Assessment of Team Cognition

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1 INTRODUCTION

1.1 Teams and Groups

To the extent that team cognition underlies team performance, its assessment is central to the understanding of the underpinnings of effective or ineffective team performance, as well as the successful design, training, or selection intervention to improve team performance.

Teams of a heterogeneous nature, in which team members have varied skills or roles, are ubiquitous in various complex military, commercial, and civilian settings. Teams are typically required because the job or task at hand is too cognitively or physically demanding for an individual. Because we are focusing on team cognition in this article, we are particularly interested in cognitively demanding tasks. Examples of these tasks can be found in command-and-control teams in a military Air Operations Center, process control teams in a nuclear power plan control room, and triage teams in a hospital emergency room.

In this chapter we distinguish between teams and groups. A group consists of two or more individuals and a team is a special type of group. In a team, individual team members have specific and varied roles and interdependence among members is required to perform a specific task. The distinction between teams and groups has been made by others (Salas *et al*. 1992) and is particularly relevant to the measurement of team variables. For instance, the fact that teams, but not groups, have members who play different roles, also implies that these members bring different knowledge, skills, and abilities to bear on the task. This is not so much the case in groups with relatively homogeneous members. Therefore, the assessment of the cognitive skill of the team must take this difference into account.

1.2 Cognitive Products of Teams

Teams performing cognitively demanding tasks carry out cognitive activities at a team level. In many cases, teams think, make decisions, plan, design, perceive, and remember as an integrated unit. Team activities like these can be abstracted into three fundamental overlapping parts, including division of labor, mediated coupling, and coordination. Division of labor connotes the disparate aspects of information or knowledge in a team environment that have to be integrated in order for a team to accomplish its goal or mission. Heterogeneous teams can vary in the degree to which their knowledge is distributed, with very specialized teams having little cognitive overlap among members, and less specialized teams having more cognitive redundancy. Mediated coupling essentially refers to the lines of media available for team member interaction (e.g. telephones or computers). Coordination is the timely and adaptive sharing of awareness or information across labor divisions through mediated couplings. Within this framework, the cognitive products of teams (e.g. decisions and plans) emerge from the dynamic interaction of team members performing a team task. To the extent that these products are adaptive and timely, they are considered to be the product of an actively coordinated team mind.

The team mind is viewed similarly to the individual mind. In terms of traditional views of cognitive psychology, team members are considered to be modules, each consisting of the activated mental model of an individual team member. These modules are subsequently operated on by team process behaviors resulting in a team mental model (Klimoski and Mohammed 1994). These process behaviors can be viewed as being analogous to cognitive processes operating on representations inside the head of an individual. Other perspectives of the team mind include ecological and activity perspectives. In these perspectives, the theory of team mind consists of team members actively encountering their local environments making their own direct perceptions available in the local environments of other team members through a mediational means, where mediational means consist of lexical devices, maps, charts, or other representations. In each of these perspectives discrete cognitive products (e.g. decisions and plans) emerge from the continuous interaction among team members, or the "team mind."

2 ASSESSMENT BY AGGREGATION

2.1 Collective View of Team Cognition

According to the collective view of team cognition, a team is a collection of individuals, and team cognition can best be assessed by measuring individual cognition and then aggregating the results across individuals (i.e. by summing or averaging individual data; e.g. Langan-Fox *et al*. 2000). For instance, members of a process control team may each be given a factual test of taskwork knowledge that is assumed to reflect the accuracy of each team member's mental model of the system that is being controlled. Presumably, given that the test of taskwork knowledge provides qualitative or diagnostic data regarding individual mental models, a representation of a team mental model can be generated through an aggregation across these qualitative data. The accuracy of the team mental model is thus inferred on the basis of an aggregate of the individual team member accuracy scores.

