Cognitive-Based Guidelines for Effective Use of Collaboration Tools

David Noble
Evidence Based Research, Inc., USA

Introduction

Industry is creating many types of collaboration tools. These include not only general purpose group collaboration tools like e-mail and shared whiteboards, but also tools to facilitate group processes like brainstorming and negotiation, tools to help manage workflow, and tools that help people understand one another. Experience shows that not all teams collaborate effectively all the time and for all tasks. We hypothesize that teams are not taking full advantage of available collaboration tools and that doing so will improve team effectiveness.

The research described here, part of a Navy SBIR, seeks to identify and validate theory-based guidelines to help teams select the tools that are right for their team and their tasks. Identification and validation of these guidelines requires taxonomies for tasks, tools, and teams, a cognitive-focused collaboration theory, and a validation process.

This research will build on the insight and expertise of expert practitioners. Such practitioners have distilled many rules of thumb for effective collaboration. Informed by taxonomies and a cognitive theory of collaboration, the SBIR guidelines to be developed here will both generalize these existing guidelines and focus them on those collaboration environments where they are most critical.

Taxonomies

The team, task, and tool taxonomies define and organize different types of collaboration. These taxonomies allow the guidelines to be tailored and organized in terms of types of teams and tasks. The SBIR Phase 1[1] report describes the team and task taxonomies fully. The tool taxonomy, developed more recently, is summarized below.

The team taxonomy characterizes teams among six dimensions: distribution, roles and functions, team structure, team member dependencies, information and information flow, and decision making. Each of these dimensions includes several dimension subcategories. The subcategories for the distribution dimension, for example, are the different ways that teams can be distributed physically, temporally, by expertise, and by information.

The task taxonomy dimensions are cognitive, workload, divisibility, and difficulty. Like the team taxonomy, each dimension in this taxonomy also includes subcategories. For example, the difficulty subcategories includes goal clarity, resource clarity, stakes,

[1] Noble, David and Buck, Diana. Metrics for Evaluation of Cognitive Architecture-Based Collaboration Tools. Phase 1 SBIR Final Report. Evidence Based Research, Inc. 2000.

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familiarity, information availability, time pressure, transparency (how easy it is to monitor what's happening), and stability.

The tool taxonomy describes four general types of tools. These are the general purpose group communications tools, special purpose facilitators of group processes, shared work and group sensemaking tools, and process support tools. The first are the normal commercially available tools such as e-mail, VTC, web pages, instant messaging, chatting, etc. They are designed to overcome the obstacles from time and space distribution. The second group of tools is intended to improve group processes, even for people meeting together in the same room. These include, for example, brainstorming tools. The third group facilitates transfer of meaning. The fourth group helps team members understand and track team and task status.

Theory and Models

The underlying theory will explain the connections between tools, cognitive understandings, information interchange and product assembly behaviors, and the quality and timeliness of team products. This theory will provide the foundation for the guidelines. Given the theory, we hope that most guidelines will become common sense. The SBIR explains the theory using several different complementary conceptual models because we have not yet found any single model able to address all cognitive aspects of collaboration. Models that promise to be useful address "teamwork and taskwork," team feedback and agility, the interplay between individual and team processes, the coupling between understandings, behavior, and products, and the team's transactive memory.

The transactive memory model seems especially well suited to understanding the cognitive foundations of collaboration. This model is based on the work of a small team of researchers conducted over the past fifteen years.[2] The transactive memory system itself consists of the collection of individual understandings and the team mechanisms to exchange information and so update these individual understandings. The research data[3] indicates that transactive memory is a very powerful intervening variable able to explain group performance. That is, if the required transactive memory system is in place, then collaboration teams perform well. If the transactive memory contains gaps and inconsistencies, then the group experiences various predictable problems.

The transactive memory itself includes all of the understandings about teamwork and taskwork that our Phase 1 metrics assumed were important. These include understandings about how to do the tasks required to perform the mission, understandings about the status of the situation and task, understandings of how the team is organized to function, and understandings about how the team is actually functioning now. It includes the common ground elements (e.g., understanding of other team member's capabilities,

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[2] For example, Wegner, Daniel M. "Transactive Memory: A Contemporary Analysis of the Group Mind." In. Theories of Group Behavior. Brian Mullen and George Goethals, Ed. Springer-Verlag. 1987.

[3] For example, Liang, Diane Wei, Moreland, Richard and Argote, Linda. "Group Versus Individual Training and group Performance: The Mediating Role of Transactive Memory." *Personality and Social Psychology Bulletin* Vol. 21 No.4 (April 1995): 384-393

workload, knowledge). Transactive memory model is also useful for understanding concepts of "team hardening" in which teams experienced working together usually perform more effectively than do new teams in which the team members do not know each other very well.

The transactive memory model describes various categories of individual understandings in terms of their relationship to the understandings of other team members. Categories include the knowledge that each individual team member is responsible for, knowledge about who else in the team knows what and how to access it, private knowledge that each person needs to show when relevant, "meta-knowledge" about the adequacy and uses of knowledge, and team consensus knowledge, a repository for what the team has agreed to.

If the utility of the transactive memory holds up as a key intervening variable in the broad range of tasks and team types that the guidelines will address, then understanding the roles of collaboration tools will be greatly simplified. In this case, the effectiveness of collaboration tools depends on how well they help the team put in place the transactive memory needed for successful teamwork.

Guideline Identification and Development

These models and collaboration theory can help identify candidate guidelines on types of collaboration tools that best support various kinds of tasks by various kinds of teams. These guidelines will build on the insights of experienced collaboration practitioners.

A final, and most important step, is guideline validation. Validation can arise through formal controlled experimentation, observations of exercises, consensus from practitioners, and validation of the underlying collaboration theory.

Metrics are key to formal evaluation. They measure each of the different links in the tool-to-performance chain. The SBIR team has identified metrics in eight categories: for individual and team level understandings, for information interaction, for product creation and assembly, and for product quality and production efficiency.

- Product quality and production efficiency metrics are the same whether applied to individuals or teams. They are the "proof of the pudding" metrics because teams that don't do well in this category are not adequately accomplishing the mission for which they are formed.

