

Group Problem-Solving Processes: Social Interactions and Individual Actions

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INTRODUCTION

Some groups work together successfully to solve problems while others do not. In particular, researchers have shown that group work can induce many beneficial outcomes in comparison to traditional forms of instruction (increased learning, decreased racial tension, more positive student attitudes toward school, etc.; see reviews by Good, Mulryan & McCaslin, 1992; Slavin, 1990). However, these results are not universal. Newman and Thompson (1987) showed that only 68% of 37 secondary school studies favored group work over other types of instruction. This variability suggests that some conditions prevent students from enjoying these theoretical benefits. A closer examination of the group's interactions can help explain these disparities by identifying beneficial and harmful consequences of specific actions and sequences of actions. Armed with this knowledge, group members can change their behavior accordingly.

Past discourse analysis research on social interactions has typically focused on either specific situations (ethnography of communication) or the role of specific interaction elements across different situations (interactive sociolinguistics, ethnomethodology, pragmatics, variation analyses, and speech act theory; see Schiffrin [1994] for an extensive comparison of all six areas). Analyses of specific situations have shown how interactions reflect social and cultural beliefs (e.g., Goffman's [1977] study of courtesy indicating expected gender roles and Gumperz [1983] analyses of inter-ethnic conversations). Meanwhile, analyses of specific elements identify their functions and application conditions (e.g., Sacks's [1979] study of the word "hotrod" and Jefferson's [1986] study of overlaps in speaker's turn-taking). As a result, these analyses have generated lists of important aspects of an interaction to consider (e.g. Hymes' [1974] SPEAKING framework [Setting, Participants, Ends, Act sequence, Key, Instrumentalities, Norms, Genres]). However, no one has introduced a systematic model suitable for statistical analyses of many interactions both in their entirety and in fine detail. Furthermore, group

problem-solving often involves mutually contested information, unlike most interactions previously studied such as narratives or initiation-reply-evaluation (IRE) (for a review of narratives, see Schegloff [1997]; for a detailed discussion of IRE, see Mehan [1979]). To address these issues, this article introduces individual action and social interaction taxonomies and shows how sequences of individual actions help constitute productive (and unproductive) social interactions.

Past researchers focusing on individual behaviors have argued that group members facilitate the group's progress by performing particular roles (Cohen, 1994) or implementing specific strategies (Barnes & Todd, 1977; Cazden, 1988; Forman & Cazden, 1984; Slavin, 1990). By playing out a role, a person uses particular strategies. Productive roles—each of which all people should eventually master—include facilitator, proposer, supporter, critic and recorder. A *facilitator* invites participation, monitors the group's progress, and promotes group harmony (by tempering conflicts, building compromises, etc.). A *proposer* suggests new ideas. In response, supporters and critics evaluate it, seeking advantages and disadvantages. A *supporter* tries to justify the claim and elaborate it. In contrast, a *critic* challenges the original claim and identifies weaknesses. The *recorder* summarizes the group's progress.

However, limiting a group member's behavior to a single role or strategy would ignore the multiple functions that a single individual action can perform to satisfy multiple goals simultaneously. Consider, for example, the following conversation segment:

Sean: Six times two is ten.

Ana: Isn't six times two equal to twelve?

Ana performs multiple roles and uses multiple strategies. Simultaneously a critic, a proposer and a facilitator, she criticized the previous action ("isn't") by contributing an alternate proposal ("six times two equal to twelve") in the form of a question (?) to soften the criticism and invite evaluation. A systematic analysis of individual actions must explain the simultaneous multiple functions of a single behavior.

Individual actions help constitute social interactions. Researchers have shown that these social interactions during group problem-solving include cooperative coordination (Piaget, 1952; Stodolsky, 1984), division of labor via jigsaw activities (Aronson, Blaney, Sikes, & Snapp, 1978), lecture (Cazden, 1988), and scaffolding (Rogoff & Gardner, 1984; Vygotsky, 1986; Wood, Bruner & Ross, 1976). People who understand little about the immediate problem but work together cooperatively (Stodolsky's [1984] cooperative coordination) may generate multiple perspectives and coordinate them to synthesize a correct solution. In division of labor situations such as Aronson, et al's (1978) jigsaw classrooms, the expert for each task component teaches it to others. This local teaching can range from lecturing to scaffolding. In a lecture, a person explains his or her understanding (sometimes

modeling the problem-solving process). During scaffolding however, an expert adapts to a novice's progress and uses leading questions to help the novice solve a problem initially beyond his or her capacity. However, the relationships among these social interactions have not been explicated.

In the remainder of this article, I introduce taxonomies that show the relationships among individual actions and among social interactions. Then, I analyze the systematic relationships among each type of social interaction and its constitutive individual actions. Finally, I discuss some limitations and directions for future research.

INDIVIDUAL ACTIONS

As discussed earlier, "isn't six times two equal to twelve?" includes an evaluation (criticism), knowledge content (a new contribution), and an invitation for others to participate (question). In this section, I explicate these three dimensions and show how they display interactive relationships among speakers. Then, a discussion of how these dimensions organize twenty-seven types of individual actions follows (including their specific functions and conditions of use). After showing the relationships between roles, strategies and actions, I discuss social interactions and their relations to individual actions.

Dimensions of Individual Actions

Building on the past studies of group roles and strategies discussed above, I propose that all individual actions include the following dimensions: evaluation of the previous action, knowledge content, and invitational form (see figure 1). In this article, an *individual action* is a sequence of one person's words, motions, and/or drawings bracketed by pauses or falling intonations (in the case of words). Three examples of actions follow: "what do we do next?", [shrugs his shoulders], and [writes " $3 \times 5 = 15$ " on the assignment sheet].

