**TIPS, TRICKS & TECHNIQUES**

**Multi-view Protocols: Visualizing the Macro and the Micro of a Laboratory Method**

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**ABSTRACT**

We present a novel adaptation of a typical science laboratory protocol, which we have termed multi-view protocols (MVPs). The purpose of MVPs is to answer and link three common questions asked by students when first learning a laboratory technique: (1) What am I supposed to do? (2) Where and how am I supposed to do it? (3) What exactly am I doing, anyway? The intent of MVPs is to facilitate parallel comprehension of both the physical “movements” of a technique and the theoretical principles behind each step of a protocol. With MVPs, we achieve this through three parallel columns that include a textual description of the protocol, photographs of the protocol being performed in the laboratory space, and an illustrative column that visually depicts the molecular details of the corresponding steps. Variations of MVPs may include having students create one or more of the parallel columns themselves. In the age of near ubiquitous high-resolution camera phones, MVPs are a practical and efficient way to simultaneously teach laboratory method and theory, adaptable to nearly any laboratory protocol.

**Key Words:** inquiry driven; laboratory; protocols; theoretical learning; procedural learning; multi-view protocols; MVP; Advanced Placement exams.

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**What Are Multi-view Protocols?**

Multi-view protocols (MVPs) present a single protocol in three separate formats in parallel columns on a page (for examples, see Figures 1–3). The three formats are as follows:

- **Column 1 (Textual Protocol):** Step-by-step instructions in text format
- **Column 2 (Photographic Protocol):** Images of the protocol being performed in the designated laboratory space
- **Column 3 (Looking Closer):** Illustration of molecular details of one or more steps of the experiment and optional “What’s the point?” notes

The purpose of column 1 is to provide textual step-by-step instructions of how a protocol is to be executed, including all necessary details (e.g., reagent names, volumes, concentrations, incubation times). The purpose of column 2 is to provide students with “in-house” instructive images of what the user is to physically do and the location where that action is to be performed. The purpose of column 3 is to present the biological theory behind a protocol and bridge the potential knowledge gap between a step-by-step protocol and a conceptual understanding of the molecular processes that underpin each step. If space allows, additional “What’s the point?” notes can be added that describe the rationale of the aforementioned steps.

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**Who Are the Intended Users of Multi-view Protocols?**

We envision MVPs as being useful for both research and teaching laboratories. Within a research laboratory setting, we have found that MVPs are useful for the initial training of a new student as well as for transferring a project from an outgoing/graduating student to an incoming student. Within the teaching laboratory setting, MVPs can be adapted and used as a teaching tool/pre-lab assignment. For example, students could be provided with an MVP with only columns 1 and 2 completed, and the students would be tasked with generating column 3 independently. We further suggest that MVPs may be useful for preparing for the Advanced Placement (AP) exams. For example, the College Board provides AP high school teachers with a relatively small list of specific biology and chemistry laboratories that they should focus their teaching efforts on. Questions about the “big ideas” from these laboratories are on the AP exams. There are specific take-away concepts that the AP exams include, and MVPs may be an option to help prepare students for these exams. Therefore, we suggest that MVPs would be useful to students ranging from high school through upper-level undergraduate laboratory-based courses.
**Figure 1.** Example of a multi-view protocol (MVP), depicting the steps of chromatin immunoprecipitation (ChIP).

**Column 1: (Textual Protocol)**

1. Fixation of mammalian cells/crosslinking of cellular DNA-bound proteins
   - (1) Resuspend cells in 10 mL of PBS.
   - (2) Centrifuge at 120 g for 10 minutes.
   - (3) Vacuum supernatant.
   - (4) Resuspend cells in 9 mL of DMEM media.
   - (5) Add 270 μL of 37% formaldehyde.
   - (6) Incubate at room temperature for 10 minutes on a rocking platform at 50-100 rpm.

**What’s the point?** Formaldehyde covalently bonds protein-nucleic acid interactions, allowing for isolation of native protein-DNA complexes. The covalent bond is made between the amino group of a protein and the amino group of a DNA base.