- Product creation and assembly metrics address how well individuals and teams are developing products. On an individual level, these metrics measure task performance, schedule adherence, adaptability, and problem handling. An example is the fraction of products completed that don't need revision. Team metrics in this category may be roll-ups from individual metrics, or may be "emergent" properties. An example of the latter is a measure of "fibrillation," where the team members

work a lot, but nothing goes together in a useful way. This is captured by a metric that compares the team's product to the sum of individual products.

- The individual and team information interaction metrics concern how well team member interactions generate the understandings that the team needs. They measure the effectiveness of brainstorming, negotiating, discovering differences, and enriching ideas. An example of a metric on an individual level is fraction of time a person asked the right team member for information. An example of a team level metric is fraction of time team members spent in a meeting not relevant to their own responsibilities and not contributing to others.

- The individual and team cognitive metrics measure the level of individual and team understandings needed to support both teamwork and taskwork. An example of an individual's metric is the correctness of a person's understanding of commander's intent. Team cognitive metrics can include aggregations, team gaps or peaks, and degree of alignment of individual understandings.

Next Steps

During the past eighteen months, the SBIR research team has generated taxonomies, models, and metrics for collaboration. In the remainder of the SBIR, the team will generate and validate collaboration guidelines, with emphasis on best use of collaboration tools. In the next step, the team will apply the emerging models to interpret the reasons for reported problems and the reasons why current guidelines work. The team will then use these models to identify promising theory-based guidelines targeted on the highest priority types of teams, tasks, and problems. The third step is the empirical validation of selected guidelines. The final step is preparation of a book that will help practitioners apply the insights developed in this research.

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David Noble

Evidence Based Research, Inc.
1595 Spring Hill Road, Suite 250
Vienna, Virginia 22182-6800
ebrinc@ebrinc.com

Cognitive-Based Guidelines
Topics

- Collaboration tool guidelines
  - Opportunity
  - Taxonomies
- Theoretic foundations--the models
  - Purposes
  - Diversity
  - Transactive memory
- Validation
  - Strategies
  - Metrics

Collaboration Definition

Collaboration, as used in this analysis, is

the mental aspects of joint problem solving for the purpose of achieving a shared understanding, making a decision, or creating a product

Opportunity

- Conditions for highly effective teamwork nearly in place
  - Rich set of collaboration tools
  - High communication connectivity
  - Understanding of cognitive basis of effective teamwork
- However, collaborating teams sometimes do not work well
- Therefore, guidelines for effective collaboration can have a significant impact

Guidelines

Examples from Current Sources

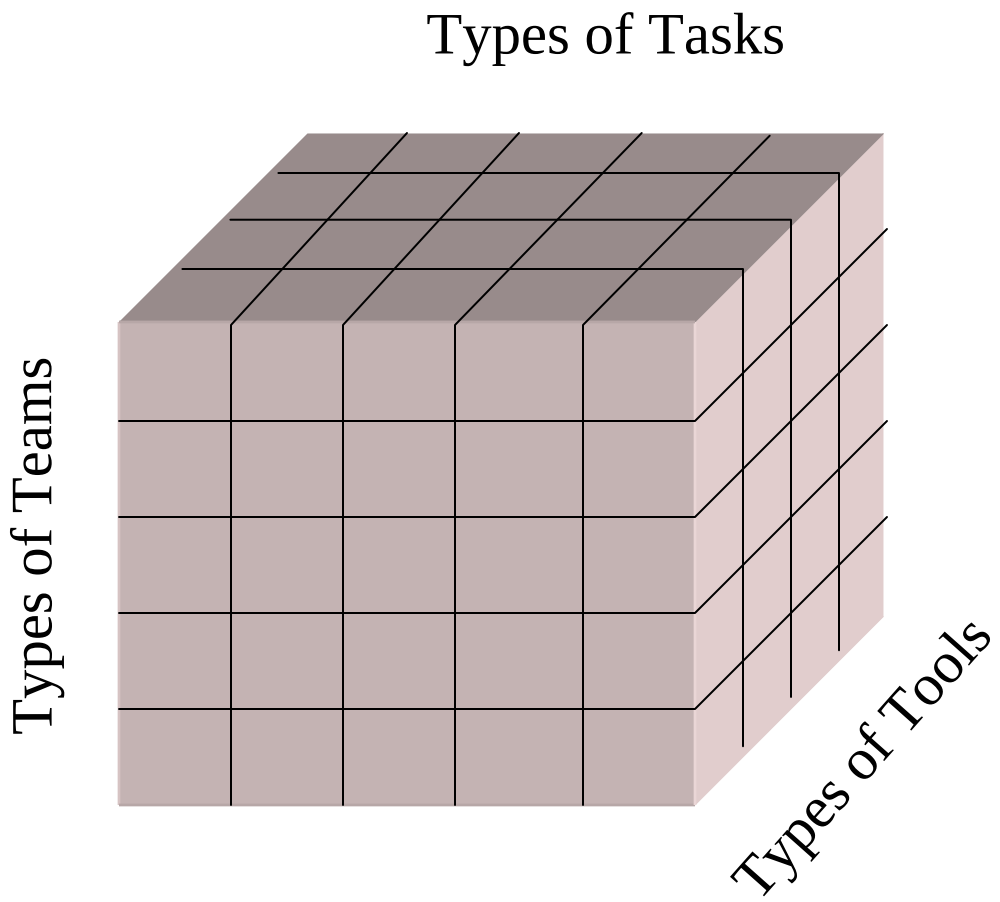
Task/Communication Mode Example (Jens Jensen)

Communication Modes	Generating ideas and plans and collecting data	Problems with answers	Problems without answers	Negotiating technical or interpersonal conflicts
Audio only	Marginal fit	Good fit	Good fit	Poor fit
Video only	Poor fit	Good fit	Good fit	Marginal fit
Data only (e.g., e-mail..)	Good fit	Marginal fit	Poor fit	Poor fit
Multi-user virtual environment	Good fit	Good fit	Good fit	Good fit

