Notational Effects on Use of Collaboratively Constructed Representations During Individual Essay Writing

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Abstract: Prior analyses of collaboration through different notational systems (e.g., threaded discussions and evidence maps) have documented differential influences of notations on collaborative processes as well as ways in which groups appropriate these notations for their work. These prior analyses have focused on collaborative interaction, yet for instrumental purposes in educational practice, the individual is the unit of analysis. Hence it is relevant to ask how individuals use the products of collaborative interaction as documented in a given notational system. This paper reports on an analysis of data from a prior study to uncover how participants went about writing individual essays, drawing on the products of interactionally prior joint problem solving. The analysis first documented parameters of the human-computer interactions through which individual participants accessed and appropriated the record of prior work. Parameters included focus shifts, use of copy/paste, and access to records of data and hypotheses considered. The analysis then compared three experimental conditions and two post-hoc groups on the selected parameters. Profiles plots reveal consistent differences between the use of the notational systems that are indicative of differences in engagement with the materials.

Introduction
Prior work in “representational guidance” tested the hypothesis that conceptual representations can address problems of coherence and convergence that have been shown to be associated with threaded discussions and more effectively support collaborative knowledge construction in online learning (Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2007; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008). In that study, participants in an interactionally asynchronous setting were enabled to construct representations of the topics and conclusions of their discussion as they interacted. Two forms of conceptually-enhanced support were compared to each other (Graph vs. Mixed) and to a threaded discussion control condition (Text). After collaborative knowledge construction, participants in the experimental study wrote individual essays with the CSCL environment remaining available and accessible for (re)appropriation. Prior results showed that the three conditions (Text, Graph, and Mixed) did not differ in optimality of conclusions in the essays: relatively few participants in all conditions identified the optimal explanation of the epidemiological facts of the given problem. Pairs in the Graph condition were more likely to converge on the same (not necessarily optimal) conclusion than pairs in the other conditions. The prior analyses tried to explain these observed differences primarily in terms of the influences of the various notations on collaborative interaction.

These analyses did not inquire into the appropriation practices of individuals, that is, how individuals used the persistent inscriptions that resulted from collaborative activity in their subsequent individual meaning-making processes during essay writing. For all practical and instrumental purposes in educational practice, the individual is the unit of analysis. Hence, in general it is appropriate to ask: for an individual, what is the return on collaborative interaction? In everyday life, we document our collaborative interactions and derive personal benefit from such documentation as resources for teaching, reading, writing, and thinking. In the context of this study, we specifically ask: does the notation influence how individuals draw upon the documentation of prior interaction? Are the differences observed in the prior study due the different notations involved? To the particular idiosyncratic and/or systematic ways in which participants used the persistence of interactionally prior collaborative work in writing the essay? Or it is a combination of these two factors?

This paper begins to answer these questions with a human computer interactional (HCI) account of how participants exploit the persistence and perceptibility of a collaboratively constructed knowledge environment by manipulating the interface during essay writing. In order to provide such an account, we first documented interactions such as how frequently focus switching was done, how multiple application windows were managed, how the knowledge-map was navigated, and how informational sources were accessed and appropriated. We then evaluated whether the interactional work done by individuals in writing the essays differed systematically between the three experimental groups and the two post hoc groups of pair convergence and divergence. We present the software environments and method of the prior study before returning to data collection specific to the essay writing analysis.
Methods
The prior study from which our data was derived (Suthers, et al., 2008) used three software environments in order to test hypotheses about the relationship between conceptual representations and collaborative discourse. All three of the environments have an “information viewer” on the left in which materials relevant to the problem are displayed. All three environments have a shared workspace or “information organizer” on the right hand side in which participants can share information they gather from the problem materials as well as their own interpretations and other ideas. The three treatment conditions corresponded to three different notational resources provided for recording and organizing information and participant’s interpretations of that information. Participants used one of a threaded discussion environment (the “Text” condition), an evidence mapping environment derived from Belvedere with embedded annotations (“Graph”), or an evidence mapping environment side by side with a threaded discussion and facilities for referential linking between the two (“Mixed”; Figure 1). Changes made to the workspace by each participant are propagated to other participant’s displays of the same workspace under an asynchronous protocol. See (Suthers, et al., 2007; Suthers, et al., 2008) for details of participants (30 gender-balanced pairs of participants were recruited from natural science courses), materials (information relevant to an epidemiological problem was distributed across participants in a hidden profile design), and procedures. The most relevant aspect of the procedures for present purposes is that after participants worked together (via a shared workspace with asynchronous updating) for up to 120 minutes on the epidemiological problem, each individual participant was given up to 30 minutes to write an essay on the hypotheses that were considered, the evidence for and against these hypotheses, and the conclusion reached. The CSCL environment remained available to each participant during the essay writing, but there was no further communication between participants. Table 1 contains the essay writing instructions.