Evaluations. The *evaluation of the previous action* (EPA) dimension characterizes how the current speaker assesses the previous action and the current problem-solving trajectory (Goodwin & Goodwin, 1987; Pomerantz, 1984) in one of three ways: supportive, critical, and unresponsive. After a person proposes an idea (for example, "two hours times six miles per hour is ten"), one can support it entirely (+), reject at least part of it (-), or ignore it (0).

Supportive (+) actions include acknowledgments ("yep"), justifications ("cause it only moves for two of the four hours"), criticisms of alternatives ("times four hours assumes it's always moving"), etc. Supportive actions tend to reinforce the direction of the current problem-solving approach (Sacks, 1987). Moreover, they

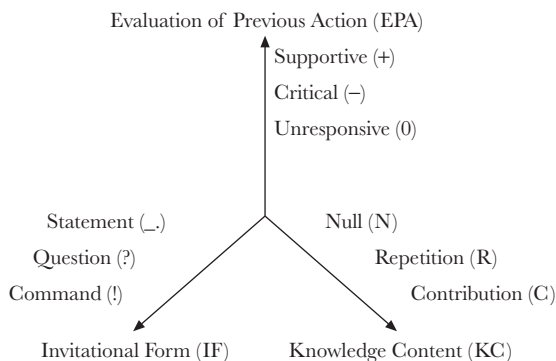


Figure 1. Properties along three dimensions for organizing different types of individual actions: evaluation of the previous action (supportive, critical, unresponsive), knowledge content (contribution, repetition, null), and invitational form (command, question, statement).

promote friendly social relationships through positive social face (Brown & Levinson, 1987), especially if the participants invest themselves in their ideas.

Critical (–) actions identify errors (“twelve, not ten”), suggest related alternatives (“how about four hours times six?”) or challenge the previous proposal (“why two hours?”). Criticisms tend to alter the problem-solving trajectory by identifying flaws and developing alternatives. In addition, cognitive rejection of the idea can threaten psychological rejection of the person, especially without accompanying face-saving measures (Brown & Levinson, 1987).

Unresponsive (0) actions do not evaluate the proposal at all and initiate new topics (“do we have a quiz tomorrow?”). Unresponsive actions draw the conversation away from the previous speaker’s solution approach and may threaten social relationships. Unlike criticisms, unresponsive actions do not acknowledge the previous speaker, which in some contexts suggest that his or her proposal was unworthy of comment. So, if group members frequently respond to one person’s unresponsive actions (to initiate new topics), their behaviors show that person’s greater authority and control over the group.

Some actions seem both responsive and neutral. For example, “let me think about that for a moment” and “finish your proposal first” seem like neutral evaluations because they postpone evaluation. When Chiu’s (1996) high school students worked together however, they typically responded to seemingly neutral evaluations in the same way they responded to criticisms; they tried to persuade the neutral person. Because neutral evaluations do not accept a proposal, these students treated them as criticisms. Unlike disciplined members of structured decision-making processes, these students tended to support or criticize ideas quickly rather than listening to a variety of proposals before judging the merits of each. For skilled collaborators however, an additional “neutral” category may be appropriate.

In short, a person can evaluate the previous action supportively, critically or not at all.

Knowledge. The *knowledge content* (KC) dimension characterizes the problem knowledge displayed during the interaction and includes at least three possibilities: contribution, repetition, and null content. *Contributions* (C) are new problem-solving ideas or actions introduced into the collaboration. They can be incorrect and hence indicate moments of *potential* problem-solving progress. Contributions include new goals, proposals, justifications, consequences, critiques, alternatives, etc. Tracing the contributions provides a map of the group's problem-solving route. Meanwhile, *repetitions* (R) repeat the knowledge content of previous actions, not necessarily the immediately preceding action (Schegloff, 1996). Repetitions can indicate the speaker's level of understanding and degree of agreement. Finally, *null* content actions (N) do not include any problem content. They include acknowledgments ("mm-hmm"), simple evaluations ("no"), and general questions ("what?"). Because null actions are often brief, they can serve as backchannel actions that provide feedback without interrupting the current speaker. (Null actions can be repeated, but they remain null actions, as repetitions repeat problem-solving information.)

The continuum of problem knowledge content runs through non-overlapping contributions, overlapping contributions, synonymous repetitions, partial repetitions, exact repetitions, and null actions. Consider each type of knowledge content in response to the phrase "two hours times six miles per hour." A non-overlapping contribution provides problem information without repeating any part of any previous action, for example, "distance." In contrast, an overlapping contribution combines new information with information from a previous action, "so the train moves twelve miles in two hours." Repetitions include substantial reiteration of a previous action. Synonymous repetitions restate previous actions, "two hours multiplied by six miles per hour." Meanwhile, partial and exact repetitions repeat part or all of a previous action precisely, "two times six" (partial) and "two hours times six miles per hour" (exact). Null actions contain no problem content ("uh-huh").

In short, knowledge content ranges from contributions to repetitions to null actions.

Invitation to participate. The *invitational form* (IF) dimension encourages participation from the audience to different degrees and also includes at least three possibilities: statements, questions, and commands. *Statements* (.) declare information unintrusively without eliciting participation from others, "five times seven is thirty-four." In contrast, *questions* (?) invite audience participation somewhat intrusively by articulating an action/information gap for them to fill, thereby requesting an action, problem information and/or an evaluation. Finally, *commands* (!) demand audience participation. Typical commands begin with verbs (with the audience as the implicit subject), "multiply two times six!"

These three forms invite varying degrees of interaction within each property as well. Statements (.) vary from low to high interactivity in the following ways: definitive vs. uncertain and summary vs. goal. Definitive statements discourage further discussion of what the speaker perceives to be a known truth (“two times six is twelve”) while uncertain statements encourage input on the validity of the statement (“two times six seems like twelve”). Likewise, summary statements tend to close interactions by articulating what the group has already accepted (“so we got twelve miles by multiplying two hours and six miles per hour”) whereas goal statements encourage interaction by presenting a target towards which the group can work (“we need to find the distance”). In short, definitive summaries, definitive goals, uncertain summaries, and uncertain goals are all statements, but invite increasing audience participation.

