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Abstract

When collaborators are doing a task and then they interactively explore some subtask that emerges, they are collaborating beneath the surface of the task. *Depth* of collaboration refers to both the frequency of, and the degree to which, students collaborate beneath the surface. In this paper we examine the notion of depth in relation to collaborative learning. We provide evidence that the extent of collaborative activity beneath the surface positively correlates to learning outcome. The measure of depth we use is easy to code and can be automatically produced.

Introduction

The literature on collaborative learning has identified some conditions and characteristics of effective collaborations. Collaborative learning works best for ill-structured domains (Cohen, 1994) or when abstract concepts that are to be learned enable representational negotiation (Schartz, Black, and Strange, 1991; Schartz, 1995). A common feature of successful cases of collaborative learning are that the collaborators are working "closely". What constitutes closeness, however, varies: the participants help by giving explanations not answers (Webb, 2001), ideas are shared and considered common resources (Barron, 2000), the students regulat*e* each other's work (Vedder, 1985), the problem-solving task is managed explicitly through talk (Chang & Wells, 1987), the participants work in a *joint problem space* (Teasley & Roschelle, 1995), verbalizations are produced that support reasoning about theories and evidence (Teasley, 1995).

A necessary, but not sufficient, condition of a collaboration that benefits individual learning is that the collaborators work closely together. In this paper, we will develop a general measure of closeness that is tied to the "depth" at which the participants interact. Those groups that more often work deeply learn more individually and as a group.

A set of interactions among actors may be embedded in a larger set of interactions. The actors are doing a task (this is the surface) and then they interactively explore a subtask of that task (this is beneath the surface). Two learners collaboratively working on an organization for their activity – e.g. agreeing on a sequence of actions to accomplish the task of writing a computer program that draws a figure – are collaborating beneath the surface. Two learners going back and forth in interpreting conceptual information and in developing a mental model of how the graphing commands in a specific computer language work, are also operating beneath the surface. In each of these cases, there is a problem space – either the task to draw the figure or the task to understand a graphing command – and within that problem space the students interact at more than one level. The notion of depth reflects both the frequency of, and the degree to which, group members collaborate beneath the surface. Any pair of learners working at depth are working closely, but not all pairs of learners that work closely work at depth.

The literature on hierarchical structure of task dialogues and the relation of talk to action and/or learning has a rich tradition in Cognitive Science. The recent work of Bangerter & Clark (2003) is an example of theory that examines the relation of talk to action. In their model, joint activity is organized into projects and subprojects. Markers in discourse – words like *yes, okay, all right* – tend to be used to either sequence through projects (*yes*) or to open and close subprojects (*okay*, *all right*). Markers in discourse that are used to navigate projects can be used to give a crude measure of "depth": a count of the number of times collaborators open and close subprojects measures how much they interact beneath the surface.

We conducted an empirical study of how dyads of novice programmers, undergraduates with various majors at Brandeis University, collaboratively learned to program graphic objects for the first time. Our results show that the degree of collaboration beneath the surface is a strong predictor of learning, both for individuals (as members of a group) and for the group as an entity. Our results also show that the amount the students talked, the frequency of their talk, and the degree to which they work on the same segment of code, did not in themselves correlate with either individual or pair learning; these results are consistent with the prior work on collaborative learning.

Literature

There are several finding in the literature that characterize the interaction among successful collaborative learners. Collaboration learning is most effective for ill-structured domains (Cohen, 1994) and for learning abstract concepts (Schartz, Black, and Strange, 1991). In general, the benefits of collaboration depend on the participants working closely together on task-related interactions (Cohen, 1984). A division of labor which breaks out a collaborative assignment into interdependent projects reduces the complexity of the task for each of the participants and thereby increasing the productivity of the group, but it also separates the competencies and understanding that each individual gains from the collaboration (Stevens, 2000).