**Figure 2.** MVP example depicting the steps of a trypsinization reaction with HeLa cells.

**Column 1: (Textual Protocol)**

1. Trypsinization of HeLa cells.
   - (1) Aspirate the media from cells with vacuum.
   - (2) To wash the cells, add 5 mL of DPBS, briefly swirl, and then aspirate DPBS with vacuum.
   - (3) Add 1 mL of 1x trypsin-EDTA.
   - (4) Incubate at 37°C for 2 min, or until cells detach from dish.
   - (5) Quench the trypsin-EDTA reaction by adding 9 mL of complete DMEM media to cells.

**What's the point?** Adherent cells have membrane proteins that allow them to adhere to culture dishes. Trypsin is a protease that cleaves these proteins, liberating the cells from the dish surface.
Why Use Multi-view Protocols?

The goal of MVPs is to increase the user’s practical and theoretical understanding of laboratory protocols. We hypothesize that MVPs will cultivate a deeper theoretical understanding of the protocol, reduce errors in protocol execution, and streamline the training of new students in a laboratory. We suggest that MVPs may also be helpful in quickly identifying gaps in a student’s conceptual knowledge. For example, when being used as pre-lab assignment (described above), if a student draws the “Looking Closer” column incorrectly, then misconceptions can be clarified before they begin an experiment. Studies have shown that using drawing as a teaching tool helps students break down larger biology concepts while allowing professors to identify students’ misconceptions (Köse, 2008; National Science Foundation, 2008; Eddy et al., 2013).

When considering MVPs and potential learning outcomes associated with them, we propose the following questions: (1) Are students who use MVPs less likely to make mistakes if they know the molecular theory of a protocol? For example, would a student be less likely to accidentally add protease instead of polymerase to a polymerase chain reaction (PCR) if they knew the functions of each of these enzymes and the fundamental theory behind PCR? (2) Would students who create MVPs for teaching laboratory protocols score better on post-laboratory assessments? Would a student then be better able to independently troubleshoot a failed experiment? For example, if a PCR reaction yielded nonspecific bands/amplification, would the student with the MVP protocol be more likely to realize that this could potentially be the result of a low annealing temperature than the student who has a standard step-by-step protocol? The answers to these questions and the efficacy of MVPs are yet to be determined but could be tested empirically in future studies.

Ramachandran et al. (2019) found that a similar teaching tool, Journal of Visualized Experiments (JoVE) Science Education videos, significantly improved student learning and helped reinforce conceptual understanding. Those videos demonstrate experiments, similar to column 2 of the MVP. Column 3 of the MVP is unique, though, in that it can require the student to actively engage with the laboratory material by creating the molecular illustrations themselves, as opposed to passively watching a video. JoVE videos provide the hypothesis of the expected results, rather than allowing students to formulate their own hypothesis. Asking the students to predict and draw the expected results using the MVP would be a way to assess students’ application skills of the concepts taught in pre-lab or lectures. Professors’ feedback for each student’s MVP would be a more personalized approach to clarify misconceptions. Furthermore, the MVP can easily be adapted and tailored to any experimental design, as opposed to using the general protocols outlined in videos. The MVP is also economical, as it only requires a camera and basic computing software.

In summary, MVPs are a practical and economical way to teach high school, college, and research laboratory students the technical and conceptual basis of laboratory methods. We suggest that MVPs are amenable to future empirical studies to test their impact on student learning, student mistake rate, experimental comprehension and independence, and long-term retention of scientific concepts.

Figure 3. MVP example depicting the steps of proteinase K digestion of mouse tissues.
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References

Eddy, S.L., Crowe, A.J., Wenderoth, M.P. & Freeman, S. (2013). How should we teach tree-thinking? An experimental test of two hypotheses. *Evolution: Education and Outreach*, 6(1), 13.

Köse, S. (2008). Diagnosing student misconceptions: using drawings as a research method. *World Applied Sciences Journal*, 3, 283–293.

National Science Foundation (2008). Picture this: explaining science through drawings. *ScienceDaily*, April 27. https://www.sciencedaily.com/releases/2008/04/080410153625.htm.

Ramachandran, R., Sparck, E.M. & Levis-Fitzgerald, M. (2019). Investigating the effectiveness of using application-based science education videos in a general chemistry lecture course. *Journal of Chemical Education*, 96, 479–485.

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