Rhetorical, tag, choice, open, and directive questions (?) also invite different degrees of interaction. Although the form of a rhetorical question invites responses (“can’t you do anything right?”), the speaker knows the answer and does not expect a response. Tag questions follow statements and anticipate simple acknowledgments, “two times six is twelve, right?” Meanwhile, choice questions offer multiple possibilities from which the audience can select, “should we add or multiply?” When speakers ask open questions, they do not restrict the answers and invite a greater variety of responses, “what should we do next?” Finally, directive questions expect audience implementation of a proposal, “can you compute the speed?” Rhetorical, tag, choice, open, and directive questions invite successively greater degrees of interaction.

Finally, people can invite different degrees of participation using open, closed or halt commands (!). Open commands request general input from the audience, “give me your opinion,” whereas closed commands specify particular actions, “measure the length of the box.” Although most commands demand audience action, halt commands demand audience inaction, for example, “wait!” As a result, halt commands are less invitational than statements as they discourage participation. Because halt commands have negative (–) evaluation and null (N) knowledge content components that distinguish them from other commands, they can be analyzed separately. Open and detailed commands demand audience participation, but halt commands demand audience inaction.

Collaborators invite audience participation in increasing degrees from halt commands to statements to questions to non-halt commands.

Interactive properties of individual actions

Every individual action has evaluation, knowledge content, and invitational form dimensions. Because evaluations look backward into the past at the previous utterance, they help glue together individual actions to form a coherent conversation. Collaborations in which participants are highly responsive toward one

another have more evaluations (supportive or critical). While contributions help trace the group's problem-solving paths, repetitions of other speakers display areas of perceived-shared understanding (Halliday & Hasan, 1976). The invitational form dimension mirrors the evaluation dimension and projects forward into the future by inviting audience participation to different degrees. Together, evaluations, repetitions, and invitational forms link adjacent actions to help create coherent interactions and allow quantitative tests of collaboration quality.

Specific individual actions

Next, I examine twenty-seven individual actions organized by properties from the evaluation of previous action (EPA), knowledge content (KC) and invitational form (IF) dimensions.

Supportive actions. Consider supportive evaluations (+), beginning with contributions (C): supportive additions, supportive proposals, and implementation commands. This set of actions justifies the previous actions, articulates additional beneficial consequences or continues with an appropriate action. The following examples are actions that follow the action "two miles per hour times six hours." Supportive additions (+C_) indicate that the speaker understands and accepts the previous action (according to his or her own interpretation), for example, "that gives us the distance." Speakers may choose supportive proposals (+C?) that suggest less certainty to test their ideas or to test the other group members' understandings, "that gives us the distance, right?" Finally, speakers use implementation commands (+C!) to order others to perform consequent actions, "so multiply two and six."

People can support the previous action (+) by using repetitions (R) that indicate their understanding. They include confirmations, verifications, and repeat commands. Confirmations (+R_) may confirm understanding of the previous action, "two times six", indicate that the speaker is trying to make sense of it "two times . . . six," or repeat the previous action to check its validity, [writes "two miles per hour times six hours" and looks at it]. To test whether the other group members understand the previous action (Gibbs, 1988), a person may use verifications (+R?), typically through synonymous or partial repetitions, such as "see how it's hours times miles per hour?" People use repeat commands (+R!) to pass along the instruction to another person "John, multiply two by six."

People can also support previous actions (+) through null actions (N): acknowledgments, supportive requests, and executions. By using acknowledgments (+N_), a person can indicate acceptance of the current speaker's idea without interrupting (backchannel feedback), e.g., "uh-huh" and [nods]. Supportive requests (+N?) include continuation requests and tag questions. Continuation requests are open questions that ask for the next step in the solution, "what's next?" while tag

questions ask for confirmation of the previous action, “right?”, expecting a “yes” or “no” response. Finally, executions (+N!) affirm previous proposals (C?) and command others to act upon them, “do it.”

In short, people can support the previous action by contributing new ideas (supportive additions, supportive proposals, and implementation commands), repeating past actions (confirmations, verifications, and repeat commands), and performing null actions (acknowledgments, supportive requests, and executions).

Critical actions. Next, consider critical evaluations (-), beginning with contributions (C): critiques, counter-proposals, and counter-orders. Critical contributions present new ideas that reject at least part of the previous action by providing an alternative, revealing a flaw in the reasoning, showing an undesirable consequence, etc. They also include simple repairs of unintended actions, both one’s own and those of others (Schegloff, Jefferson & Sacks, 1977). People use critiques (-C_) directly to state their objections to the previous action with an alternative (“two PLUS six”), a revealed flaw (“the train only goes four hours”) or an unwanted consequence (“but by then the train has passed the car”). Counter proposals (-C?) soften critical suggestions by inviting others to evaluate the criticism, “shouldn’t we multiply by two because the car only goes for two hours?” The question form may also indicate low confidence in the suggestion, “should we multiply by two?” In contrast, a counter-order (-C!) not only criticizes the previous action but expects the audience to act immediately on a new order, “do two times four, not six.”

People can also criticize (-) with repetitions (R): repeat critique, exact challenge, and repeat counter-order. Repeat critiques (-R_) reject the previous action by repeating an earlier action (“it’s only going four hours”) or indicate violation of an earlier premise (“you said that it was only going four hours”). This tactic should be extremely persuasive if the audience had agreed upon the earlier premise. Exact challenges (-R?) can soften premise violations “didn’t you say that it was only going for two hours?” or question the validity of the previous action by requesting clarification, “it’s going for two hours?” If a person issues a repeat counter-order (-R!), he or she has repeated an order over someone’s criticism, “do two times four anyway!”