- "Expertise location software, audio conferences, web conferences, and other interactive technologies can be as effective as databases for sharing tacit knowledge
- Intranets can be powerful tools for tailoring information and improving organizational performance

Mary Boone. Managing Inter@ctively. Page 159

Taxonomies for Collaboration Environments



- Characterizes types of collaborative tasks, teams, and tools
- Describes collaboration space
- Provides framework for specifying when to apply different types of guidelines

Team Taxonomy Dimensions

- Distribution
- Roles and Functions
- Team Structure
- Team member dependencies
- Information and Information Flow
- Decision Making

Team Taxonomy Examples

Team Dimension	Dimension Subcategories
Distribution	• Physical—spatial separation • Temporal—e.g., working different shifts • Expertise—spatial and temporal distribution of experts and expertise • Information—spatial distribution of information
Team Structure	• Hierarchical vs. flat—extent that team has designated leader in charge or is peer-to-peer • Size—number of members • Permanent vs. ad hoc—extent it works together over extended period of time, or is brought together for one task • Single vs. team-of-teams—extent that teams can be decomposed into collaborating sub-teams • Turn-over—stability of team membership
Team member dependencies	• Independence—extent that each team member depends on other team members to perform his task • Interaction frequency--how often team members must interact • Synchronization—requirement for and schedule tolerance of temporal sequencing of tasks performed by different members • Cognitive—extent that team members must pay attention to each others' tasks • Task sharing—extent to which each team member has own task or all team members share the same tasks • Processing flow-- individual/parallel or sequential

Task Taxonomy Dimensions

- Cognitive domain
- Workload
- Divisibility
- Difficulty

Task Taxonomy Examples

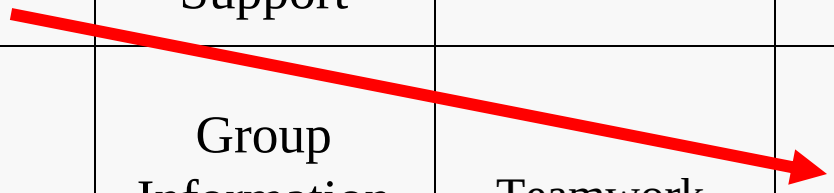
Task Dimension	Dimension Subcategories
Cognitive domain	• Stage(s) of decision making emphasized--goal specification, monitoring, situation diagnosis, opportunity/problem ID, alternative ID, alternative evaluation, selection • Interaction focus--info exchange, brainstorming, review, negotiation, consolidation, handoff
Workload	• Effort--amount of work required to carry out team assignment • Duration--length of time over which work must be performed • Expertise—amount of expertise work requires for successful completion (extent that work requires specialists) • Degree of reach--extent that assigned work requires tasks carried out at different places and at different times
Difficulty	• Goal clarity--extent that objectives are well defined • Resource clarity--extent that available resources are well specified • Stakes--importance of the outcome • Familiarity—extent that tasks are routine or novel • Information availability--extent that needed information is readily available • Time pressure--extent that task has hard real or perceived deadlines • Transparency--the ease or difficulty required to monitor the tasks status or progress • Stability—extent that tasks, resources, and information requirements may change in response to new opportunities and problems

Tool Taxonomy

- General purpose group communication tools
  - E-mail, video and audio conferencing, shared white board, shared documents and databases, bulletin boards, news groups, web pages, “sticky notes,” chat rooms
- Special purpose facilitators of group processes
  - Electronic meeting systems, brainstorming, negotiation, review and editing, idea enrichment tools
- Shared work and group sense making tools
  - Tailored interactive visualizations of shared data
- Process support tools
  - Workflow managers, electronic document management, calendar support, collaborative planning, plan monitors, dialog managers, audit trail managers, expert finders, mail lists

Modeling Goal

Individual Understandings	Individual Information Interaction Support	Individual Task Performance	Individual Products
Team Understandings	Group Information Interactions	Teamwork	Team Products



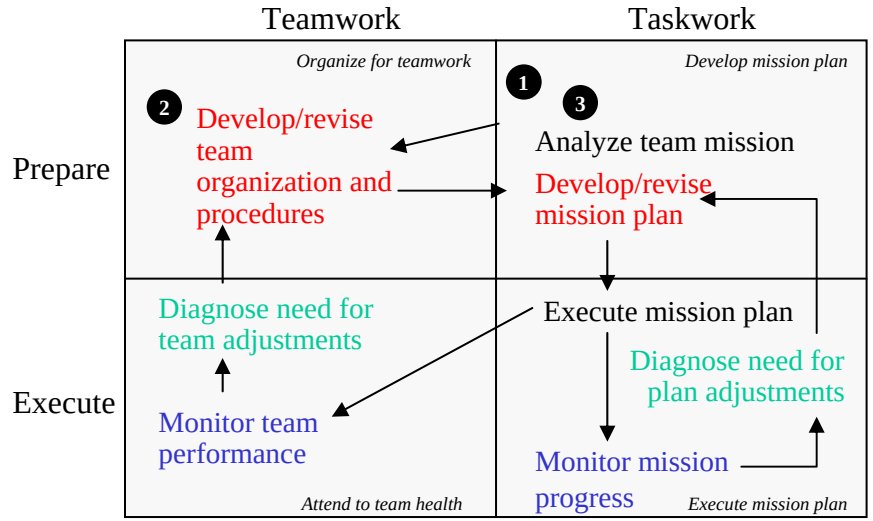
Modeling goal: Describe mechanisms that connect individual understandings to the quality and timeliness of team products and to team efficiency

