Physics in Canada, Special Issue on Physics Education Research, 70 (2), pp. 81-83 (2014)

Invention Activities: A Path to Expertise

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(Dated: September 13, 2013)

To help prepare our students for future learning, we have developed and refined various innovative instructional methods for the first-year physics lab at UBC. One such method is the invention activity. In this article, invention activities are introduced and guidelines for their creation are presented.

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I. INTRODUCTION

The success of instructional techniques is often a function of the desired learning outcomes. Operant conditioning, in which an individual's conduct is modified by its consequences, might be used for fostering desired attitudes or behaviors. Rote learning, a memorization technique based on repetition, might be used for developing motor skills. Despite the particular approach, humans create knowledge and meaning from reciprocal action between their experiences and their ideas. But in many educational settings, it is difficult for students to make such connections. For example, focused instruction in problem-solving routines is unlikely to prepare students for the novel situations they are likely to encounter [1]; for this, instruction should develop students' abilities to learn from new situations and resources. Students need to apply the skills, abilities, or knowledge acquired in one setting to a second, unfamiliar setting (i.e., transfer [2]). Preparing students for future learning is a lofty educational goal. Achieving this goal necessitates the development of innovative instructional methods.

To best prepare our students for future learning (of concepts related to the proper statistical treatments of real data), we have adopted the use of invention activities [3]. An invention activity is an exercise that helps students to notice important structural features and to form an organizational schema that prepares them to learn from being told the expert interpretation. This paper highlights the key differences between novices and experts and details how instructors can build their own invention activities to better prepare their students for future learning.

II. THE DIFFERENCE BETWEEN EXPERTS AND NOVICES

The study of differences between experts and novices has revealed distinctions in how they organize and apply their existing knowledge, and how they learn new ideas [4, 5]. It is more than general ability, such as memory, intelligence, strength, or dexterity that distinguishes the expert from the novice. It is also more than the application of specific procedures from a bank of strategies.

Experts have a well-developed capacity to detect relevant features, structure, or patterns in data or situations; novices often overlook important cues that should elicit new lines of thought. Experts possess a mental framework for coordinating their knowledge, allowing for effortless and flexible retrieval of relevant facts from memory and for efficient integration of related ideas into memory; novices lack such a framework and tend to rely upon fragmentary memorization rather than a unified integration of ideas.

Experts' knowledge reflects context of applicability, and they recognize when data or ideas conflict with prior knowledge, novices' knowledge can be reduced to sets of isolated facts or propositions and they often do not realize when they are living with a contradiction. Experts have varying levels of flexibility in their approach to new situations because they organize cases to find structure and can therefore recognize whether disparate instances have the same underlying structure, whereas novices tend to dive into a task without first organizing the information, and instead organize examples based on surface features [6].

Understanding expertise is important because it provides meaningful insight into the nature of thinking and problem solving.

III. INVENTION ACTIVITIES: WHAT THEY ARE AND HOW TO MAKE ONE

An invention activity in an instructional lab helps students focus on the relevant underlying structure in data and to build a mental framework that prepares them to comprehend standard representations. Like any other innovation in the classroom, care must be taken when using this type of activity. Without proper design and implementation, students can become frustrated and lose their motivation.

In principle, a good invention activity has a few specific characteristics [7]. To put some of these characteristics into context, parts of a "real" invention activity, designed to prepare students to learn about histograms and standard deviations, are provided for the reader. The activity can be found, in full, in Ref. [8]. In the first part of the activity, students receive four full data sets in tabular form, *summarized* here for the reader in Table I and displayed in a histogram in Fig. 1. The students are told that the data is associated with four different water flow meters and they are asked to invent a procedure for graphically representing the water flow data for each of the four devices. In the second part of the activity, the students are asked to invent a "blue-ribbon factor" for each these four flow meters: a value for how well the device measures the flow rate of water. They are told that a smaller "blue-ribbon factor" means the device performs more reliably.

TABLE I. The data, *in summary form*, associated with the invention activity.

machine	N	μ	σ_μ
A	10	9.9 mL/s	0.25 mL/s
B	20	10.0 mL/s	0.25 mL/s
C	10	11.1 mL/s	0.25 mL/s
D	10	9.9 mL/s	0.50 mL/s

A good invention activity must present a clear and challenging goal to the student—preferably an authentic problem. The student should be applying all their cognitive resources to solving the task, rather than figuring what is being asked [9]. The goal of the activity is, in most instances, to invent a concise and consistent description of the important features across some given cases. Typically, the description entails integrating multiple features into a single representation (mathematical, graphical, or otherwise). An appropriate goal is consistent with what an expert does when trying to describe or present real data. A simple case could be for that of a ratio (density); a more challenging case could be for that of non-linear regression.

The use of suitable contrasting cases in an invention activity is essential [1]. Contrasting cases help novices to notice the distinctive features of each case. Contrasting cases help the student to be oriented to understand the key structures in what they are seeing. Students cannot simply look at the data and learn from it, and a random set of different examples are just as confusing. The expert's role, in providing carefully selected contrasting cases, is to help the students to make sense of the differences. An invention activity should present multiple cases at once, so that students notice both the structure itself and the structural variations across cases that go beyond their surface differences. Ideally, these contrasting cases are made to vary systematically on key parameters, so that students can discover how the variations relate at a deeper, structural level. Four contrasting cases usually provides a reasonable level of difficulty. See the grayed cells in Table I for the contrasts.