In order to illustrate this, assume that the Pathfinder network scaling technique (Schvaneveldt 1990) is used to analyze relatedness judgments for pairs of system-relevant concepts for process controllers. Concepts such as boiler, motor, pump, and electronics may be presented to individuals using this technique. Individuals then provide relatedness estimates on a relatedness scale of 1 to 9, for instance, that reflect their understanding of the degree of association between system concepts. Pathfinder can then take all pairs of these estimates and generate a graph representation in which concepts are represented as nodes and relations as links between nodes. This structure is often assumed to reflect the judge's conceptual structure, or in this case, mental model of the system. This procedure not only generates a network representation of conceptual structure, but through comparison between this structure and some referent structure (e.g. for a subject matter expert) in terms of shared links, can also provide a quantitative estimate of knowledge accuracy. In terms of aggregation then, individual team members can be quantitatively compared to one another to assess intrateam knowledge similarity. Averaging these estimates across team members provides an estimate of team knowledge accuracy in line with the collective view. In addition, there are ways to combine network representations (e.g. averaging ratings and submitting them to Pathfinder or forming a network with links weighted by the number of team members who have that link) in order to generate a team mental model representation.

We label this procedure a "collective" approach to aggregation because it implicitly assumes through the testing and aggregation procedure (i.e. number of common links) that all team members are alike or homogeneous and therefore, team cognition is simply an additive process constituting a collection of individual cognition. We believe that this assumption of homogeneity is largely inappropriate for the heterogeneous nature of teams as we have described them here. Further, this approach tends to focus on the cognitive structure inherent in teams more than cognitive process. In the following section we discuss alternative collective approaches that begin to address these shortcomings.

2.2 Heterogeneous Teams and Knowledge "Sharing"

The difference between the heterogeneous and homogeneous metrics applied to teams also maps onto two senses of the term "shared" as in shared mental models. Shared can, in one sense, mean to have in common, such as "shared" or "common" beliefs. It is this sense that is reflected in homogeneous measures and in general, aggregation across individuals on a team. Shared can also mean to distribute, as in time-sharing or sharing a dessert. It is this sense of shared that more clearly portrays the type of knowledge or skill distribution occurring in heterogeneous teams. The top panel of Figure 1 represents shared knowledge as common knowledge and the bottom panel represents shared knowledge as distributed knowledge. Most teams will have a combination of common and distributed knowledge.

One approach to the assessment of knowledge or cognitive structure for heterogeneous teams is to assess individuals against a role-specific standard (Cooke *et al*. 2000). In other words, the surgeon is given a test of knowledge pertinent to a surgeon and the anesthesiologist is given a test of anesthesiology knowledge. Referring again to the Pathfinder example, the network representation of each team member could be compared to a role-specific referent and to referents associated with other roles, yielding one positional accuracy score and one or more interpositional accuracy scores. In this way, it is possible to (1) assess the degree to which each member has positional

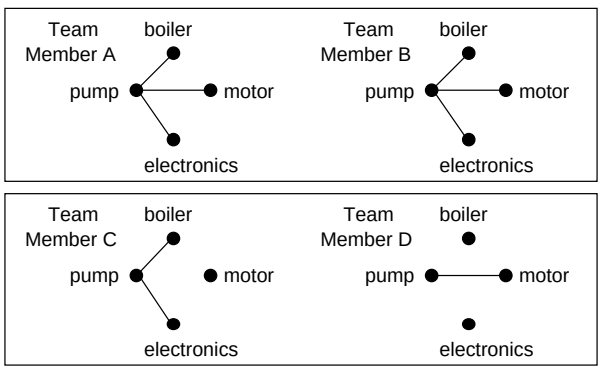

FIGURE 1 Example pathfinder network representations. Top panel: team members A and B share common knowledge; Bottom panel: team members C and D share complimentary knowledge: knowledge is apportioned; in both top and bottom panels, the same conceptual relations are present, however on the bottom panel there is a division of labor.

knowledge or knowledge relevant to his or her own role, and (2) the degree to which each team member has interpositional knowledge or knowledge pertinent to other team roles. In addition, it is possible to add to this the homogeneous metrics of team member-to-team member similarity and overall knowledge using a team-level referent. In order to assess knowledge at the team level, these individual metrics (heterogeneous or homogeneous) are aggregated across team members. Thus, for instance, heterogeneous metrics allow for the representation of heterogeneous team knowledge in command-and-control teams.