People also criticize (-) through null actions (N): denials, general challenges, and halts. Denials (-N_), the mirror images of acknowledgments, provide negative backchannel feedback, such as “uh-uh” and [shakes her head]. Unlike exact challenges, general challenges (-N?) do not specify the area of concern, “why?” Finally, people use halts (-N!) to prevent someone from performing an action, “Stop!”

In short, people can criticize the previous action by contributing new ideas (critiques, counter-proposals, and counter-orders), repeating past actions (repeat critiques, exact challenges, and repeat counter-orders), and performing null actions (denials, general challenges, and halts).

Unresponsive actions. Finally, individual actions that ignore (0) the previous action and contribute new ideas (C) include: announcements, proposals, and sudden orders. Announcements (0C_) are statements that initiate a topic of discussion (“we have to find the distance”) or occur during brainstorming (“we can try graphing it”). Proposals (0C?) serve the same purpose, but also elicit evaluations or information from others (“are we finding the distance?” and “what’s nine times twenty-two?”). Finally, sudden orders (0C!) demand implementation from the audience without requesting any input, “multiply two times six”.

Now consider actions that are both unresponsive (0) and repetitions (R): nostalgic actions, nostalgic requests, and nostalgic orders. By using these actions, the speaker reconsiders an earlier idea without regard to the current conversation. Nostalgic actions (0R_) may indicate building new understanding of the old idea “distance is rate times time!” or an attempt to do so “rate times time . . .” without intruding upon others. In contrast, nostalgic requests (0R?) engage others to consider a past idea, “rate times time equals distance?” while nostalgic commands (0R!) demand that the audience act on a past idea, “multiply the rate and time again!”

The last set of unresponsive actions (0) are null actions (N) that ignore the previous action but do not specify another direction for the conversation: external actions, general requests, and starters. External actions (0N_) indicate that the speaker is attending to something other than the problem-solving activity, such as looking out the window or humming a tune “skiddly dee dop, da dee dop, da dee dop.” Meanwhile, general requests (0N?) invite others to participate in a new series of actions “what are we supposed to do?” or to summarize “what did we do?” Finally, starters (0N!) initiate activities without specific instructions, “get to it!”

In short, people can ignore the previous action by contributing new ideas (announcements, proposals, and sudden orders), repeating past actions (nostalgic actions, nostalgic requests, and nostalgic orders), and performing null actions (external actions, general requests, and starters).

Relating roles, strategies and individual actions

This classification captures the simultaneous multiple effects of an individual action that theoretical constructs such as roles and strategies can not. To explicate how individual actions cover most roles and strategies (see Table 1), recall my earlier discussion in the introduction. Roles include facilitator, proposer, supporter, critic and recorder. A facilitator can invite participation through questions (?) and commands (!) and monitor group progress through supportive (+) and critical (–) evaluations. To promote group harmony, facilitators can soften criticism with critical questions (–?) and balance support with criticism (+ and –). A proposer can suggest new ideas through contributions (C). In

Table 1. Relationships between collaboration roles, strategies, and individual actions. Each role includes particular strategies that collaborators can implement through specific actions.

| Role | Strategy | Individual Action |
|-------------|-------------------------------|---|
| Facilitator | Invite participation | Question (?) Command (!) |
| | Monitor progress | Supportive Evaluation (+) Critical Evaluation (-) |
| | Softening criticism | Critical Question (-?) |
| | Balance support and criticism | Adjacent Supportive (+) and Critical (-) Evaluations |
| Proposal | New Idea | Contribution (C) |
| Supporter | Show Benefits | Supportive Contribution (+C) |
| | Elaborate Idea | Supportive Contribution (+C) |
| Critic | Show Flaws | Critical Contribution (-C) |
| | Alternative Idea | Critical Contribution (-C) |
| Recorder | Summarize | Supportive Repetitions (+R) |

response, supporters can show their benefits and elaborate them with supportive contributions (+C). Critics can show flaws and provide alternatives with critical contributions (-C). Finally, a recorder can summarize the group's progress through supportive repetitions (+R) of previous ideas.

SOCIAL INTERACTIONS

This section examines the collaborative consequences of different social interactions. In particular, I discuss two dimensions, problem knowledge and degree of cooperation, for organizing social interactions. Then, I show how the individual actions discussed earlier help constitute these social interactions.

Problem knowledge of participants during a social interaction

Group members' knowledge of a problem affects how they work together to solve it. For example, Forman and Cazden (1985) showed that student pairs in which one person knows a solution differed from those in which neither person

knew a solution. Consider the following problem: “find the shortest route between Boston and Quebec.” A person’s knowledge of the problem may include goals, observations, methods, and/or algorithms. At one extreme, a person may understand almost nothing about the problem and struggle to even make sense of it (“what’s a route?”). In contrast, a person who knows an algorithm for a problem treats it as an exercise to be solved with little effort (“just use the Hamiltonian procedure”). As a result, people with different problem knowledge view a given problem differently.

A person’s problem knowledge can be classified as either knowing a problem-solving approach (including methods, but not necessarily algorithms) or not knowing one. In this article, the term “locally knowing person” (LKP) refers to the former and “locally unknowing person” (LUP) refers to the latter. At the beginning of a problem, LKPs have a sequence of actions they are ready to try, whereas LUPs have at best a few scattered observations. In contrast to a group of active LKPs working steadily on the problem, LUPs may alternate periods of silence (uncertain how to proceed) with periods of activity (when an LUP has an idea). Thus, LKPs and LUPs behave differently during collaborative problem-solving.

