Graphical Insight: How to Read an Unconventional Graph

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Abstract. How do you make sense of a graph that you have never seen before? Building on recent work demonstrating that prior knowledge of conventional graph types is extraordinarily difficult to overcome, we explore the use of *implicit scaffolding* to reconstruct graph reading as an insight problem. We hypothesize that constructing a mental impasse will improve learner performance by increasing the probability learners will reconsider their default interpretation strategies and recognize alternative interpretations of novel graphical forms. In a between-subjects laboratory experiment we find support for this hypothesis. Analysis of qualitative data suggests promising directions for understanding graphical intuitions, and we conclude with suggestions for future work that address the timing of mental model formation for unconventional graphic forms.

Keywords: graph comprehension; unconventional graphs; graph schema; insight problems; mental impasse

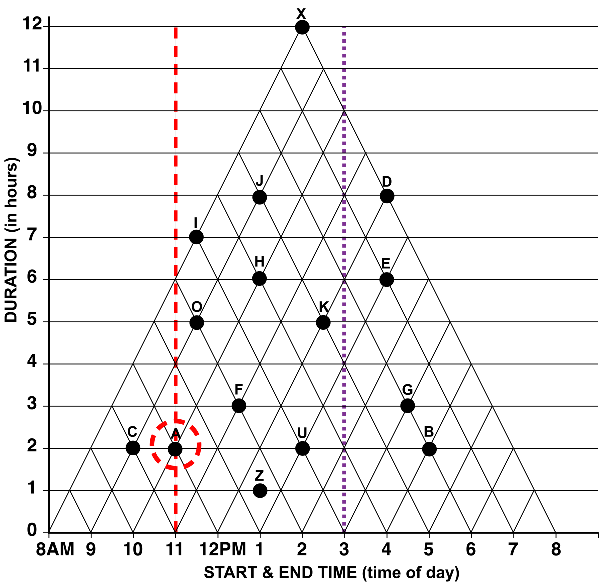
Introduction

Owing largely to their importance in STEM education, techniques for supporting graph comprehension have been a focus of research in the learning, cognitive and computer sciences alike. The most minimal interventions involve *graphical cues*—visual elements that guide attention, akin to gesture and pointing in conversation. Acartürk (2014) investigated the influence of point markers, lines and arrows on bar charts and line graphs, finding that different cues lead readers to interpret a graph as depicting either an event (points) or process (arrows). Mautone & Mayer (2007) investigated techniques from reading comprehension to support meaningful processing of graphs in a college geography classroom. In a series of experiments, they found that *signalling, concrete* and *structural graphic organizers* were effective learnings aids, affecting subsequent structural interpretation of the graphs (measured by relational or causal statements).

Importantly however, the cognitive aids explored in this literature do not instruct users on *how* to read the graphs – the “rules" for their representational systems. Rather, it is assumed that the reader has familiarity with the type of graph being read (scatterplots, line graphs, bar charts), all relying on the Cartesian coordinate system. Rather, these scaffolds serve to connect the variables in a graph to their real-word referents. In recent work (Fox & Hollan, 2018), we investigated learner behavior when presented with a simple but unconventional graph for temporal intervals: The Triangular Model of Interval Relations (Figure 1), for which learners had no prior knowledge. In an observational study, we found that learners struggled to make sense of the graph, misinterpreting the coordinate system as Cartesian. In an experimental study we evaluated four scaffolding techniques for self-directed learning: two text instructions, one static image depicting axis intersections and an interactive image in which the intersections appeared on mouse hover. The results revealed that *only* the interactive image condition significantly improved comprehension over a no-scaffold control. Prior knowledge of conventional graph types proved extraordinarily difficult to overcome, though subsequent analysis of differences between two sets of materials suggested that task structure–specifically the extent to which a problem poses a *mental impasse*–may function as a powerful aid for comprehension.