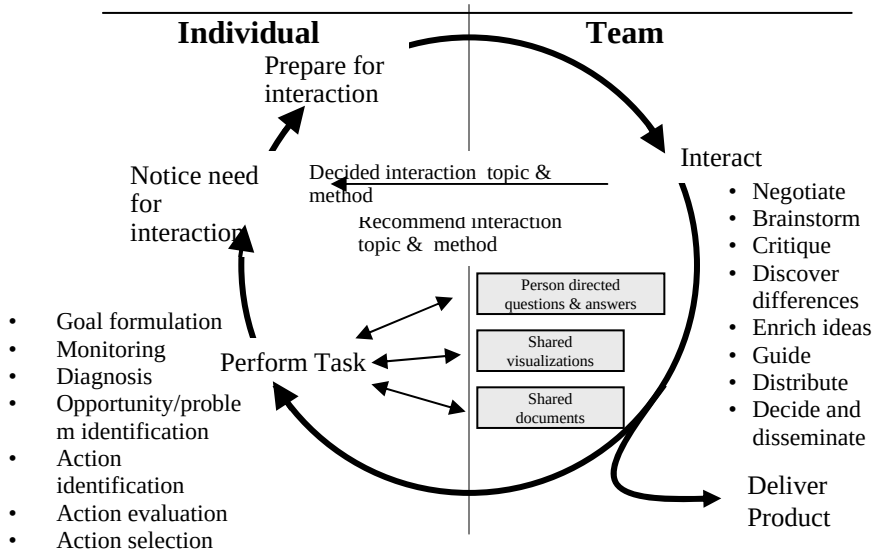
Need for Complementary Collaboration Models

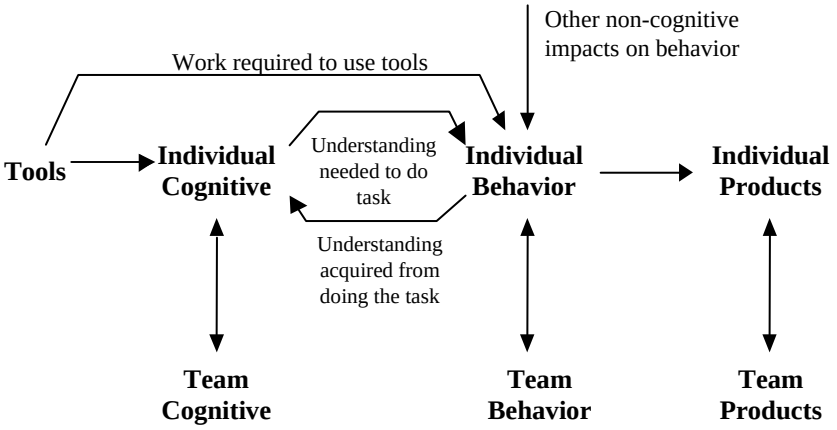
- No model can likely address all aspects of collaboration
- However, a set of complementary models, each addressing different aspects of the same underlying process, can
- Five models of value to the SBIR are
  - **Teamwork and Taskwork**: all teams engage in activities to develop tasked product and to maintain team health
  - **Feedback:** teams must monitor progress and make corrections for both teamwork and taskwork
  - **Individual/Team Interplay**: many collaborative tasks call for a cycle of individual and group processes
  - **Coupling Cognition, Behavior, and Products**: team processes and products emerge from individual understandings, behaviors, and products
  - **Transactive memory**: the relationship among team member's individual understandings drives the quality of team performance

Complementary Collaboration Models

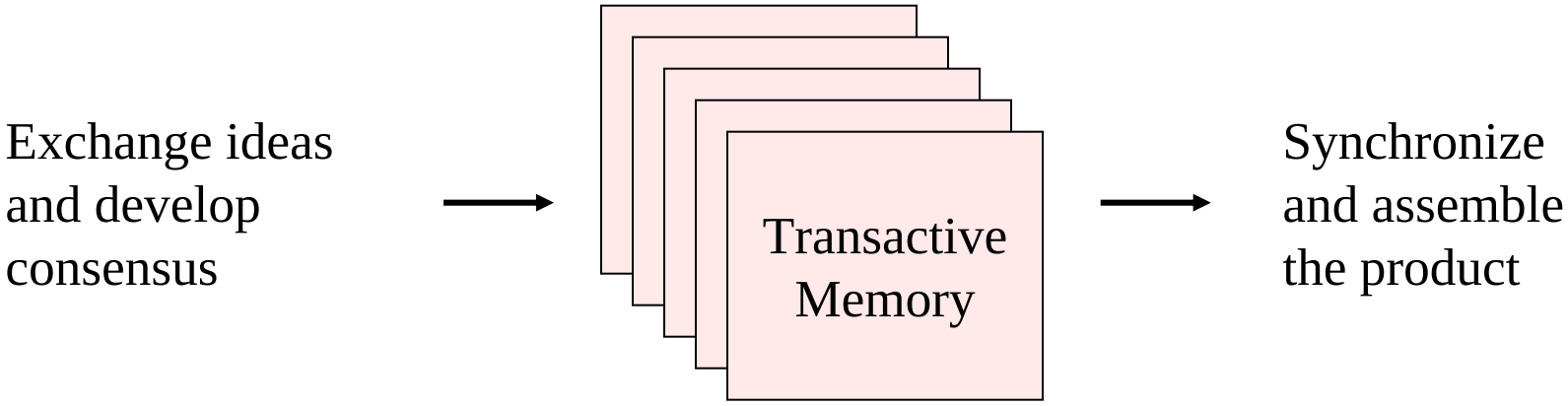
	Teamwork Team organization and maintenance	Taskwork Accomplishing mission goals
Prepare	Organize for teamwork • Agree on goals • Identify tasks • Assign roles • Develop schedule • Identify interaction criteria and methods	Develop mission plan • Analyze mission • Identify tasks • Allocate tasks • Develop schedule • Assign resources • Identify constraints • Develop contingencies
Execute	Attend to team health • Monitor team processes • Cue and alert to possible problems • Diagnose nature of team problem • Reengage "organize for teamwork"	Execute mission plan • Monitor • Assess situation • Decide on needed plan adjustment • Issue directives • Execute / develop products