A person’s problem knowledge can also change during the collaboration. When a person learns how to solve a problem, an LUP can become an LKP. People can also recognize flawed solutions, so an LKP can become an LUP. An LUP’s observation may change his interpretation of the problem so that he can then apply an algorithm. On the other hand, an LKP may recognize that a problem approach does not work. The latter case shows that this dimension is more accurately characterized as a person’s *self-perceived* problem knowledge rather than actual problem knowledge. For this type of analysis, discourse markers such as “Oh!” (indicating sudden understanding as in “Oh! We should divide!”) provide critical guidance (for detailed discussions and examples of discourse markers, see Brown & Levinson [1987], Halliday & Hasan [1976], Levinson [1983] and Schiffrin [1984a]).

Each of the N people in a group is either an LKP or a LUP, so there are 2^N possible combinations. However, these possibilities reduce to three major categories when considering possible goals: (a) finding a way to solve the problem, (b) ensuring that everyone understands, and (c) computing an answer. If no one knows a problem approach, then they try to find one. If at least one person knows one, the LKP’s goal can be to teach the others. Finally, if everyone knows a solution approach, then they implement one. Thus, the problem knowledge dimension for organizing social interactions consists of three major categories: no one knows a solution approach (all LUP); some know (at least one LKP and at least one LUP); and everyone knows (all LKP).

Each problem knowledge distribution predicts different group behaviors in the areas of solution correctness, rejection of ideas, speed, and explanations. Groups with at least one LKP are likely to solve the problem correctly. Likewise, for

relatively short interaction segments, groups with all LKPs typically produce results consistent with the problem situation whereas those with all LUPs are likely to produce some results that are inconsistent with the problem situation. In addition to incorrect ideas, LUPs also mistakenly criticize correct ideas. As a result, the presence of LUPs predicts rejected ideas, unlike all LKP groups. LKPs have approaches to the problem, so they tend to act quickly to obtain a result. In contrast, LUPs, uncertain of what to do, tend to take more time, typically in shorter speaker turns because they have, at best, fragments of a problem approach. Lastly, LKPs may explain goals and methods to LUPs, whereas groups consisting of either all LUPs or all LKPs should display few explanations. The all LUP groups are less likely to know them, and the all LKP groups are less likely to need them.

In short, all LUP groups display incorrect solutions, rejected ideas, slow problem solving, and few, if any, explanations. In groups with some LUPs and some LKPs, there are correct solutions and many explanations. Lastly, all LKP groups solve the problem correctly, do not reject partial results, work quickly, and provide few explanations.

Degree of cooperation during a social interaction

Stodolsky (1984) argued that people in a group can interact in different ways: working independently, displaying information to each other, explaining ideas, or completely cooperating. In the simplest case, independent people work alone. People may also show each other their answers (display) or describe their reasoning processes behind the solution (explain). Meanwhile, completely cooperative people coordinate their different problem-solving approaches.

All of these may occur within a single activity. For example, people may work independently and arrive at an answer without saying anything to one another. Then they may exchange answers (“I got ten”). After giving different answers (“wait, I got eight”), someone may show his or her reasoning (“I did five miles per hour times two hours”). Finally, they may attempt a new solution in which they all contribute ideas, evaluate them, and build on them to construct a solution (“He’s going at five miles an hour, right?” “But you slow down” “Yeah, but only for a little bit” . . .). Only the last category (interacting with each other’s reasoning) requires moment-to-moment cooperation. In the other cases, a person can act alone and need not actively engage with other people. As shown below, the two categories of cooperative and relatively independent are sufficient to show the relationships among different social interactions in this taxonomy.

The degree of cooperation also predicts specific group behaviors: addressing, attention, response, degree of overlap, speaker turn length, and encouragement of participation. In a cooperative group, a person directly addresses someone by

speaking to a specific target audience. In independent groups however, a speaker may toss out ideas to no one in particular. Cooperative audiences listen attentively to a speaker and respond when appropriate. In contrast, people working independently need not attend to a speaker. As a result, they may ignore the speaker or interrupt with unrelated ideas. Meanwhile, cooperative audiences are likely to respond with words and ideas that overlap with and build on those of the previous speaker. Whereas independent speakers may dominate a collaboration and discourage audience participation, cooperative speakers often speak in short turns and invite others to participate (“tell us what you think”). (As noted earlier, LUPs may also speak in short turns because they have little problem knowledge to contribute.) On the other hand, an LKP working independently may speak in a few long turns. Unlike relatively independent groups, cooperative groups display all of the following behaviors: direct addressing, attentive listening, responsiveness, overlapping ideas across turns, short speaker turns, and invitations to others to participate.

In summary, problem knowledge distribution (no one knows, some know, everyone knows) and degree of cooperation (independent, cooperative) can organize social interactions.

Types of social interactions

The combinations of properties from problem knowledge distribution and degree of cooperation organize six different social interactions (see Table 2): (a) piecemeal guessing, (b) joint construction, (c) lecture, (d) guided construction, (e) accepted demonstration, and (f) automatic joint solution. Each type of social interaction is likely to occur in specific contexts and yield particular collaborative problem-solving results. Changes in one or more collaborator’s problem knowledge or cooperation can cause transitions to different social interactions during a single problem-solving session. These changes can be external, such as a collaborator joining (or leaving) the group or an outside person introducing a complication into the problem situation. Changes can also arise internally through an insight from the discussion or a disruptive disagreement.

Piecemeal Guessing. Consider the following unproductive piecemeal guessing segment. (All examples in this article are from diverse students working together in an urban, public high school 9th grade algebra classroom [see Chiu, 1996]. The last three columns indicate evaluation of previous action [EPA], knowledge content [KC] and interactive form [IF] respectively. A number inside parentheses, (), refers to the length of silence in seconds while words inside brackets, [], indicate non-verbal behavior. Dashes,—, indicate no pause between speakers.)