Figure 1. Mixed environment

Table 1: Essay Writing Instructions

Instructions. Now that you have completed your exploration of the Guam Science Challenge Problem, please write a short essay (1 – 2 pages) that summarizes your findings. Please structure your essay as follows:

1. For each working hypothesis that you considered, write a brief paragraph describing the hypothesis, and summarizing the evidence for and against it.
2. Write a concluding paragraph in which you identify one or more hypotheses that you believe are best supported by the evidence. Discuss your reasons for choosing that hypothesis or those hypotheses, as well as your reasons for rejecting the other hypotheses you considered.

You will type in your essay into a word processor, using the document that has already been set up for you. As you write your essay, please keep the following three points in mind:

- We will evaluate your essay based on its content; you don’t need to worry about spelling or formatting.
- Remember to save your document frequently.
- You have up to 30 minutes to write your essay.

Process data was collected through the Morae™ recording software and software logs of all the events at each client workstation. Post-session data included the essay, a usability questionnaire elicited immediately after the experimental session, and a post-test elicited one week later. For the purposes of this paper, we segmented and analyzed the Morae™ screen recordings of the individual essay writing task.

Results
The analysis focused on the (1) total time taken to write the essay, (2) focus shifts between the CSCL environment and the essay application and the essay, (3) note pad window movements, (4) copy+paste instances from the CSCL environment into the essay, (5) accessing individual study materials, accessing elements of the co-constructed knowledge-map such as (6) shared data and (7) shared hypotheses, (8) collaborative discourse, (9) knowledge-map navigation and (10) knowledge-map re-organization. A multivariate analysis of variance
with the independent variable of CSCL environment (Graph, Mixed, Text) and the ten dependent variables listed above was significant (Roy’s largest root=0.516, F(10, 48)=2.48, p=0.02). However, no significant results were observed with a multivariate analysis of variance with the independent variable of essay pair convergence (convergence and divergence) and the ten dependent variables listed above (Roy’s largest root=0.195, F(10, 47)=0.92, p=0.53). Below we describe each univariate measure and the results from univariate analyses of variance, with profile plots for significant results.

Total essay writing time was defined as the time in seconds between the creation of the text editor window and the participant’s closing of the editor window. This measure did not differ significantly either between the three experimental conditions or between the two convergence groups. However, average total essay time was higher for Graph as well as for collaborative dyads that converged on their final conclusion in the individually written essays.

Due to the single monitor setup of the experimental study, the text editor window was overlaid on the CSCL environment. A focus shift resulted when participants switched between the CSCL environment and the text editor by selecting either to be the active window. The total number of focus shifts varied significantly between the three experimental groups \( (F(2,56)=3.43, p=0.04) \). A post-hoc comparison showed that the focus shifts were significantly higher in the Mixed CSCL environment when compared to the Graph environment. No significant differences were observed between the convergent and divergent participant groups. The profile plot for focus shifts is presented in Figure 2.

Since the text editor window was overlaid on the CSCL environment, participants would move the text editor window around the screen in order to make the relevant areas of the CSCL environment perceptible. The total number of notepad window movements (or re-positioning) did not vary significantly between the three conditions or the convergence and divergence groups. On average, the text editor window moves were higher in the convergent group and in the Mixed condition than the Text and Graph conditions.