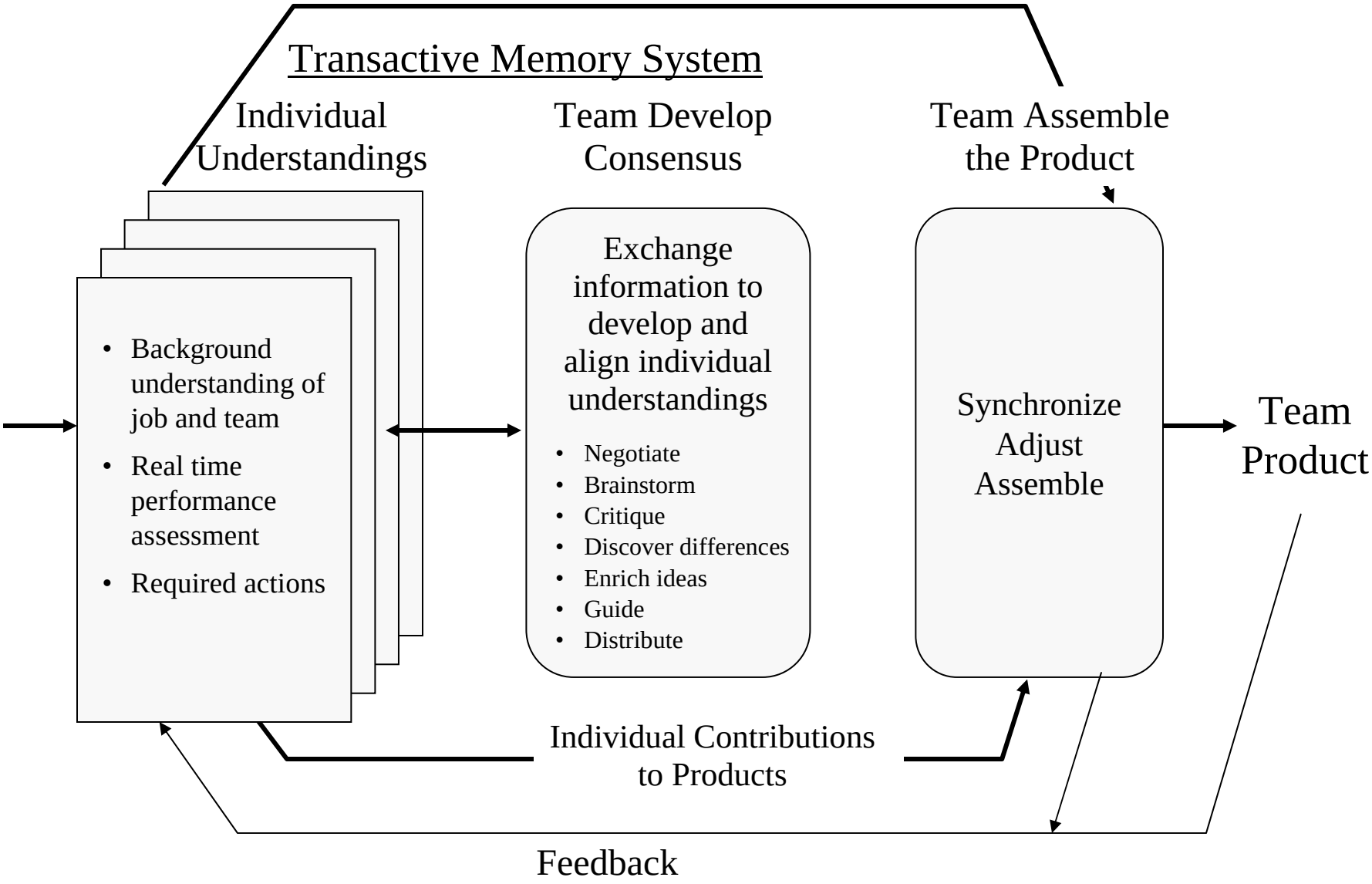
Transactive Memory As a Key Intervening Variable



Transactive memory is the distribution of knowledge within a team

It functions as a powerful intervening variable between group discussions and group behaviors

Transactive Memory Model



Individual Understandings

Organization to Support Teamwork and Knowledge Sharing

Meta memory	Private memory	Shared information	Transactive information	Consensus items
Team member's assessment of his ability to recognize when knowledge is needed and to recall and use his knowledge	What team member knows about that though not expected to be needed in this particular joint action could be critical	Items that a person is responsible for knowing within the team, and that others know he's responsible for. Multiple team members can share responsibility	Items team member knows that somebody else is responsible for, and knowledge of how to obtain that information	Things that the team has decided

Guideline Validation

- Strategies: a combination of
  - Assessments of experienced practioners
  - Observations from exercises or wargames with “natural” control
  - Hypothesis testing experiments with control group
  - Validation of model/theory that guidelines are based on
- Metrics are key element of validation

Metrics

Individual Understandings	Individual Information Interaction Support	Individual Task Performance	Individual Products
Team Understandings	Group Information Interactions	Teamwork	Team Products

Metrics
Product and Team Efficiency

- Bottom line "proof of the pudding" metrics
- Metrics for a particular product are the same, whether produced by an individual or a team
- Examples
  - Product timeliness
    - Timeliness of product production--product completion time relative to deadline
  - Product quality metrics (plan example)
    - Useful life of plan compared to its intended useful life. No plan "survives contact with the enemy," but better plans last as long as intended
    - Fraction of commander's objectives that plan addresses
    - Fraction of plausible contingencies covered by plan
  - Team efficiency
    - Total amount of time required to complete the product
    - Person hours to complete product

Metrics
Individual and Team Task Performance

- Individual
  - Measures individual performance in task performance,
  - Behavior categories: task performance, workload, level of engagement, schedule adherence, problem handling, and task flexibility
  - Metric examples
    - Fraction of individual tasks started late
    - Fraction of person's delivered products needing revision
- Team
  - Measures team behaviors
  - Includes roll-ups (computed from individual metrics) and emergent behaviors (not an aggregation property of an individuals' behaviors)
  - Emergent behaviors: team agility, synchronization, "fibrillation," and "friction"
  - Metric examples
    - Time required for team to recognize a problem in teamwork or product development
    - Fraction of preliminary individual products never used