Cruise Ship Problem: A ship left port 5 hours ago moving at 22 mph. When will a helicopter moving at 90 mph catch the ship?

[Four students are looking down at their own papers for this entire segment]

Table 2. Types of social interactions, their constituent actions and other properties.

| Distribution of Knowledge | Degree of Cooperation | |
|--|--|--|
| | Independent | Cooperative |
| All Locally Unknowing Person(s) | <p>Piecemeal guessing</p> <p>Unresponsive statements across turns (0C₋ 0R₋ 0N₋)</p> <p>Incorrect ideas, Rejected ideas</p> <p>Short turns, Few explanations</p> | <p>Joint construction</p> <p>Supportive & Critical Contributions (+C₋ +C? -C₋ -C?)</p> <p>Supportive statements (+R₋ +N₋)</p> <p>Questions (?)</p> <p>Incorrect ideas, Rejected ideas</p> <p>Short turns, Few explanations</p> |
| At least one Locally Knowing Person(s) and one Locally Unknowing Person(s) | <p>Lecture</p> <p><i>Locally Knowing Person(s):</i></p> <p>Supportive additions (+C₋)</p> <p>Correct ideas, Accepted ideas</p> <p>Long turns, More turns</p> <p>Many Explanations</p> <p><i>Locally Unknowing Person(s):</i></p> <p>Supportive statements (+R₋ +N₋)</p> <p>Questions (?)</p> <p>Incorrect ideas, Rejected ideas</p> <p>Short turns, Few explanations</p> | <p>Guided Construction</p> <p><i>Locally Knowing Person(s):</i></p> <p>Responsive contribution questions (+C? -C?)</p> <p>Supportive statements (+R₋ +N₋)</p> <p>Correct ideas, Accepted ideas</p> <p>Short turns, More turns,</p> <p>Many Explanations</p> <p><i>Locally Unknowing Person(s):</i></p> <p>Supportive Contributions (+C₋ +C?)</p> <p>Supportive statements (+R₋ +N₋)</p> <p>Questions (?)</p> <p>Incorrect ideas, Rejected ideas</p> <p>Short turns, Few explanations</p> |
| All Locally Knowing Person(s) | <p>Accepted demonstration</p> <p><i>Demonstrating Person(s):</i></p> <p>Supportive additions (+C₋)</p> <p>Correct ideas, Accepted ideas</p> <p>Long turns, Few explanations</p> <p><i>Other(s):</i></p> <p>Supportive statements (+R₋ +N₋)</p> <p>Short turns, Few explanations</p> | <p>Automatic joint solution</p> <p>Supportive additions (+C₋)</p> <p>Correct ideas, Accepted ideas</p> <p>Short turns, Few explanations</p> |

| Name | Action | EPA | KC | IF |
|------|---|-----|----|----|
| RR | (4) [crosses out several numbers on her paper] | 0 | C | _. |
| MM | I just take hmm. | 0 | N | _. |
| | (5) four hundred fifty so four fifty of those [taps “ $22 \times 5 =$ ” on a calculator] a hundred and ten in five hours. | 0 | C | _. |
| RR | Okay, I have um | 0 | N | _. |
| MM | (4) A hundred and ten in five hours, five hours at four fifty, four fifty, um | 0 | R | _. |
| | (8) [enters “450/110 =” into a calculator] Four point o nine? | + | C | ? |
| RR | (4) Wait | - | N | ! |
| | multiply ninety times something else | 0 | C | ! |
| MM | (2) Ninety times five equals four fifty. | 0 | R | _. |
| DD | (5) I think we should subtract | 0 | R | _. |

As shown by their actions, these participants were LUPs who worked independently. The unresponsive actions (0) within a speaker turn indicate the absence of a consistent problem-solving approach. Unresponsive actions (0) across speakers showed changing problem-solving paths and hence slower progress. Their incorrect contributions, absence of supportive evaluations, and absence of explanations also showed that they were LUPs. Furthermore, their unresponsive statements (0 _) showed that they ignored each other, did not connect to previous ideas, did not invite participation, and as a whole, worked independently. During piecemeal guessing segments, LUPs generate lonely ideas in a crowd.

Joint construction. In contrast, consider the more productive *joint construction* segment (Cobb, Yackel, & Wood, 1992) that follows:

Problem: Enter the equation of a line into the computer so that the line touches “black blobs” on the screen to score points

| Name | Action | EPA | KC | IF |
|------|---|-----|----|----|
| RR | Three point four. [types “ $y = 3.4$ ” on the computer] | 0 | C | _. |
| | Three point five [backspaces over “3.4” and types “3.5”] over | - | C | _. |
| | [types “/10.5”] | | | |
| MM | Negative. | - | C | _. |
| RR | [moves cursor back and types a “-” in front of “3.5”] | + | R | _. |
| MM | No, | - | N | _. |
| | wait. | + | N | ! |
| | Should that be a positive dot? | + | C | ? |
| RR | (3) It’s going up that way [motions hand towards NW direction], um. | - | C | _. |

| | | | | |
|----|---|---|---|---|
| MM | (2) If we drew a line from here [points near (-5, 0)] to here [moves hand to point near (0, -2)]— | + | C | — |
| RR | —then the little man would be walking down. So it's negative. | + | C | — |
| MM | Okay. | + | N | — |
| RR | Okay. | + | N | — |
| MM | Y-intercept? | 0 | C | ? |

These actions showed LUPs working cooperatively. As shown by their criticisms (–) and questions (?), these participants produced incorrect results, incorrect evaluations, and uncertain ideas, indicating that they lacked problem knowledge and were LUPs. Also, rather than explaining coherent problem-solving procedures, they improvised problem-solving actions. Unlike the piecemeal guessing segment, these participants cooperated by evaluating (+, –), building (+C, –C) on each other's ideas (showing attentive listening and responsiveness) and asking questions (?) to invite participation. In a joint construction, LUPs weave strands of knowledge together to create new understanding, increasing their likelihood of a correct solution compared to piecemeal guessing participants.

