Let Your Ideas Flow: Using Flowcharts to Convey Methods and Implications of the Results in Laboratory Exercises, Articles, Posters, and Slide Presentations

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INTRODUCTION

Communicating science to peers and students often involves constructing clear, concise flow diagrams and illustrations as well as writing narratives (1, 2). Diverse methods for learning, including the use of diagrams of complex biological pathways (2), help increase the number of active retrieval pathways, lengthen memory, and improve recall efficiency (3). Diagrams vary in their complexity, which should match the audience’s familiarity with the topic. High school, pre-medical, and medical students who reviewed a brief set of comic strips or a comic chapter book on the anatomy of the digestive system had greater recall of the organs’ functions than control students (4). A group of tenth-grade biology students who studied diagrams enhanced their restudy and recall of biology concepts (5). A different group of tenth-grade biology students improved their comprehension of scientific ideas by participating in workbook-focused instruction on conventions of diagrams and discussions led by a teacher (6). Since even physicians have been shown to prefer flowcharts and flow diagrams for learning and recalling clinical guidelines (7), science communicators should consider flowcharts and diagrams as important tools for teaching or refreshing science concepts with students of most ages and levels. While we present tips and tools for teaching students in grades 6 through 12 and college, all scientists and communicators can use the same tips and tools (tables, figures, and URLs) to design effective diagrams that communicate complex processes in simple and engaging ways.

Both flowcharts and flow diagrams can help students and readers who learn through seeing comprehend the relationships between objects or steps. Some people can remember details from a picture with text for a longer time than details from prose; for example, pictures with text in patient leaflets improve recall, comprehension, and medication adherence by the general public (8). Flowcharts and flow diagrams commonly use brief text and graphic elements to give an overview of a multistep process, a theory, or comparisons (Table 1). Although some students have better spatial cognition than others, all students who actively construct diagrams discover how to “follow the arrows” (9, 10). Students who self-completed diagrams with both text and graphic elements but not diagrams with only graphic elements could transfer inferences to a different scientific field (11). Furthermore, teacher instruction with a workbook that explains the common meanings of symbols and graphic elements in the diagrams from their biology textbook improved students’ comprehension (6).

The recently described Scientific Process Flowchart Assessment method can help evaluate students’ comprehension and visualization of the scientific process (12). Questions in prose help assess students’ grasp of concept definitions and facts but not how students organize the knowledge and relate it to similar fields (12). Diagrams can help students organize the knowledge (10) and apply it to other fields. Students who create flow diagrams may form a better-integrated or deeper understanding of the topic (10) because they need to notice all of the elements and their functions (13). In addition, flowcharts and flow diagrams are easy to understand for someone even with limited knowledge of the language; effective diagrams help students and scientists convey their research to peers and international colleagues at scientific meetings. Because students developing their own flowcharts may be able to more rapidly interpret flowcharts made by others (9), we encourage teachers to make construction or use of flowcharts a weekly activity, possibly as part of their preparation for laboratory exercises.

PROCEDURE

Teachers and professors can ask their students to prepare a flowchart of the procedure as pre-laboratory...
TABLE 1.
Common uses of flowcharts and flow diagrams.

| Content and Examples | Flowcharts | Flow Diagrams |
|----------------------|------------|---------------|
| 1. Linear progression of steps | • Steps in laboratory procedure | • Complex set of inputs, and interactions, in a process or theory |
|                      | • Overview of steps in procedure for scientific poster, article, or slide set for presentation | • Life cycle of microorganism |
|                      | • Theory of straightforward method with linear input | • Interaction of key signaling pathways in a process, such as Krebs cycle |
| 2. Group of steps that are repeated | • Procedure of polymerase chain reaction (PCR) | • Theory of complex method |
|                      | | • Theory of how process works |
| 3. Relationships between members of group | • Relationship of levels in multi-tiered organization | 2. Comparison of two similar but distinct processes, or comparison of two substances affecting a process |
|                      | • Family tree for related organisms | • Comparison of mitosis and meiosis |
|                      | • Family tree of extended family, for disease status | • Comparison of activity of two or more immunotherapy drugs for cancer |

| 4. Simplified illustration of a biological process | • Simplified illustration of condensation of DNA helix into metaphase chromosome |
| 5. Zooming in or out of an organ or organelle | • Zooming in or out of an organ with panels showing different magnifications, such as a lung, bronchiole, alveolus, proteins on the surface of cells lining the alveolus |