Metrics

Individual and Team Information Interactions

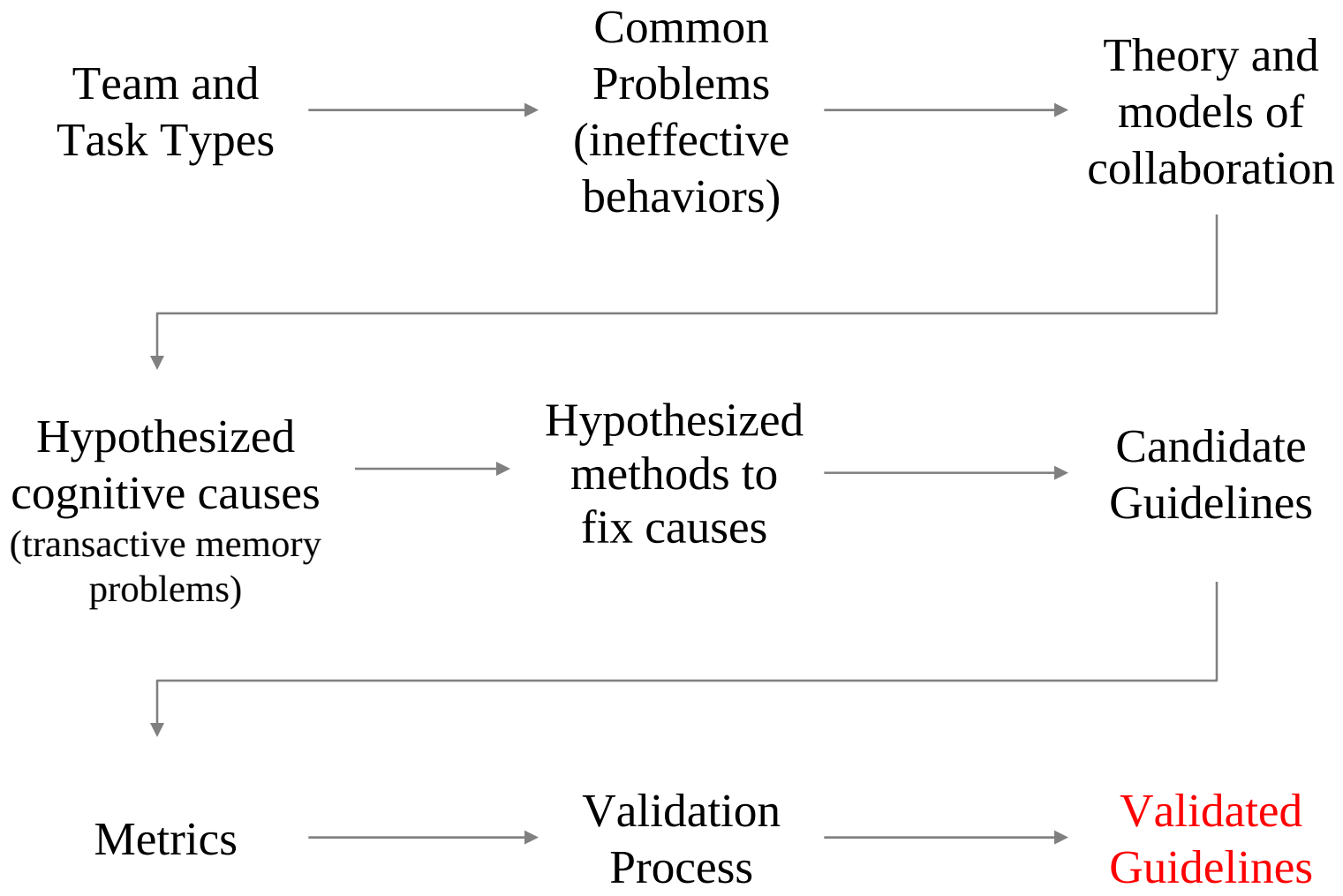
- Individual
  - Measures individual performance to support development of group consensus
  - Includes information acquisition, formulation, and dissemination
  - Metric examples
    - Fraction of times right person asked for information
    - Fraction of time information needed by others conveyed in ways that could be understood without need for clarification
- Team
  - Measures behaviors for consensus building
  - Includes team member participation in brainstorming, idea enrichment, discovery of differences, negotiation
  - Metric examples
    - Fraction of differences in understanding identified
    - Fraction of time spent in meeting not relevant to own responsibilities and not contributing to others

Cognitive Metrics

- Individual metrics
  - Team member understanding of status and processes for teamwork and taskwork
  - Organized into seven cognitive categories
    - Goal formulation, monitoring, situation diagnosis, opportunity/problem identification, identification of candidate actions, evaluation of these candidates, actions selection
  - Examples
    - Correctness of team member understanding of commander's intent
    - Correctness of knowledge of deadlines of decisions
    - Correctness of common ground elements (next slide)
- Team Level metrics
  - Three types
    - Roll-ups average individual cognitive metrics
    - Team coverage measures best knowledge in team and gaps
    - Alignments summarize extent of shared understanding
  - Examples
    - Average accuracy of each team member's estimates of information needed by other team members
    - Consistency and overlap of shared understanding of problem, goals, information cues, and strategies

