience or the Likert scales; thus, the entry was eliminated before performing the analysis.

The years of experience ranged from 3 to 25 years, with an average of 12.6 years. The ranking of sensemaking clusters captured in the survey shows a stronger association with *Discussing within the team* (see Figure 2).

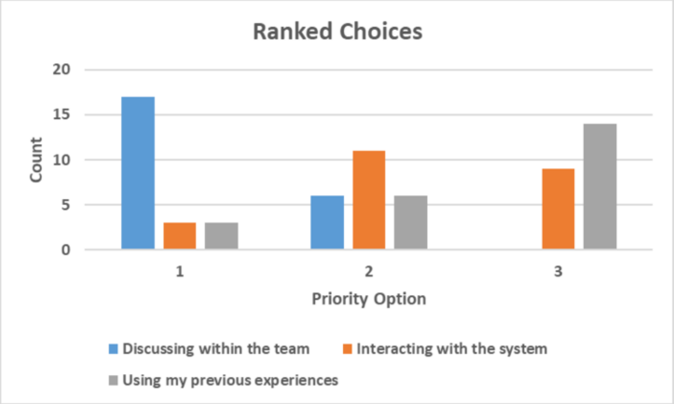

Figure 2. Ranked sensemaking clusters according to participants. The survey partipants were asked to rank the sensemaking cluster according to what they prioritized in their story – since the openness of the story makes it difficult to discern. In aggregate, the most popular sensemaking cluster was *Discussing with the team*, followed by *Interacting with the system* and *Using my previous experiences*.

While the answers of ranking show a preference, the answers provided by the participants are not clear-cut. The triad of sensemaking clusters (shown in Figure 3) shows a more nuanced picture of the weight participants give to the different aspects of sensemaking.

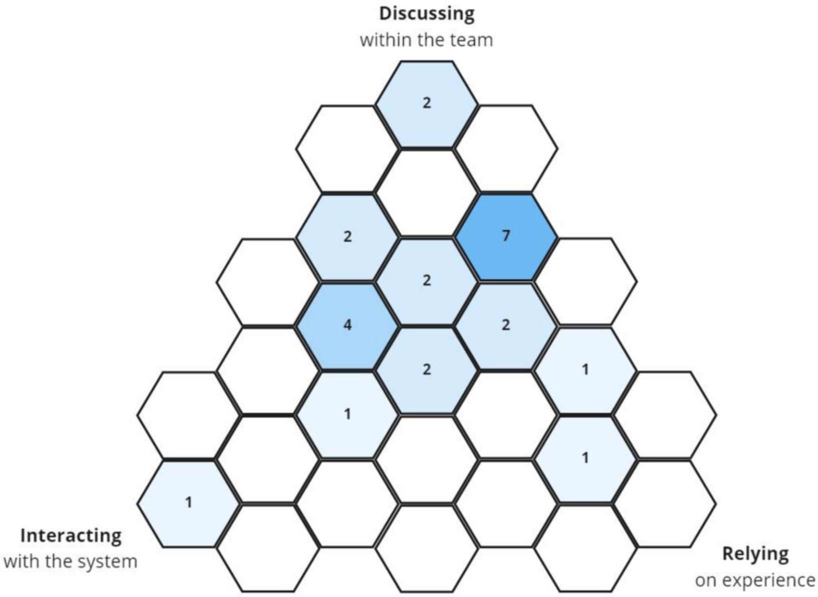

Figure 3. Closeness of the story provided by the participants with respect to sensemaking clusters. This figure shows the count of locations provided by the survey participants. It is meant to show the tension that participants perceive when forced to decide "how much" of a certain sensemaking property their experiences are using.

Finally, by analyzing the free-form responses the participants provided (Table 2 - Question 3), we also constructed a small catalog of measurable events associated to sensemaking:

1. Using shared documents.
2. Meeting with the team and organizing workshops.
3. Aligning the team members under a single purpose.
4. Meeting with stakeholders.
5. Reaching out to out-of-team experts.
6. Executing feasibility studies & additional experiments.
7. Requesting more information.
8. Gathering knowledge of the process and product.
9. Creating small prototypes.
10. Asking questions to experts.
11. Reviewing survey data.
12. Observing customer behavior.
13. Investigating if the problem is repeatable in a lab environment.
14. Having a single source of data.
15. Creating solution proposals.
16. Analyzing off-line. E.g. root-cause method.
17. Learning more about the business environment.
18. Using analytical frameworks.
19. Collecting and sharing facts.
20. Communicating not with words and text but also withs

drawings, diagrams, pictures and mock-ups.