Finally, a more balanced focus on process as well as structure can be addressed by employing a social decision scheme approach (Hinsz 1999). Using this approach aggregation schemes are principled, involving more than simple averaging for example, and can involve complex aggregation schemes based on hypothesized team processes. For instance, if a leader is expected to drive team process, then data for the leader might be more heavily weighted in an aggregation scheme (see also Steiner 1972).

In general, under the collective approach to the cognitive assessment of teams, there are several possibilities for exploring heterogeneous knowledge backgrounds and for aggregating based on somewhat richer, inferred process behaviors. Nonetheless, the fact that individuals are measured and the results later aggregated approximating a "team level," makes even the more complex heterogeneous approaches another form of additive collective aggregation.

3 DYNAMIC AND HOLISTIC ASSESSMENT

3.1 Ecological and Holistic Perspectives of Team Cognition

The ecological perspective holds that team cognition emerges as the adaptive self-organization of teams due to environmental perturbations. The holistic perspective similarly holds that team knowledge emerges from the dynamic interplay of individual knowledge through team process behaviors. Unique to both of these perspectives is their focus on the team-level as the most fundamental unit of team cognition analysis, as opposed to an aggregate of individual team member mental models or other representations. Thus, both of these views can be construed as systems-level, versus aggregate, perspectives of team cognition (see Figure 2). Specifically, in a system, individual team members cannot be considered outside of their team context, whereas in an aggregate the properties of individuals do not necessarily incorporate interactions among team members (Juarrero 1999). Human factors researchers taking either of these perspectives tend to study, analyze, and theorize in terms of team-level units, such that a team comprises a single perception-action system capable of meaningful behavior in its own right.

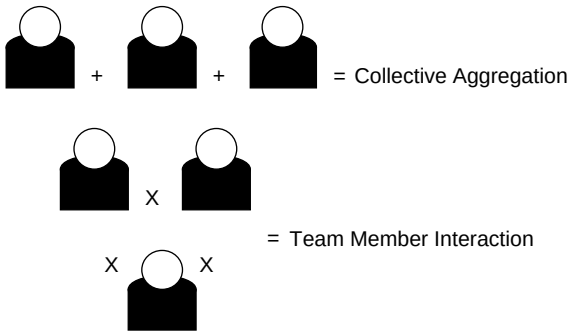

FIGURE 2 On the top panel the sum of individual cognition is the collective aggregation approach to assessing team cognition; on the bottom, team member interactions are also an important consideration for assessing team cognition.

Perhaps the most distinctive feature of these perspectives of team cognition is an emphasis on team member interactions. In the ecological perspective, team members coordinate through mediated couplings (e.g. full duplex radio communications) about various aspects of the team environment to which they are specifically attuned. Team members thus make their direct perception of ecological affordances, or opportunities for behavior (Reed 1996); indirectly available in the local environments of other team members given isomorphic team goals and constraints and dimorphic team member orientations. In this sense, team members themselves thus afford activity for other team members. This dynamic system of sharing complimentary aspects of awareness of the team environment thus affords behavior at the team level. Similarly, in the holistic perspective, team members coordinate through the "pushing and pulling" of information via team process behaviors. In this view, information is considered to be transferred directly from one team member to another such that team members have direct access to the elements of information necessary for accomplishing their complimentary roles in the team task. In both of these perspectives a measure of coordination or coordinated knowledge, respectively, is taken as the fundamental unit of analysis.

3.2 Holistic Elicitation and Communication Analysis

When taking a holistic perspective, discrete sampling of declarative knowledge is acceptable to the extent that the measure reflects coordinated team knowledge. One way to migrate collective approaches toward this more holistic goal is to conduct knowledge elicitation at the team level (Cooke *et al*. 2004). That is, one could elicit relatedness ratings or answers to taskwork questions from the team as opposed to the individual. A team response will necessitate

team process and this approach will be viable to the extent that the process used by the team to generate the ratings or answers are similar to the processes used to interact in the actual task. In our research, we have used a consensus task in which team members interact in order to come to consensus on a relatedness rating or other query. Once consensus is reached the response is given by the team and the next item is considered. Data from this approach can be submitted to the same analytic processes as individual data with the results presumably reflecting the holistic representation of process-imbued team knowledge. We have had mixed success with this method and we suspect that one problem is that the consensus process that we instantiate may not reflect the actual team processes.