Lecture. Next, consider a *lecture* segment with a clearly knowledgeable participant:

Problem: Compute the talus slope of a pile of beans in a shoe box

| Name | Action | EPA | KC | IF |
|------|--|-----|----|----|
| JJ | [picks up string] What's this for? | 0 | C | ? |
| KK | (2) Okay. | 0 | N | — |
| | I know what we gotta do. | + | N | — |
| | We gotta make a stair. | + | C | — |
| | Like this. [takes pipe cleaner] | + | C | — |
| | We put this here. [puts pipe cleaner vertically into pile of beans at box corner]. | + | C | — |
| | Measure it from like there [finger at box corner] to here [moves finger to top of pile]. | + | C | — |
| | You measure it. | + | R | — |
| | And then we get our rise and run. | + | C | — |
| | And then we get our decimal thing. | + | C | — |
| | I don't know what that's [points to string] for. | 0 | R | — |
| PP | Yeah. | + | N | — |
| | We go up. | + | R | — |

These actions showed at least one LKP and at least one LUP working relatively independently. KK's series of supportive actions (+C_) within one speaker turn

explained the appropriate problem-solving procedure quickly and correctly, revealing her to be an LKP. JJ's question (?) showed his lack of knowledge (as a LUP) and invited contributions (C) from the LKPs. Although PP acknowledges (+N_) KK's procedure and confirms (+R_) it by repeating the central element, KK worked relatively independently without building on others' ideas (0) and without inviting others to participate (_). During a lecture, an LKP teaches by explaining a procedure independently while the LUPs acknowledge, confirm and ask questions.

Guided construction. Now consider another teaching segment, guided construction (Wood, Bruner & Ross's [1976] scaffolding):

Problem: Graph the locations of a moving toy crocodile

| Name | Action | EPA | KC | IF |
|------|---|-----|----|----|
| NN | We begin at ten. | 0 | C | _. |
| T | But if it starts at five, NN, is it at ten at zero seconds? | - | C | ? |
| NN | No. | + | N | _. |
| T | Where is it at zero seconds? | + | R | ? |
| NN | Five? | + | C | ? |
| T | Uh-huh. | + | N | _. |
| | And how do you figure out where is it after one second? | + | C | ? |
| NN | Add two and so it's seven. | + | C | _. |
| T | And after two seconds? | + | C | ? |
| NN | Nine, and then eleven and then thirteen. | + | C | _. |
| T | Uh-huh. | + | N | _. |

These actions showed at least one LKP and one LUP cooperating to solve a problem. While T's correct evaluations (+, -) and leading questions with embedded explanations (C?) indicated his LKP position, NN's uncertain response (?), brief supportive additions (+C_), and incorrect action revealed her LUP position. Moreover, these participants cooperated using evaluations (+, -) and questions (?), showing attentive listening, responsiveness, connected ideas and invitations to participate. The LKP gradually reduced his problem-solving role as the LUP's contributions increased over time. Although an LKP can present information more quickly and more easily during a lecture, an LKP provides more adaptive assessment and learning opportunities for LUPs through guided construction.

Accepted demonstrations. Consider the following accepted demonstration segment in which two students are entering equations into the computer so that it will graph a starburst, lines that go through the origin of a Cartesian plane.

Problem: Graph a starburst on the computer screen

| Name | Action | EPA | KC | IF |
|------|--|-----|----|----|
| BO | I'll do this. [types "y = 2x" into the computer] | 0 | C | .. |
| PA | You got it. | + | N | .. |
| | Two x. | + | R | .. |
| | [computer draws "y = 2x"] | + | C | .. |
| BO | [types "y = 3x" into the computer] | + | C | .. |
| | [computer graphs y = 3x] | + | C | .. |
| BO | [types "y = 4x" into the computer] | + | C | .. |
| | [computer graphs y = 4x] | + | C | .. |
| BO | Go ask for a ruler. | 0 | C | ! |
| PA | Mm-hmm [leaves]. | + | N | .. |

These actions showed one LKP solving a problem while the other LKP concurred. BO's supportive actions (+C..) solved the problem quickly and correctly, revealing her to be an LKP. Meanwhile, PA's acknowledgement (+N..) and confirmation (+R..) before the computer validated BO's action provided evidence of PA's understanding and LKP status. BO does not provide any explanations, and PA does not ask for them (no ?'s). As with the lecture, the LKP solved the problem independently without inviting much participation (..) from other group members. If LUPs try to appear knowledgeable to an LKP, lectures resemble accepted demonstrations. During an accepted demonstration, everyone knows a solution approach and one person implements it.

Automatic joint solutions. In contrast, consider a more cooperative automatic joint solution segment:

Problem: Graph a starburst on the computer screen

| Name | Action | EPA | KC | IF |
|------|---|-----|----|----|
| BB | [types "y = 1x" into the computer] | 0 | C | .. |
| | [computer graphs y = x] | + | C | .. |
| PP | Got it? | + | N | ? |
| BB | Yes. | + | N | .. |
| PP | Mmm, one. [writes "y = 1x"] | + | R | .. |
| | Two x. [writes "y = 2x"] | + | C | .. |
| BB | [types "y = 2x" into the computer] | + | R | .. |
| | [computer graphs y = 2x] | + | C | .. |
| PP | Yes. | + | N | .. |
| BB | [types "y = 3x" into the computer] | + | C | .. |
| PP | Three x, y equals three x. [writes "y = 3x"] | + | R | .. |
| | [computer graphs y = 3x, taking about 10 seconds this time] | + | C | .. |
| PP | God. | 0 | N | .. |
| PP | Four x. [writes "y = 4x"] | 0 | C | .. |

| | | | | |
|----|--|---|---|----|
| BB | [types “y = 4x” into the computer] | + | R | _. |
| | [computer graphs y = 4x, taking about 8 seconds] | + | C | _. |