21. Writing-down assumptions.

Note that the items in the sensemaking catalog are all observable and measurable. This is the desired outcome of the study: a list of potential signals that indicate the variety of activities people engage in while working on complex problems. The industries mentioned by the respondents include: medical devices, facility automation, automotive, software developmen and IT.

4. Discussion and Limitations

This paper proposes a preliminary pattern of sensemaking property dependencies and a starting list of measurable events associated with sensemaking. The progression of this study will assess how sensemaking properties correlate to clusters based on events within the stories among a larger sample size.

The low sample size of this study also presents a significant limitation of this study. Numerous confounding factors, unknown context from multiple participants, and unavoidable interrelations among sensemaking properties require an increased study population to solidify initial conclusions. It is reasonable to expect that people will have a sensemaking approach they will rely on the most. However, the frequency of individual predisposition and its effect on teams is unknown and since adding more controls to the context of team operation, the current study is not able to shed light on this area. Furthermore, the problems discussed by each participant are unrelated to others. Thus, the findings of this study cannot yet inform generalizations about the frequency of the type of sensemaking in the real world.

In addition, the preliminary results of this paper show discrepancy in cluster selection based on the format in which the participants are surveyed. Although survey format may be a confounder, it may serve as an alternative comparison to assess internal validity of comprehension of participants of the sensemaking properties.

Nonetheless, the ability to associate a numerical value to the role of sensemaking properties, as indicated by the position in the triad, and the *meaning* of that position, indicated by the actions people take, creates the space to define sensemaking patterns. With further data acquisition and verifying the validity of instances of sensemaking, we can deplot this method in the analysis of live workshops. For example, in the theoretical situation where we want to test whether engineering artifacts, such as CONOPS diagrams [22], have an influence on the way engineering teams follow to make sense of a complex problem, it would be possible to graphically show distinct patterns in the sensemaking tryad. The theoretical representation of that scenario is shown in the following diagram (see Figure 4), where the *Control Team* does not have access to CONOPS diagrams, as does the *Treatment Team*. If the data filling the triad is taken at an individual level, that would indicate that the team as a unit relied and *gave meaning* to the engineering artifact. The final step is to verify whether the difference in sensemaking patterns actually led to an improvement in the performance of the team, as measured by a simulation that provides the system's figures of merit. Thus, closing the sensemaking loop.

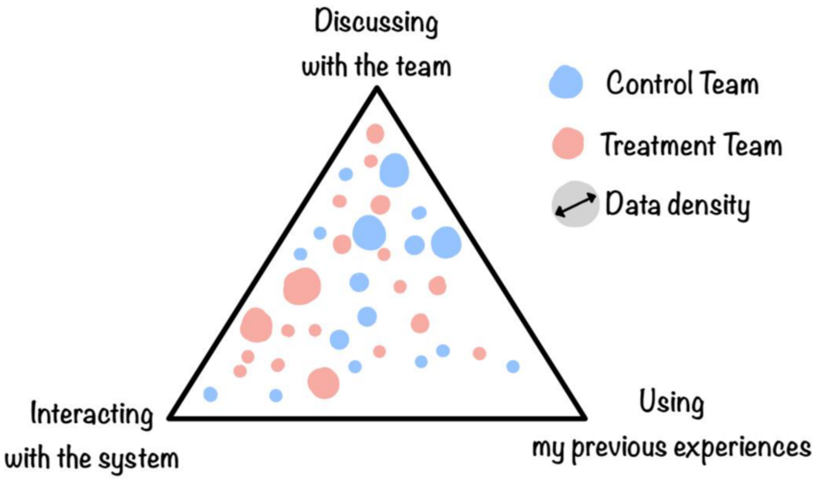

Figure 4. Sensemaking patterns based on a simple A/B Test experiment.

5. Future research

For truly complex systems, the time-scale at which organizations make sense of such systems is not in hours, but could take weeks or even months to engage multiple teams in a varying context. The approach proposed here can be complemented with instruments that analyze similar signals but on a larger time-scale [23]. Ultimately, distributed sensemaking happens across scales, where small activities among a few individuals ripple across the organization triggering ation and generating shared knowledge [24].

Another interesting research avenue is the influence of team composition, if we assume that the formation of a team is not random, and instead a team is *designed* for sensemaking. It should be possible to use this framework with a setup in which teams with varying levels of collective intelligence [25] are compared on their ability to go through a better sensemaking process.

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