Flow diagrams can show the relationship of a small part to a large part. For example, Figure 2 shows a model of chromosome condensation. It displays a naked DNA helix, and zooms out in five steps to show the structures in which the DNA lives, up to a condensed metaphase chromosome. This model does not provide the mechanisms and proteins involved in going from the DNA helix to the condensed metaphase chromosome. Thus, the designer needs to decide not only what to include, but also what to leave out to avoid too much information and clutter. To avoid audience overload in diagrams for slide presentations, diagram creators can group similar variables or processes together and show the relationships between four groups or fewer on a slide. Adding animation to highlight group X can help focus the audience's attention on a specific point during the oral presentation. Since students who draw and use diagrams, especially those containing text, can more easily comprehend and apply the displayed scientific concepts in future biological and microbiological knowledge and research, scientists and communicators may wish to include at least naming and explanatory labels, graphic elements, and a detailed legend in their flowcharts and diagrams.

Several vendors sell templates of biological shapes and some flow diagrams with a non-exclusive license for use of modified works. To save time and maintain quality, we modified two PowerPoint templates from the scientific illustration toolkits for presentations and publications from MOTIFOLIO to make flow diagrams for our figures. Scientists and communicators should consider using unambiguous conventions, especially unambiguous graphic elements, in their diagrams to optimize the audience's focus at the start and support the appropriate flow of their attention to subsequent parts.
TABLE 2.
Explanation and examples of conventions of diagrams.

| Title | Conventions of Diagrams—Prose | Examples in Figure 1 |
|-------|-------------------------------|----------------------|
| • Is at the top | The title at the top: “Life cycle of Chlamydia” |
| • Tells key idea of diagram | |

| Caption | Conventions of Diagrams—Prose | Examples in Figure 1 |
|---------|-------------------------------|----------------------|
| • Is next to the figure number; often located below a figure | “FIGURE 1. Flow diagram showing the life cycle of Chlamydia.” |
| • Expands on key idea of diagram (what to notice) | Provides description of each panel of figure: A), B) |
| • May include abbreviations | EB = elementary body of Chlamydia; RB = reticulate body of Chlamydia. |

| Labels | Conventions of Diagrams—Graphic Elements | Examples in Figures 1 or 2 |
|--------|------------------------------------------|---------------------------|
| • Inside diagram | Arrows | Figure 1: The five blue process arrows show the sequence of events during Chlamydia infection. Note that the length of the arrows does not correlate with the length of elapsed time. |
| - Naming labels: Name parts of things | Cycle or circle | Figure 1: The life cycle is drawn as a circle. |
| - Explanatory labels: Describe what is happening in a part of the diagram | | Figure 1. Drawings of an infected cell as it progresses through all the stages of infection. |
| - Labels of passage of time: List amount of time that has passed between two events | Color | Figure 1B: Change in color of arrows—from light blue at beginning of infection to dark blue at release of infectious EBs—shows direction and correlates with passage of time. |

| Legend | Conventions of Diagrams—Graphic Elements | Examples in Figures 1 or 2 |
|--------|------------------------------------------|---------------------------|
| • Identifies what any symbols used represent | Color | Figure 1. The contents of the cell, the EBs, and RBs use false color to make them easier to see. |

EB = elementary body; RB = reticulate body.
CONCLUSION

Flowcharts and diagrams help many people remember a sequence of events and recall interactions in a complex process. Teachers, professors, and science communicators can display information for their students and audiences via flowcharts in class discussions, on handouts, in articles, during continuing education programs, and in slide presentations. Explaining the conventions of diagrams in the figure legends and clearly indicating the sequence in which to read them can help all audiences better assimilate the relationships the flow diagram conveys. Students who use and make flowcharts as part of weekly laboratories may become more adept in applying complex concepts (15). Students of all ages, colleagues, and readers likely will appreciate these insights and enhanced communication skills.

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