These actions show LKPs cooperating. As both PP and BB used supportive statements (+_) and contributed supportive actions (+C_), both were LKPs who agreed on a common problem-solving approach that solved the problem quickly and correctly without the need for explanations. They cooperated by using a supportive request (+N?), confirmations (+R_), and acknowledgments (+N_) to coordinate their problem-solving. Cooperating LKPs integrate problem-solving actions seamlessly to produce an automatic joint solution. Automatic joint solutions are more efficient than accepted demonstrations if the time saved by parallel contributions exceeds the additional time needed for coordination between participants’ actions.

Occurrences of each type of social interaction

Although any of these interactions may occur during group work, each interaction tends to take place during particular circumstances. Piecemeal guessing and joint construction are more likely to occur during novel problems and at the beginning of a problem-solving session whereas the other four interactions are more likely during familiar problems and towards the end of a problem-solving session. Piecemeal guessing is also more likely among strangers, egocentric children (Piaget, 1965), and during brainstorming sessions. In contrast, joint construction is more likely among friends, older children and adults (Piaget, 1965). Lecture segments often occur during teaching by children (Forman & Cazden, 1985) as well as by adults in attempts to convey information quickly. In addition, alternating lectures occur during arguments, during debates among people with fixed positions and during jigsaw activities (Aronson, et al, 1978) in which each group member learns a special part and explains it to the rest of the group. Guided construction also occurs during coaching (Bibby, 1990; De Marco & McCullick, 1997) and mother-infant interactions (Mize & Petit, 1997; Wertch, 1980). Meanwhile accepted demonstrations and automatic joint solutions should occur more often in routine problems by definition. When there are large status differences among group members, accepted demonstrations can occur more often than automatic joint solutions as the high status person implements the solution alone or orders a lower status person to do so.

CONCLUSION

To help consider why some groups solve problems successfully but others do not, this article introduces a framework for statistical analyses of many group

interactions both in fine detail and in their entirety. Organizing individual action and social interaction properties along dimensions allows for mutually exclusive categories without sacrificing multiple functions. Furthermore, the dimensional simplicity increases the tractability of coding for large sample-size statistical analyses both at and among the levels of (1) individual action, (2) interaction segment and (3) whole activity. These dimensions also provide possible quantitative measures of collaborative quality. Furthermore, the specific dimensions organize each type of individual action, each type of social interaction and help explain how specific individual actions partially constitute specific social interactions. If additional empirical research provides further evidence for these relationships, group work trainers and group work members can use this information to improve their group problem-solving at work, play, school etc. The applicability of this framework to related interactions, such as business meetings and diplomatic negotiations, remains an empirical question.

Limitations

This taxonomy does not capture fine gradations within each category and omits the influence of many factors. For example, “I don’t think so” and “that’s @#\$\$% idiotic!” are both criticisms but have different intensities and can have different effects on an audience’s interpretation and its subsequent responses (Goodwin & Goodwin, 1987; Jefferson, 1978; Schiffrin, 1984b). Likewise, a simple addition such as “two plus one is three” and a novel representation that frames the solution to a problem can both be contributions, but their impacts on the collaboration differ.

This taxonomy omits the influence of many micro-level factors (such as prosody, rhythm and silence) and macro-level factors (such as relationship histories, physical environments, and societal/cultural expectations). Additional micro-level elements can provide additional information for researchers to improve their interpretation of interactional data (see Auer & di Luzio [1992] and Gumperz [1978] for discussions of prosody and rhythm and Schegloff [1995] for ways to analyze silence). Also, the shared history between people who know each other provides common knowledge and psychological expectations that strangers lack. Thus, a person may interpret and respond to a friend’s action differently than to an identical action by a stranger (e.g. ritualistic insults [Goodwin, 1990], solidarity through disagreement [Schiffrin, 1984b]). The physical environment can also influence collaborations through its resources and its history of expectations (Hutchins, 1995). Using physical resources such as rulers or calculators for instance, students can solve many more problems than they can without them. Furthermore, collaborators are likely to behave differently based on their experience with a particular location (Lave, 1983). For example, they may say and do things at their friend’s house that they would not do in class or in a library. Finally, societal and

cultural expectations may influence social interactions. As discussed above, societal expectations in public places constrain our behavior. People can also conform to (or intentionally violate) norms in other cultures when interacting with a person perceived to hold those values and beliefs (Gumperz, 1978).

Future research

These classifications of social interactions and individual actions enable testing of several hypotheses. Do highly collaborative groups show more supportive actions, critical actions, contributions, repetitions, or questions? Can one or more of the individual action dimensions be used to create a quantitative operational definition of collaboration? Do particular individual actions constitute each social interaction? Do particular individual actions increase the likelihood of other individual actions? Do particular patterns of individual actions predict successful problem-solving? By addressing these questions, researchers can help group members understand and improve their group problem-solving.

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Acknowledgements. An earlier version of this paper was presented at the annual meeting of the American Educational Research Association. This research was partially funded by a Chinese University of Hong Kong Direct Grant, a McDonnell post-doctoral fellowship, and a National Academy of Education/Spencer post-doctoral fellowship. I would like to thank Andy diSessa, Alan Schoenfeld, Rogers Hall, George Lakoff, Emily van Zee and Young Mhoon for helpful discussions. I also appreciate the comments on earlier drafts provided by Sung Wook Joh and Kwan Choi Tse.

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