Context must be considered when constructing an invention activity. The invention activity should involve material that is somewhat familiar and meaningful to the students.

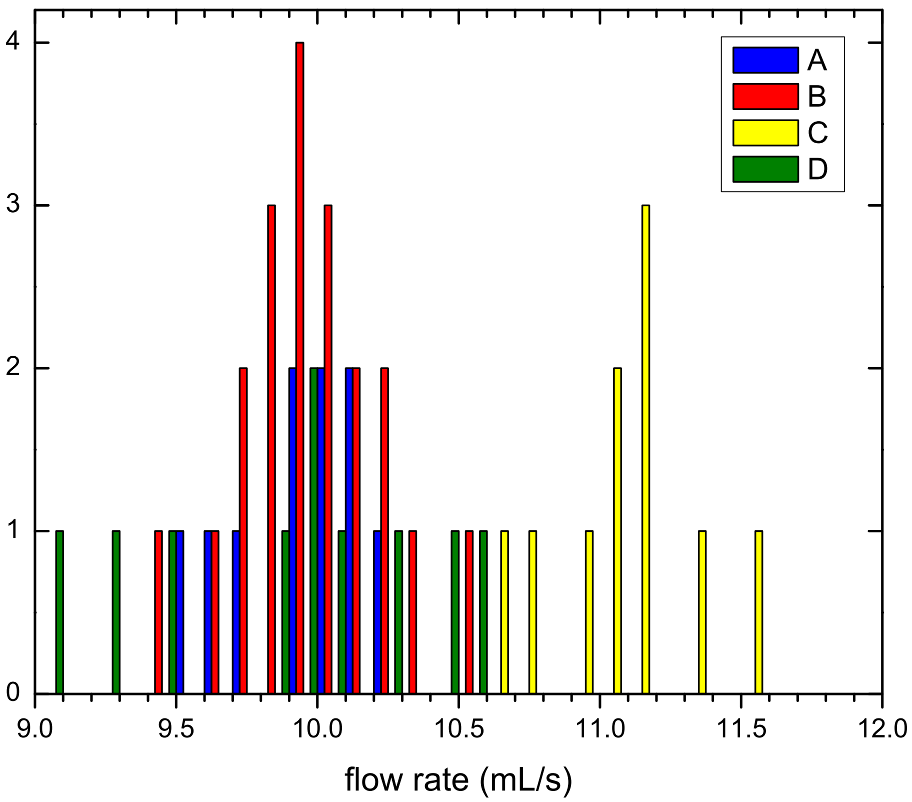

FIG. 1. A histogram of the data associated with the invention activity, shown to students after they have invented their own graphical representations; specifically, the lesson they have been prepared to learn from the first part of the invention activity.

When such context is lacking, students might not be able to recognize when a description or representation fails for a given case. We have seen invention activities fail because they involve things unfamiliar to some students at UBC, such as pitching machines or pumpkin pies.

Language must be considered when constructing an invention activity. As a rule, the invention activity should be devoid of domain specific jargon. Use of specialized language can trigger the common student response of equation-hunting ("What was that formula we learned?"), rather than the desired preparing-to-learn response ("Ok, this is new to me."). An indication of problems with the language is when students attempt to force some previously learned process or concept upon the task. Worse still, students might immediately try to look up the solution. To be clear, recalling familiar concepts should not be discouraged, only the unthinking use of tangentially related concepts or algorithms.

The level of difficulty associated with the invention activity should be set so that students achieve partial success, but usually do not come up with the expert solution that covers all cases [10]. That solution, often, took experts decades or even centuries to discover.

When teaching complex ideas, multiple activities can be used that are each limited in their scope. In this instance, each activity could be used to introduce one or two new structural parameters at a time.

Invention activities should be completed collaboratively. Multiple students will generate multiple ideas to consider. Explaining their arguments and conclusions requires of the student an analysis of their own thought processes. Conveying these ideas to others deepens their understanding, because the student has to explain it in a manner that their peers can also understand. Critiquing the ideas of others has similar benefits. In this way, small group work fosters deep learning. Furthermore, memory encoding, storage retention, and retrieval are heightened when one establishes meaning and understanding through presentation to others

Because of their complexity, invention activities must go through a design cycle. One should field-test the activity with a few representative students first and modify as needed before using it with a real class. Further modifications are then typically needed before use in the following year.

In summary, to make an invention activity, you must think about your own knowledge to isolate key concepts (do not fall prey to expert blind spots). Consider each case as an experimental treatment to isolate each key variable. Alternatively, think of formulas or units and make sure they contrast for each case. Have cases that will highlight probable student thinking pitfalls. Make the activities approachable. Your activity does not have to be highly entertaining, but it should be an engaging problem in a context that's different from the course material (like physics). Then you can help students map the ideas into the new context.

ACKNOWLEDGMENTS

Helpful discussions with N. G. Holmes, H. Nakahara, B. Ramshaw, I. Roll, and J. Taylor are gratefully acknowledged.

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