The total number of instances of copy and paste of prior text from the CSCL environment into the individual essays was calculated. The number of Copy+Paste instances varied significantly between the three experimental conditions \( (F(2,56)=3.17, p=0.05) \) and was marginally higher for the convergent groups \( (F(1,56)=3.50, p=0.07) \). Figure 3 presents the profile plot.

The study materials were distributed between the two participants in a hidden profile design. Participants needed to not only share the relevant information with their study partner but also collaboratively...
We counted instances in which participants accessed data items in the shared workspace. This included accessing data nodes as well as data shared in the embedded notes and threaded discussion messages for the Graph and Mixed conditions respectively and data shared as threaded discussion messages in the case of the Text condition. Access to shared data items was significantly different between the three experimental conditions ($F(2,56)=4.18, p=0.02$) but not between the convergent and divergent groups (see Figure 4).

Counts were similarly calculated for instances in which participants accessed hypothesis items in the shared workspace. This included accessing hypothesis nodes as well as hypotheses stated in the embedded notes and threaded discussion messages in the Graph and Mixed conditions respectively and hypotheses stated in the threaded discussion messages in the case of the Text condition. Hypothesis item access was significantly different between the three experimental conditions ($F(2,56)=4.97, p=0.01$) but not between the convergent and divergent groups (see Figure 5).

Counts were calculated for instances in which participants accessed collaborative discourse in the shared workspace. This included accessing embedded discussion notes and threaded discussion messages in the Graph and Mixed conditions respectively and threaded discussion messages in the case of the Text condition. There were no significant differences between the three experimental conditions and the two convergent groups.

Counts were obtained for instances when participants navigated the CSCL environment by scrolling vertically or horizontally. Scrolling was the mechanism through which participants could access the regions of the CSCL environment that couldn’t fit the screen and were therefore hidden from present view. There were no significant differences between the three experimental conditions or the two convergent groups.

Counts were obtained for instances when participants re-arranged or re-organized the knowledge-map nodes in the Graph and Mixed conditions and the display of threaded discussion board by collapsing or expanding the tree view in the case of the Text condition. Results showed that marginally significant differences between the three experimental conditions ($F(2,56)=2.54, p=0.09$) with no significant differences between the convergent and divergent groups.

Latent semantic analysis (Landauer & Dumais, 1997) was done on the two individually written essays of each collaborative learning session. Pair-wise comparison of each of the two essays of the 30 experimental sessions was conducted within the topic space of High School Biology with 300 Factors and High School Biology with 941 Factors. Thus, we obtained 30 LSA pair-wise agreement values for the 60 individual essays across the 30 sessions (10 each of Mixed, Graph, and Text). A one-way analysis of variance of the LSA pair-wise agreement values was significant within the topic space of High School Biology with 300 Factors ($F(2,27)=6.10, p=0.01$) as well as the topic space of High School Biology with 941 Factors $F(2,27)=10.98, p=0.0003$. In both cases, post-hoc comparisons showed that pair-wise agreement in the Text condition was significantly higher than Mixed and Graph conditions.