Conversation in itself is not sufficient to produce benefits for collaborative learning. Helping by giving and receiving elaborate explanations is a positive predictor of learning, but providing a right answer to a question without explanation is not (Webb, 1991:1992:2001). The talk of the participants must produce certain types of verbalization – those that support reasoning about theories and evidence (Teasley, 1995). For example, in the domain of scientific discovery, the success of collaboration, as compared to the work of individuals, was due to the active involvement of pairs in interactive activities such as providing explanations and considering justifications (Okada & Simon, 1997). Collaborators are more likely to produce these kinds of verbalization than individuals working alone (Teasley, *ibid*). If one participant rebuffs another's attempt to effectively collaborate, the verbalizations that are produced may be more about face-saving than explaining and reasoning (Afard & Kieran, 2001). With training, groups of students provide and receive higher-order explanations at a greater rate (Swing & Peterson, 1982). If one of the collaborators is trained to play the role of facilitator, the talk of the participants is more likely to produce the kinds of scientific talk that increase individual learning (Ehrlich, 1991).

Joint attention is a central idea behind various cognitive accounts of the interactive processes responsible for the success or failure of a student collaboration. The conscious coordinated effort to achieve a genuine collaboration, rather than just cooperate with one another, is what determines learning outcome in students' problem-solving (Roschelle, 1992; Teasley & Roschelle, 1995; Barron, 2000; Matusov, Bell & Rogoff, 2002).

While problem-solving, group members negotiate meanings, which allows them to converge on the certainty of conceptual understanding (Roschelle, 1992). In a successful collaboration the students construct a joint problem space, which is the result of a continued conscious effort to coordinate language and activity with respect to shared knowledge (Roschelle et al., 1995). Students who build on each other's ideas and provide solution proposals that are relevant to the immediately proceeding conversation learn the most (Barron, 2003). A higher level of reasoning is achieved when collaborators work to develop a common representation that incorporates the multiple perspectives of all the participants, and thus the representational product is at a more abstract level (Schwartz, 1995).

The effort invested in organizing a group's activity through explicit talk also affects learning outcome. Chang and Wells (1987) define learning as problem-solving where the planning and execution of tasks are brought under conscious control. The group setting particularly supports this process by making thinking explicit and available for inspection and revision. Effective collaboration entails the learner regulate each other's work (Vedder, 1985). To work together, students not only have to negotiate conceptual meaning, but also goals, plans, procedures, and alternatives. Thus, through explicit talk learners need to manage both the problem space and the activity (or organizational) space.

When the participants are interacting with one another they are paying attention to one another but not necessarily at any depth. When collaborators talk without paying attention to one another's thinking and/or ideas there is no depth to the interaction. Depth measures how often the participants switch levels within a task, interactively exploring some subtask that has emerged. Negotiation of meaning, construction and maintenance of a joint problem space, task alignment, or effort to manage the collaborative task are all interactions that indicate depth.

Experimental Study

In our experiment, students were asked to draw a geometrical figure of a man (see Figure 1), using the programming language JScheme. The participants had no previous experience with programming. Correctly drawing the figure required writing code for drawing rectangles, lines, circles, and arcs. Students needed to learn the appropriate commands and to acquire an understanding about the parameters for commands, as well as about the way drawn objects map to the *display page*. The most challenging part of the task is understanding the way the coordinate system works - it originates in the upper left corner of the screen with the y-axis growing downwards, and each axis has a fixed length. Placing a point requires thinking in terms of distance from the origin or from the endpoints.

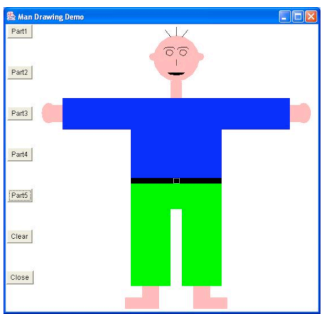

Figure 1: The man figure task.

Measuring Collaborative Depth

We will use Bangerter & Clark's study (2003) of project markers in discourse. Words like *yes, yeah, uh-huh* and *m-hmh* are used by collaborators to step through a project. They indicate progress of activity within the current depth level and are referred to as *horizontal* transitions. Words like *okay* and *all right* imply opening or closing of subprojects. These signify a move below the surface or a return from one, i.e. a change in depth level. They are *vertical* transitions. For our purposes, a count of the number of times collaborators open and close subprojects is a simple measure of the number of times collaborators switch between levels of the task hierarchy. It is a cumulative measure both of how deeply collaborators work and of the extent to which they navigate through depth levels in their activity.