Summary

Generating Collaboration Guidelines

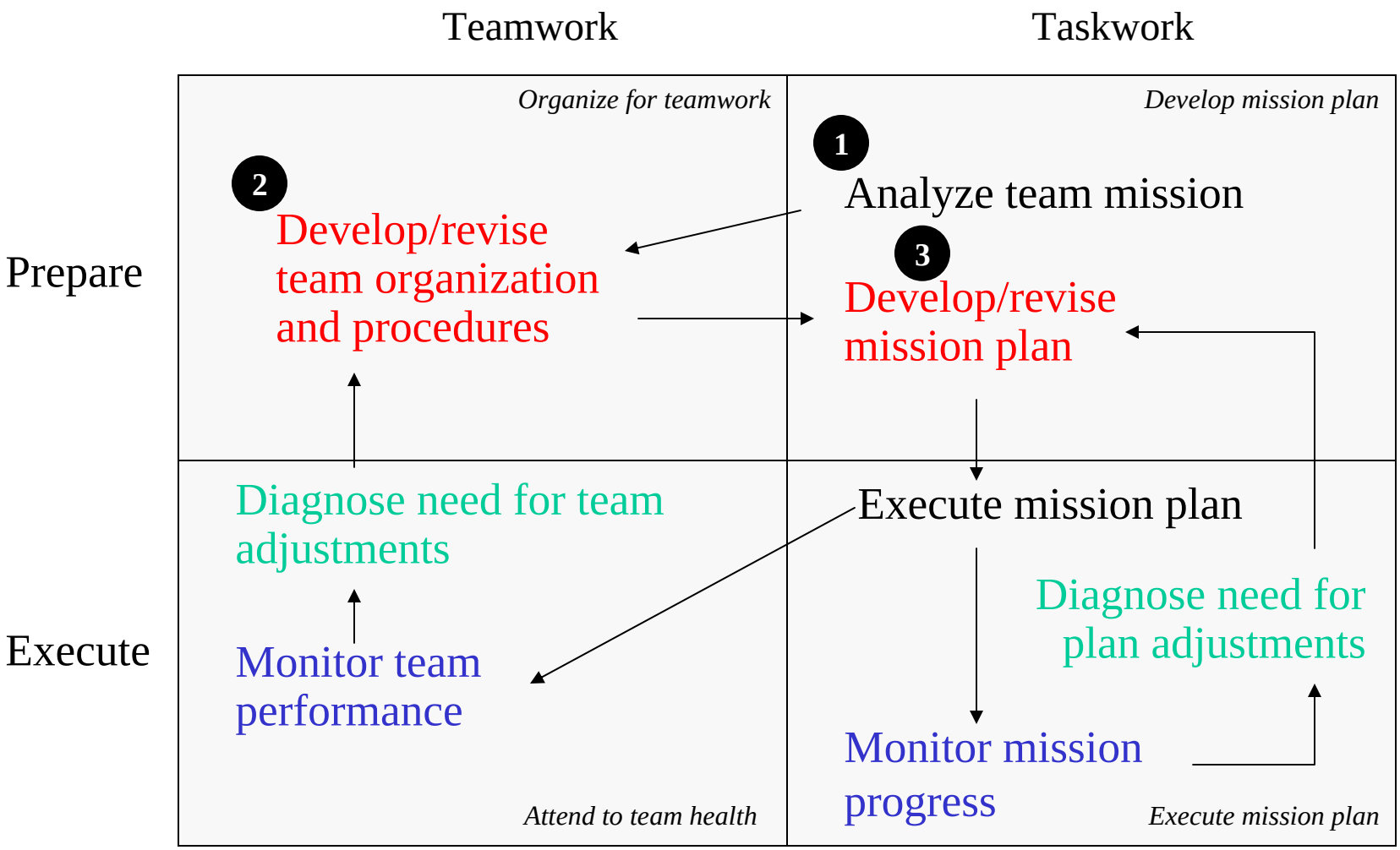


Backups

Model 1: Teamwork and Taskwork

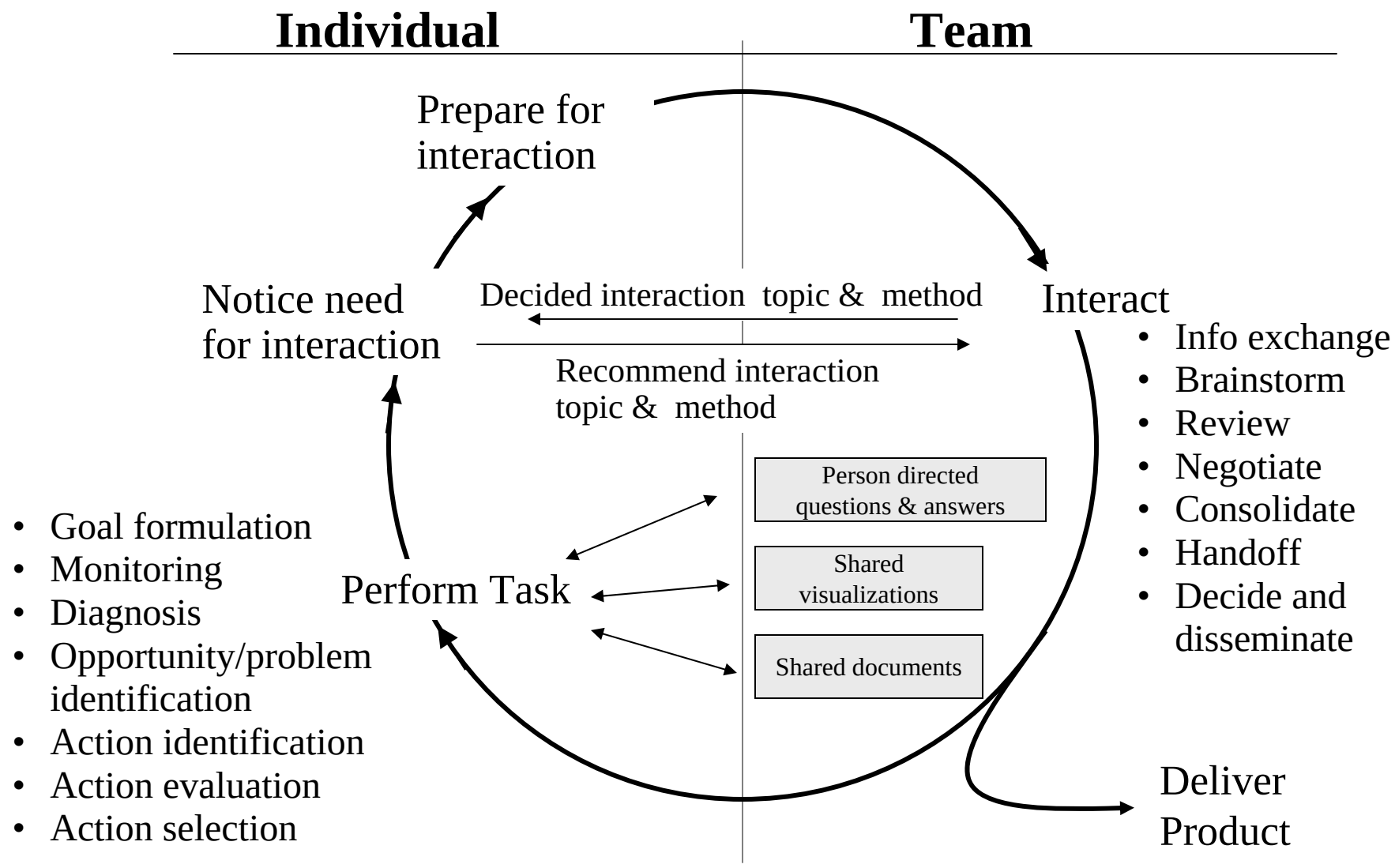
	Teamwork Team organization and maintenance	Taskwork Accomplishing mission goals
Prepare	**Organize for teamwork** • Agree on goals • Identify tasks • Assign roles • Develop schedule • Identify interaction criteria and methods	**Develop mission plan** • Analyze mission • Identify tasks • Allocate tasks • Develop schedule • Assign resources • Identify constraints • Develop contingencies
Execute	**Attend to team health** • Monitor team processes • Cue and alert to possible problems • Diagnose nature of team problem • Reengage “organize for teamwork”	**Execute mission plan** • Monitor • Assess situation • Decide on needed plan adjustment • Issue directives • Execute / develop products

