Putting the pieces together: The challenge and value of synthesizing disparate graphs in inquiry-based science learning

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Abstract: A comparative synthesis of multiple graphs is a common practice in scientists' work as well as in everyday contexts. We refer to this process as graph meta-analysis. We present findings from a classroom enactment in which cultivating students' graph meta-analysis skills was one aspect of fostering scientific literacy through an inquiry-based unit on socio-scientific dilemmas. We highlight the challenges that learners and teachers encountered, and their implications for future instruction and design.

Scientists conducting a literature review or citizens searching the web often encounter the same conundrum: making sense of an abundance of sources, each of which provides only a partial answer to the search question. In many cases, these may even be contradictory answers. This creates a need to synthesize and compare the different sources. Research articles that deal with similar questions often test different variables, operationalize the same variables in different ways, use different experimental manipulations or sample different populations. A simple comparison or aggregation of the information can yield erroneous conclusions. Therefore, special meta-analytic steps need to be taken to juxtapose and synthesize the information, such as using effect size to normalize findings to a common scale. This can be a complex and demanding process.

We have chosen to address this issue in the context of graph comprehension (Bertin, 1983). Graphs are central communication devices in most empirical reports, especially in science. Not surprisingly, graph interpretation and production skills are emphasized in national science standards (NRC, 1996). However, several studies have shown that full competence in reading and producing graphs is not achieved even by college and university graduates (Bowen, Roth, & McGinn, 1999; Leinhardt, Zaslavsky, & Stein, 1990). Bowen and Roth (2005) found that pre-service teachers, most of whom had a BSc degree, lacked basic skills in graph interpretation, and reached the sad conclusion that "preservice teachers do not seem to be ready to teach data collection and analysis in the way suggested by reform documents." These findings highlighted the need for concerted instructional attention on graphic literacy skills (di Sessa et al., 1991; Shah & Hoeffner, 2002). If making sense of a single graph is a difficult task, then having to glean information from a comparative synthesis of multiple graphs is even more challenging. This activity, which we refer to as graph meta-analysis, is a common feature in the work of scientists (and other professionals) when they analyze their own data or when they review data published by others. A similar challenge is faced by citizens who encounter graphs when they make decisions about science-related issues based on information that they garner from news reports, web searches or other similar sources.

We examined the ways in which 10th grade students (N= 35) and their teacher (in a pilot study) tried to contend with a graph synthesis task. The students compared drug effectiveness studies for four pharmacological smoking cessation treatments in order to recommend the best treatment for a particular case. This activity was part of a broader research project ("CoReflect") that aims to cultivate scientific literacy among European youth by having them produce evidence-based decisions, explanations and recommendations on socio-scientific dilemmas. The project uses web-based inquiry environments, one of which was developed by the authors and concerns nicotine addiction.

The specific inquiry task on which we focus required the students, who worked in pairs, to extract data from two graphs (one bar graph and one line graph) in order to rank the 4 treatments by their success rate, defined as abstinence from smoking. The graphs were modified from recent published articles. Each graph contained data from a different clinical study, in which only 2 or 3 treatments were compared, in addition to a placebo control group, but none of the graphs contained data concerning all 4 treatments. This is typical of clinical studies (and applied science in general), because very few studies compare all available treatments and the overall ranking of treatments requires a process of meta-analysis, involving measures of effect size. Another feature of the meta-analytic process represented in this task is the need to handle variability in the operationalization of the same variable, mainly, one study defined abstinence as refraining from smoking since the inception of the study, while the other defined it as refraining from smoking over the past seven days. We recorded the responses of the students to these graphs in the form of computerized worksheets ("templates"). In addition, we used audio recordings to document discussions between the teacher and student pairs, as well as whole-class discussions. These recordings were consulted in combination with retrospective reflections of the teacher in order to identify points of impasse and progress on the part of the students.

Preliminary findings

Not surprisingly, the students found the overall investigation very challenging and even frustrating. Their science studies to date did not prepare them to deal with the demands of complex graph interpretation and synthesis. Some students were completely helpless, and did not make any progress prior to teacher intervention. Others seemed oblivious to the fact that the two studies used different operational definitions for abstinence. Therefore, they simply used raw data (percentages) in order to rank the treatments. . The teacher tried to raise students' awareness of these issues through discussions with individual groups while they were working on their investigation, and through the asynchronous feedback notes that attach to the students' workspace. These mediations were not enough, so the teacher also held an impromptu whole class discussion that delved deeper into these issues. Obviously, the challenge for students became a challenge for the teacher, who played a central role in providing guidance (Tabak, 2004) that was not provided by the computerized environment. This challenge is amplified in settings where students work in small groups, each of which faces different obstacles in different time points.

Some of the specific challenges faced by students include:

1. *Merging data from different graph types*. Similar data (independent variables: time, treatment type; dependent variable: abstinence rate) were presented using a bar graph and a line graph, making the synthesis even more difficult.
2. *Focusing on specific features of data in the line graph*. In this task, abstinence rates were plotted as a function of time using multiple lines of different colors. One of the challenges was to differentially focus on the latest time points depicted, in order to discern long-term abstinence. The second challenge had to do with noting and understanding that two lines crossing each other means that one treatment is superior in the short run and the other in the long run.
3. *Understanding the implication of different operationalizations for the same variable*. Students needed to realize that "raw" success rates could not be used to merge the findings from the two studies, because one used a much stricter criterion to consider a participant as abstaining from cigarette smoking.
4. *Understanding the need to consider effect size*. The data in the graph showed that one treatment was the best in both studies and therefore should be ranked first of the four. However, identifying the 2nd, 3rd and 4th treatments required students to estimate the effect size of each treatment, using the data from the control groups.

Conclusions and implications

We realized that answering inquiry questions through a synthesis of existing disparate sources of information, especially scientific research reports, relies on a better understanding of the nature of experimentation, and on specific synthesis strategies as we described above. This informed some redesign decisions that include: (a) replacing the bar graph with a second line graph, thus ameliorating the cognitive load on students (see point 1 above); (b) adding prompting questions and hints in the text that accompanies the graphs and adding "synthesis templates" in the students' computerized workspace. These additions focus students on key issues and structure the synthesis process, and are aimed to reduce the load on the teacher as an agent of scaffolding. In fact, the added text was based on stimulating questions asked by the teacher (in class or using the feedback notes); (c) adding an introductory class on placebo effects and control groups in clinical trials. This class introduced the importance of the use of control group data in order estimate effect size. The efficacy of this redesign is to be tested in a second enactment, conducted in the same school. Our hope is that this work will yield key instructional strategies for supporting the critical, but neglected skill of graph meta-analysis.

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