The above set of discourse markers is minimal. People use a number of other discourse transitions – words and sentences – to open and close subprojects. In our analysis we considered an extended set of vertical markers that we found commonly used throughout the interactions. These included: *so*, *cool*, *let's*, *let me*, *true*, *thanks*, *and*, *wait*, *stop*, *sure*. However, the results produced by the original and the expanded sets were almost identical. We believe this is evidence that even though measuring depth by means of vertical transitions does not provide an exact count of entries into and exits from subprojects, it gives a very good estimate – sufficient to reveal trends in joint activity. For clarity we decided to keep the presentation and discussion of our data to the original model's set of markers.

We performed an analysis of the transcripts of students' collaborative sessions, counting vertical project markers to calculate the depth of collaboration. Example 1 shows an interaction segment and Figure 2 provides a graph of the

Example 1: Conceptual understanding and depth.

1.	A: **ok**	*Opens surface project and first subproject*
2.	A: do you understand the whole concept of pixels?	
3.	B: not really	
4.	A: the screen is 500 x 500 pixels	*Opens sub-subproject*
5.	A: **ok**	*Closes sub-subproject*
6.	B: oh yeah no i understand that it's like a grid	*Continues with project; opens sub-subproject*
7.	A: x,y	
8.	A: **right**	*Closes sub-subproject, subproject and surface project*

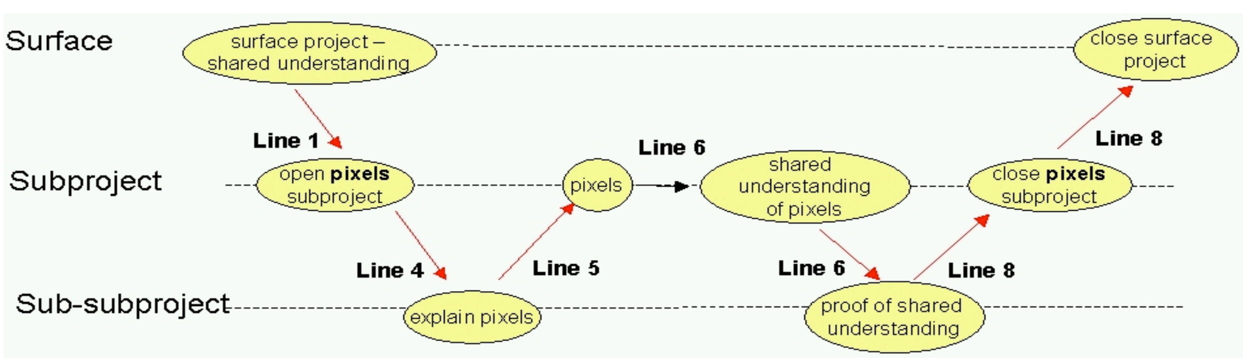

Figure 2: Representation of depth of student chat.

sequence of projects and the opening and closing of subprojects. In total there are six vertical moves between levels: three up and three down. The surface project is to reach shared understanding of the material in order to start working on the assignment. At line 1, *A* opens the first subproject with *"ok"* to establish that they share understanding of the concept of pixels. At line 4, *A* initiates the first sub-subproject of explaining the concept in order to reach shared understanding. At this point the participants are two levels beneath the surface. In line 5, *"ok"* marks the closure of the sub-subproject and brings the activity back at the subproject depth level. In line 6 *"oh yeah"* signifies movement of the activity within the same depth level – common ground is established in relation to the concept of pixels. However, in line 6 *"no"* starts a divergence, a sub-subproject in which *B* explicitly reconfirms shared understanding. *"Right"* in line 8 concludes the episode by confirming the overlap in conceptual understanding – this closes all nested subprojects as well as the main, surface project.

Whereas the first example shows two subjects interacting beneath the surface as they try to understand the coordinate system, this next example shows a pair of subjects switching levels as they work on the solution.

1. A: **ok** now we mirror image it
2. D: but I think its a bit long
3. A: oh yea...well, lets finish this hand firs tthen with the oval before we do the next one
4. A: that way we can see it all together
5. D: **okay**
6. A: cuz i think some of the oval will overlap with the wrist
7. A: and it will look shorter
8. D: **okay**

Example 2: Task work and depth.

These collaborators are coordinating the sequence of actions they will undertake. The surface project in Example 2 is to make a plan on how to complete the shared solution for drawing the hands of the man-figure.