Model 2
Team Planning/Execution Feedback

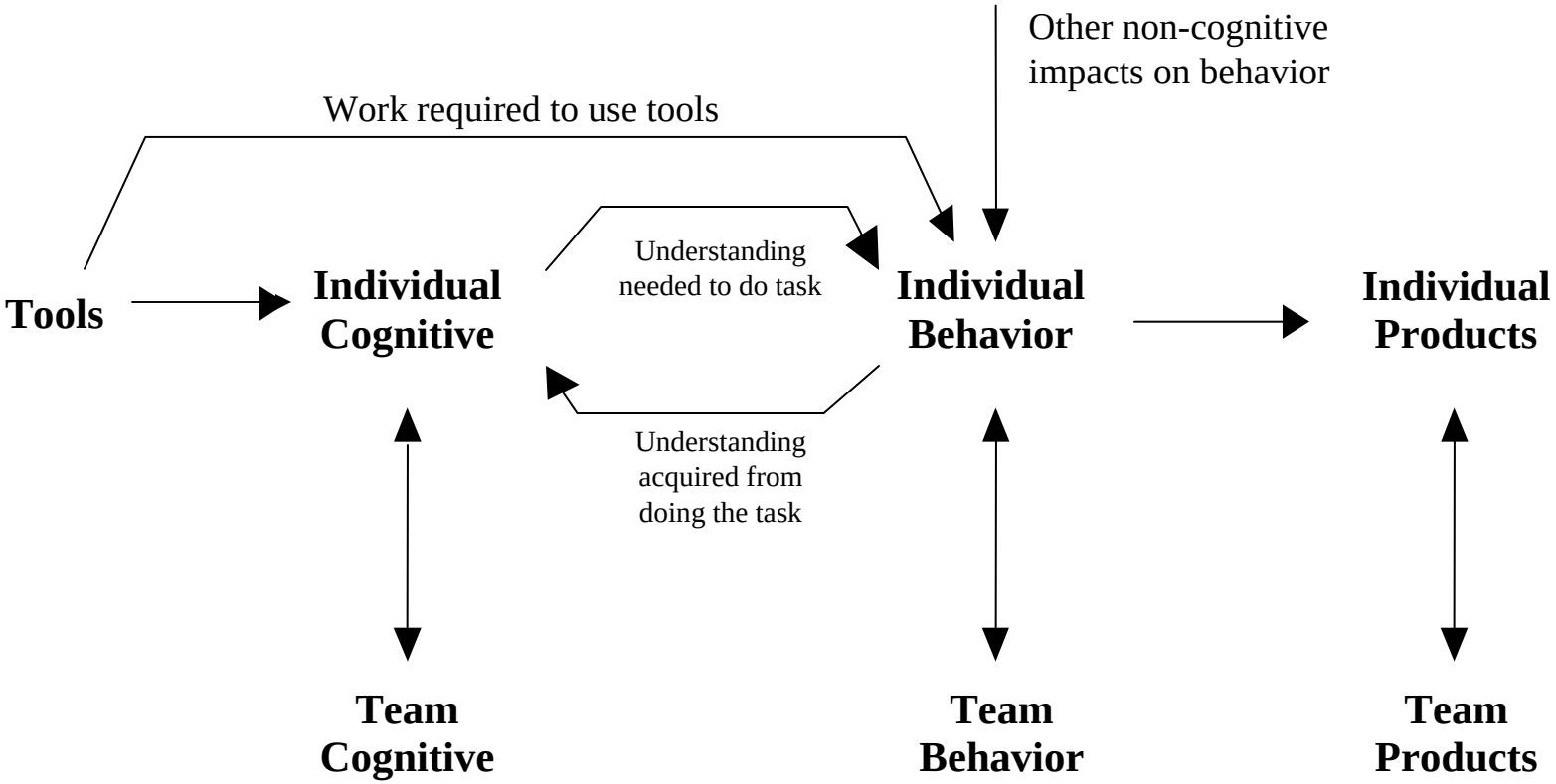


All processes may be accomplished through an interplay of individual and team work

Model 3: Individual/Team Interplay



Model 4
Coupling Cognition, Behavior, and Products



Common Ground

- What each collaboration participant assumes about each other in order to have effective interactions
- Includes each team member's assumptions about other team members'
  - Goals; e.g., where they're coming from
  - Skills, expertise, and information, to include knowledge about the external situation
  - Status, to include workload, fatigue, distraction, level of engagement
  - Degree of commitment and buy-in
  - Cognitive strategies and approach to problem solving