**Discussion**

A previous analysis (Suthers, et al., 2008) showed greater convergence (pair agreement on the final conclusion) in the Graph condition. This suggested that Graph participants may have shared more information, but our analysis of essay contents did not back up this interpretation: participants in all conditions were equally likely to cite information that was originally given to their partner. Subsequently, we conducted the present analysis of the individual essay writing in order to better understand these results by documenting the human-computer interaction practices by which the essays were composed. The results reveal three empirical trends. The first empirical trend is that for the HCl analysis measures of focus shifts between the CSCL environment and the text editor (Figure 1), text editor window movements, number of Copy+Paste instances (Figure 2), and access to hypotheses shared in the CSCL environment (Figure 4), estimated marginal means for the Graph condition were lower than those of Mixed and Text. Frequent focus shifts between the CSCL environment and the text editor window and frequent text editor window movements in the Text and Mixed conditions may induce context switching costs between tasks and ultimately lead to less sustained engagement in either context. Comparatively less number of Copy+Paste instances in the Graph condition might also be indicative of higher re-interpretation of and reflection on prior work. The second empirical trend is that for the measures of access to data items shared in the CSCL environment (Figure 3), and access to study materials estimated marginal means for the Graph condition were in between those of Mixed and Text. This seems to suggest a point of diminishing returns with regard to individuals’ access to shared data artifacts and uniquely provided materials. Due to the “hidden profile” design of the study materials, information uniquely provided to the study partner is accessible to a particular individual participant only if it is shared. The third empirical trend is that for the measures of total essay writing time (Figure 4), access to collaborative discourse in the CSCL environment, navigation of the
**CSCL environment**, and **CSCL environment organization**, estimated marginal means for the Graph condition were higher than those of Mixed and Text. These four measures can be read as indirect indicators of sustained engagement with the essay writing activity, particularly with respect to the essay instructions provided to each participant (see Table 1). To summarize, the results suggest that participants better exploit the persistence of collaborative knowledge-building and discourse in the Graph condition. As it is to be expected, given the hidden profile distribution of the study materials, higher access to uniquely provided study materials during essay writing is found in the divergent group. In the collaborative phase of the Text condition, participants would usually copy and paste entire study material articles into the shared threaded discussion area. During the individual essay writing activity, Text participants were more likely to access the data items shared in the threaded discussion than the uniquely provided study materials in the “information viewer.” This might explain greater latent semantic similarity in the text condition.

We speculate that active navigation and organization of the co-constructed knowledge-map and access to collaborative discourse partially account for the convergence differences. We acknowledge the problematic nature of the casual direction of the explanatory account. Our analysis results provide a tentative answer to the question raised at the beginning of the paper as to whether it is the differential nature of the design of and collaborative knowledge-construction in the Graph condition or the differential essay compositional strategies and human-computer interactional practices that better explain the differential essay convergence outcomes. The analysis of essay writing sheds some light on the human-computer interactional practices of the actual essay composition. The HCI measures introduced in this paper help provide a partial explanation for the between-group differences in individual learning outcomes with respect to the essays, supplementing the traditional explanations that attribute the between-group differences to investigative session alone (Cf. Ruben, 1990 for the distinction between partial and full explanations and the distinction between processes and products of explanation).

The HCI analysis reported here applies a variable-based approach to categorizing and aggregating individual interactional acts in order to investigate the relative distribution of pedagogically interesting behavior, in contrast to sequential analysis (e.g., Medina, Suthers, & Vatrapu, 2009). The analytical focus was on “usage” rather than the formal properties of interactional structures and functions. This analytical goal was to operationalize, in an experimental setting, traditional interaction analysis concerns with participants’ perceptual orientation and allocation of attentional resources from a HCI perspective. In light of the recent methodological discussions within the CSCL community, our analysis adopts and advocates a modestly mixed research approach and introduces some HCI measures for CSCL analysis.

Even though co-constructed collaborative knowledge is expressed in the persistent digital medium, it might not be readily accessible and available for re-appropriation by individuals. The question then is: How easy or difficult do different CSCL environments make it for individuals or small groups to return to the environment to reap the benefits of prior collaborative achievements and interactional accomplishments? Are there tradeoffs in designing and implementing CSCL environments for real-time collaborative interaction versus the individual learner returning to a partial or complete interactional archive any-time re-appropriation? According to Pirolli and Card (1999, p. 643), “Information Foraging Theory is an approach to understanding how strategies and technologies for information seeking, gathering, and consumption are adapted to the flux of information in the environment.” In CSCL environments, to what extent does information foraging differ between individual and collaborative modes of interaction? These remain empirical questions for future CSCL research.

**References**


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PART II

CSCL PRACTICES
IN EDUCATIONAL SETTINGS