- line 1: "*ok*" opens a subproject of mirroring the image of one hand for the representation on the display page of the other hand.
- line 3: They open a sub-subproject of finishing up the first hand.
- line 5: "*okay*" closes the sub-subproject.
- line 6: *A* opens another sub-subproject of further negotiating actions.
- line 8: "*okay*" closes the sub-subproject, and the subproject of mirroring the image. The plan is completed and the surface project is closed as well.

The vertical transitions give us a good estimate of the extent to which group members switch levels beneath the surface of a task. In Example 3, the participants maintain a joint focus, but are not working in the problem space, nor are they interacting beneath the surface.

1. E: what is ur major?
2. B: psychology
3. B: u?
4. E: u look lilke a bio major
5. B: ahahah
6. B: hey
7. B: do you speak japanese?
8. B: for some reason i had the feeling that you do
9. E: not too much

Example 3: Lack of depth.

The conversation between these two participants goes for forty-eight lines without a single use of a *vertical* transition marker. The interaction does not involve any subprojects – the surface project is for the students to get to know each other and this is accomplished by a sequence of questions and answers. The group members show a high degree of joint focus. The lack of any vertical markers accurately reflects the lack of depth.

Methodology

Groupware as Experimental Platform Groupware systems are software applications that support groups of people engaged in a common task. The use of groupware to study collaborative learning has many advantages – chief among them is the ability to collect a complete replayable transcript of all the interactions between collaborators without any transcription cost. The experimental platform we used for this study was GrewpTool (Langton, Hickey & Alterman, 2004; Langton, Granville, Hickey, & Alterman, 2004).

GrewpTool The GrewpTool environment has a chat window where students communicate using an IM-like interface, a collaborative editor that allows one or more students to simultaneously edit code, and a pair of browser windows where students can navigate through the assignment and a manual. All user interaction with the tool is logged and there is a playback mechanism, which allows one to analyze the learning session in great detail. Figure 3 shows a snapshot of GREWPtool as seen by the students.

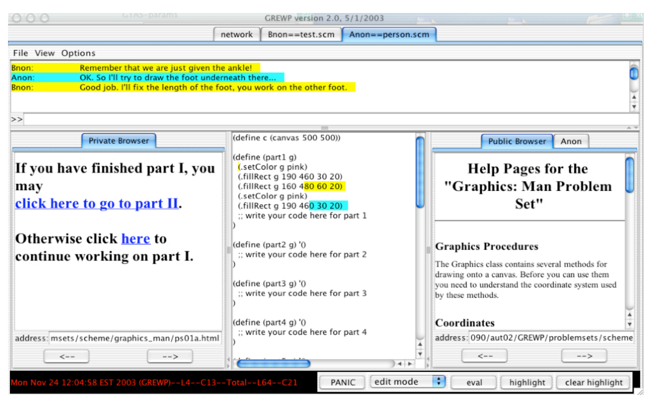

Figure 3: The GREWPtool as seen by the students.

Protocol Throughout the Fall 2003 semester, we conducted experiment sessions that took place in one of the computer labs. Upon arrival students were briefed about the study and trained on using the tool. Pairs were randomly assigned and were placed to work on distant workstations (separated by cubicles). After completing an entrance survey and a ten-minute pre-test, participants were instructed on the task and on how to use the online scaffolds. Students were given ninety minutes, after which they had to complete a post-test and an exit survey. The tests were intended to assess three categories of coding knowledge – vocabulary, syntax, and semantics.

Learning Learning achievement was determined by the difference between pretest and posttest score.

Participants The participants were Brandeis University undergraduates with backgrounds in various academic disciplines, none of whom had any prior programming experience, i.e. their expertise level was that of pre-novices (VanLehn, 1989). The analysis presented in this paper is based on the data of the interactions of ten dyads, or twenty participants. The rest of the data was excluded from our analysis due to technical problems with the early versions of GrewpTool. All participants volunteered to take part in the study and were compensated for their time.

Results

In the discussion below we first examine the relation of talk and action independent of depth. Four measures are considered: time spent chatting, number of chat utterances, frequency of chat segments, and the use of horizontal marker to sequence through projects at the same level. These results are consistent with other findings in the literature. Next we examine whether subjects working closely together in the code window was a predictor of learning. The final result we present shows that collaborative depth, independent of topic, does correlate to learning.

Chatting itself is not enough

Group members who talk extensively, or talk frequently are indicators that the participants are interacting. The amount of time spent talking, the number of utterances exchanged, and the frequency of chatting are measures of how much collaborators talked, and consequently, of the degree of joint focus. Each of these factors measures closeness but not depth of collaboration.