To the degree that team members interact using verbal or textual messaging, a finer-grain holistic assessment of team cognition can be accomplished through communication analysis. By observing the content and flow of team member interactions, a human factors researcher can gain direct access to the processes as well as the products of the team mind. Assessment methods using communication data can be generally characterized by their emphasis on either content or flow of communication.

Flow methods generate analyses based on the physical act of speaking (or typing) rather than the meaning of what is said. Flow methods tend to focus on the sequencing and timing of communicative interactions among team members, but may also incorporate assessment of more static quantities such as total speaking time for different team members over a task or mission. Procedural networks, Petri nets, and time series models are examples of flow methods used in human factors research. Content methods focus on an analysis of the meaning of communications. Semantic analysis, keyword indexing, content coding, and word counts are examples of content analysis methods used in human factors research. Combining flow and content methods give a human factors researcher a window into the team-level cognitive processes underlying team cognition.

To the extent that verbal or textual media are primary for team member interaction, communication analysis can also provide a method for assessing team coordination. Given a normative model of team member interaction at critical task or mission points based on sequencing or content of interaction or both, observed deviations from this model are a good assessment of the team's coordination, and thus the extent of coordination underlying the team's cognitive products. In this capacity, strengths and weaknesses in terms of under utilized team members and bottlenecks, respectively, can be identified for design or training intervention. Overall, the use of continuous process data such as communication and coordination provide a sound basis for both holistic and ecological assessments of team cognition.

4 AN EXAMPLE OF MEASURE DESIGN AND TEAM COGNITION ASSESSMENT

A good example of the difference between the collective and ecological/holistic approaches is apparent in two different measures of team situation awareness. In this section we outline the essential basics of a measure of team situation awareness constructed first from a collective-homogeneous perspective and then from an ecological perspective. These examples are meant to emphasize the collective focus on individual team members coupled with a lack of focus on team member interaction contrasted with an ecological focus on team member interaction and meaningful behavior at the team-level.

4.1 Team Situation Awareness Viewed Collectively

Using a collective approach, we have measured team situation awareness (accuracy against realized criterion) by querying individuals, one-at-a-time, in the course of a command-and-control mission. The queries regard the status of events (mostly future) in a mission. For instance, individual team members reply in turn to the query: "how many targets will your team get in this mission?" Then post-mission, responses are assessed for accuracy and intrateam similarity. Team situation awareness is then quantified as the mean accuracy of the individual team members and intrateam similarity. Note that this collective procedure assumes homogeneity in that all team members are queried similarly and thus expected to understand the situation similarly. Further, individual data are aggregated by averaging in order to obtain a team score, against which other teams under other task conditions are compared.

4.2 Team Situation Awareness Viewed Ecologically

Here, we assume that the picking out of new opportunities for behavior due to perceiving changing structure in the team environment indicates an awareness of a changing situation. Further, we assume that the picking out of affordances for a team member can stem from interactions with other team members as well. Taking an ecological perspective on team cognition, team situation awareness can be assessed as teams dynamically self-organize through the discovery of new affordances when confronted with an environmental event that somehow changes the structure of the team environment. This change in structure corresponds to a barrier, or roadblock, that may encumber a team in the near future while the team is trying to accomplish its goal or mission. Thus, whether introduced experimentally or observed during the natural course of task performance, the term "roadblock" necessarily entails impedance unless successfully negotiated.