The Present Study

Results of our prior studies (Fox & Hollan, 2018) give us reason to suspect that conventional graph knowledge may hinder comprehension of unconventional representations. In this case of the TM graph, Cartesian expectations for the structure of the coordinate system interfere with our ability to follow perceputal cues provided by the graph's diagonal gridlines. Lockhart, Lamon & Gick (1988) describe difficulties in problem solving as a, "failure to access available information" (pg. 36). We can characterize misinterpretation of the TM graph as a failure to perceive and/or recognize the importance of the graph's diagonal gridlines. Lockhart et. al propose students must *reconceptualize* a problem in order to solve it, and that simply giving students information may not be sufficient. This provides an explanation for why explicit instructions given to students through static text and image scaffolds by Fox & Hollan (2018) did not improve performance with the TM graph, while the lack of available answers to the first problem in a particular set of materials *did*. The latter induces a state of puzzlement, which Ohlsson describes as an mental *impasse*: "a state in which problem-solving has come to a halt; all possibilities have been exhausted and the problem-solver cannot think of any way to proceed" (Ohlsson, 1992, pg. 4). In the present study we test the hypothesis that constructing a mental impasse will improve comprehension of this unconventional graph.



<u>The Triangular Model (TM) Graph</u> represents intervals of time (such as events). In the graph at left, each point represents an event. To find the start and end time of an event, the reader follows the diagonal gridlines from the point to the intersections with the x-axis. *For example, event B starts at 4pm and ends at 6pm*. The duration of the event can be read from the y-axis.

In the **<u>Control (non-impasse) Condition</u>**, a reader will find an *intersecting data point* if they misinterpret the coordinates as Cartesian. In the graph at left, the question "What event(s) start at 11am" has a correct answer of event F. But most students mistakenly report event A, based on their projection of an orthogonal (red dashed line) intersection with the x-axis. This is a question from the control (non-impasse) condition.

In the **<u>Impasse Condition</u>**, the reader *will not* find a data point if they misinterpret the coordinates as Cartesian. At left, the question "What event(s) start at 3pm?" has a correct answer of G, but no available answer for the orthogonal projection (purple dotted line). This is a question from the impasse condition.

Figure 1. The Triangular Model (TM) Graph, with Control (non-impasse) & Impasse examples

Methods

Sixty (55 % female) undergraduate STEM majors at an American University participated in exchange for course credit (age: 18 - 33 years). We utilized a between-subjects design with two groups and one independent variable (implicit scaffold: none[control] vs. impasse). Participants were randomly assigned to an experimental group, yielding thirty students per condition. For each participant, we collected comprehension score (max = 15 points) as the dependent variable, as well as recordings of all mouse movements in the experimental application.

Participants completed a graph reading task individually on a laboratory computer, viewing graphs and questions in accordance with their randomly assigned experimental condition. The graph reading task consisted of a TM graph and 15 multiple choice questions asking about the temporal relationship between data points in the graph (*see Figure 1*). Questions were presented one at a time without feedback, in the same order for both conditions. The first five questions of each graph-reading task were structured based on the assigned scaffold group (none[control] or impasse). The following ten questions were the same (non-impasse) for both groups. Prior to data analysis, data from six participants were excluded based on their failure to correctly answer an an attention check question.

Results

The mean accuracy score across the sample (n = 54) was approximately 6 points with a standard deviation of 0.68, and values ranging from 1 to 15 (max) points. On average, participants in the *impasse* group had higher scores (M = 7.6, SD = 5.2) than participants in the non-impasse control group (M = 3.9, SD = 4.2), yielding a statistically significant difference $t(49.7) = -2.8$, $p = 0.006$; a moderate-sized effect $r = 0.37$.

Discussion

The results of this study support our hypothesis that constructing a problem to present a learner with a mental impasse yields significantly better performance on the unconventional graph reading task. We expect this technique should generalize to other representations with unconventional coordinate systems, thought it is unclear whether the same attention-directing mechanisms would be appropriate for forms utilizing alternative markings. Importantly, this techqnique seems to be effective in directing learner's attention away from their default Cartesian interpretation based on prior graph knowledge. This effect is particularly evident when reviewing video replays of mouse movements of learners in the impasse condition. Most learners first trace an orthogonal intersection from the x-axis, before finding that no data point intersects the projected line. It is at this point that learners have reached the "mental impasse". We also observed greater variance in the answer choices by learners in the impasse condition. While control condition participants tended to choose the incorrect 'Cartesian' answer, learners in the impasse condition who did not discover the correct answer nonetheless found alternative interpretations for how the graph might work. We are presently conducting follow-up interviews to explore the nature of these strategies and how they may reflect learner's graphical intuitions. Based on our present analysis of the timecourse of response accuracy, we suspect that that to be effective, the learner must confront a mental impasse in the *initial* phase of graph interpretation—while their mental model for the graphical framework is being constructed. Future work should address this question by varying the timing of impasse vs. non-impasse questions with analysis of the time course of correct and incorrect responses.

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