- Does the total amount of time spent chatting positively correlates to learning achievement?

We correlated the total time a dyad spent talking to the total learning the dyad achieved. The result was not statistically significant: $r_{(10)} = -.348$, p = n.s. The time spent chatting did not correlate to individual learning either - $r_{(20)} = -.253$, p = n.s.

- *Does the number of chat utterances positively correlates to how much is learned?*

We tested this hypothesis on both the group level and the individual level. For both we found no significant correlation. Within a group we found $r_{(10)} = -.434$, p = n.s. and per individual $r_{(20)} = -.242$, p = n.s.

- *Does the frequency of chat between participants positively correlate to the learning outcome?*

Participants' interaction can be divided into segments. By definition, a chat segment is a set of utterances exchanged while both students are in the chat window. The beginning and end of a segment is marked by activity of either participant in a window other than the chat area – e.g. in the editor or browser. Frequency of chat was operationally defined as the total number of chat segments for a complete learning session. Some groups went for long periods of time without communicating, while others "kept in touch" by chatting frequently. The frequency of chat interactions per group was compared with the total learning for the group. No statistical significance was found: $r_{(10)} = -.272$, p = n.s.

- Do pairs of students that more often sequence through projects together learn more than those that do not?

We tested for correlation between the use of horizontal markers and learning – at the individual and at the group level. The relations were not significant: $r_{(10)} = -.261$, p = n.s. at the group level, and $r_{(10)} = -.307$, p = n.s. at the individual. (Note: this relationship was also tested relative to the amount of chat and still resulted in no statistical significance)

In summary, the amount of time spent chatting, the number of utterances, and the frequency of conversational are not predictors of learning. Hence, for this task is not sufficient to explain differences in collaborative learning outcome.

Measuring Closeness in the Code Window

Suppose a pair of subjects divide up their task and work on different segments of code at the same time. As they write code, they are not working very closely. Subjects that work on the same segment of code are working at the same time are working more closely, but not necessarily very deeply – they may only be peripherally aware of what their partner is doing as they code. We measured the distance between the cursors of each pair of subjects as they wrote code in the code edit window. Subjects working on the same segment of code will have a smaller mean difference between their cursors in the code window than pairs of subjects who are coding separately on different parts of the assignment.

- *Do subjects that more frequently work on the same segment of code at the same time learn more?*

We compared the mean distance, in pixels, between the cursors of collaborators to the learning they achieved. While closeness of cursors was a strong predictor of the closeness in learning outcome that members of the same group scored ($r_{(10)} = .872$, $p < .01$), it did not account for the degree of learning achieved ($r_{(10)} = .017$, p = n.s.). In other words, pairs of students that organized their efforts by working on the same segment of code at the same time were working "closely" but they did not necessarily achieve more as individual learners. This result is consistent with prior research. Peripheral awareness does not necessarily entail depth only "closeness".

Depth of Collaboration

The amount of *vertical* transition markers utilized by collaborators reflects the depth of collaboration.

- *Does depth correlate to learning?*

As described earlier in this paper – vertical discourse markers crudely measures what we refer to as depth of collaboration. We tested this hypothesis at the individual and at the group level – at both the relationship was strongly significant: the relative use of vertical markers (as a percentage of the whole interaction) positively correlated to total group learning with $r_{(10)} = .762$, $p < .01$; at the individual level, the correlation was with $r_{(20)} = .560$, $p < .01$.

Concluding Remarks

Collaborating students can be working closely, talking and interacting a lot, without having meaningful interactions. Meaningful interaction depends on depth.

Depth lies at the intersection of joint focus, joint problem space and the structure of activity. It is when collaborators switch levels within a hierarchy of tasks, in an interdependent fashion, as they jointly progress through the problem space that they interact beneath the surface. Our findings show that a simple measure of depth is sufficient to predict whether pairs of learners in our experiment benefited from the collaboration. These findings do not depend on an analysis of which tasks and subtasks were explored in depth.

Depth is a dimension of closeness that differentiates between effective and ineffective learning collaborations. We used a measure of depth that is easy to code and can be produced automatically, and for this reason, depth is an especially useful tool for the analysis of the role of collaborative interaction in learning.

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