In the course of our research we have developed a two-pronged (coordinated perception and coordinated action) measure of team situation awareness based on experimentally introducing environmental roadblocks. Initially, an environmental roadblock is made experimentally available. A team member, or members, must perceive an affordance of the roadblock through their unique perspective given a division of labor. So, for instance, given a flight planning and navigation command-and-control team, a team member charged with tracking weather might foresee a problem for his or her team on the horizon. To the extent that this requires adjustments to be made by another team member, for instance a navigator, the direct perception and pick up of what the roadblock affords the team by a primary team member (in this case the weather tracker) should be coordinated with those of a secondary, or indirect team member, to constitute a team-level awareness of what the changing environment affords. To the degree to which this translates into an indirect perception and pick up of the affordance by the secondary team member; that is, interaction with the weather tracker provides an affordance for the navigator (and *vice versa* assuming the navigator makes a route change), the perception of the roadblock's affordance is coordinated across team members (see Figure 3). Coordinated perceptual episodes can also differ in terms of the extent to which affordances are redundant or distributed across team members. However, just because a perception is coordinated speaks little of whether it is beneficial or injurious to the team (cf. the resonance of a perception within an individual). Thus, the coordinated perception is useless unless it is both adaptive for the situation at hand and it is acted on in a timely manner, requiring mediated coupling (i.e. note that the degree to which the coordinated perception entails coordinated action is another dimension along which this measure may vary).

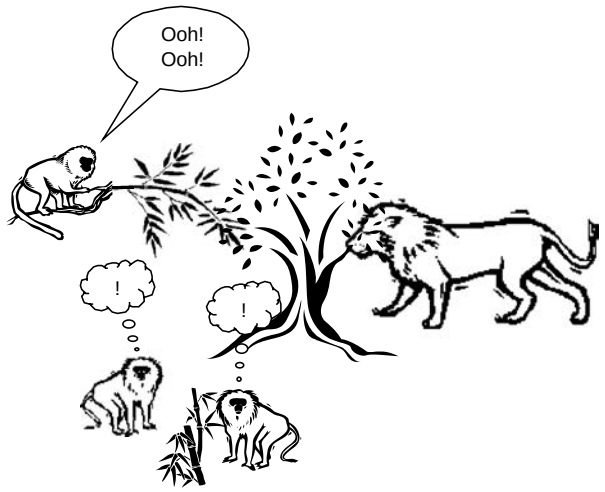

FIGURE 3 An illustration of coordinated perception.

It is by the adequacy or failure of both the coordinated perception as well as the team's coordinated actions in negotiating a roadblock from which we infer the level of team situation awareness underlying the quality of the team's adaptive, embodied behavior. Given a set of roadblocks we would score the presence or absence of coordinated perception (in our case through a vocalized exchange) and coordinated action (the roadblock is avoided) as a measure of team situation awareness in negotiating each roadblock.

5 CONCLUSION

Here we have presented human factors researchers with several options for assessing team cognition. Collective aggregation methods have been nominally applied assuming homogeneous team member roles, or what we have termed here a "group" structure. Collective aggregation methods have also been designed that acknowledge team heterogeneity and employ more complex inferred team processes, however all collective aggregation methods are limited by embracing an additive view of team cognition with little consideration for interactions among team members given a division of labor, or heterogeneous team structure.

Alternatively, we presented ecological and holistic perspectives for the assessment of team cognition incorporating a heterogeneous team structure. These approaches are distinct in that they emphasize team member interactions and their concomitant importance in the generation of team cognitive products. The ecological perspective assumes that other team members, as well as the team environment, are a source of affordances such that the direct perceptions of primary team members can be made available in the local environments of secondary team members through mediated, or indirect perceptions. This allows for adaptive self-organization of teams due to perturbations from the dynamic team environment. The holistic perspective assumes a similar sort of adaptive team coordination through the pushing and pulling of information by various team members in order to produce a coordinated team cognitive product. In both of these perspectives the fundamental unit of analysis is assumed to be at the team-level, thus assessment must incorporate the knowledge or activities of individual, heterogeneous team members as well as the contemporaneous interactions among team members. Assessment through team communication methods is a promising area in this regard.

We believe that what drives highly coordinated team cognitive products is the adaptive and timely interactions among a group of heterogeneously skilled team members, and thus should drive team cognition assessment. Therefore, we believe that the future of team cognition research will focus on either the ecological or holistic perspectives, or both. Accordingly, human factors researchers should incorporate these perspectives for assessing team cognition whenever feasible.

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