6.7 USING WORKED EXAMPLES TO IMPROVE STUDENT UNDERSTANDING AND PROBLEM SOLVING SKILLS

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1. INTRODUCTION AND BACKGROUND

Educators are well-aware that students do not retain all of the information that is taught to them. There are numerous reasons for this, including a mismatch between faculty teaching style and student learning style (e.g., Felder 1993; Roebber 2005), student misconceptions left unaddressed (e.g., Halloun and Hestenes 1985; Shulman 1999; Davenport et al. 2015), and student motivation and attitude (e.g., Ames 1992; Pintrich 2003; McConnell and van der Hoeven Kraft 2011). When teaching traditionally complex and challenging topics such as atmospheric dynamics (often introduced in the third year of the undergraduate meteorology curriculum), careful thought and consideration is needed to the aforementioned concerns when determining the appropriate instructional approach. Atmospheric dynamics can be particularly perplexing for students as some concepts are counter-intuitive (Persson 2010), and the traditional emphasis on complex derivations and theory conflicts with student preference for application-based learning (Roebber 2005).

A growing consensus of research indicates that students must take an active role in constructing knowledge to maximize their learning; simply transmitting information via lecture is insufficient (e.g., Johnson et al. 1991; McDermott 1998). One way to promote student engagement is to teach concepts using real-world examples and applications. In fact, in the early stages of learning, novices rely on, heavily prefer, and actually learn more through examples (e.g., Pirolli and Anderson 1985; Cooper and Sweller 1987; Anderson et al. 1997). The most *effective* examples that enhance learning are those that *guide* students through self-explanations of concepts (Chi and Bassok 1989). Self-explanation is achieved through a series of questions that prompt students to critically examine the given scenario, and also target and correct common misunderstandings and misconceptions. The more self-explanation a student does, the more successful they will be (Chi and Bassok 1989).

Additional benefits of students working through examples with self-explanation prompts include explicit demonstration of domain-specific problem-solving strategies, as well as a reduction in cognitive load (e.g., Sweller and Cooper 1985). Cognitive load refers to the extent of mental effort used in working memory; novice learners often experience a high cognitive load when presented with a problem to solve, making it more difficult to recognize patterns and identify key concepts needed to solve the problem, resulting in a lower rate of success (Sweller and Cooper 1985; Yuan et al. 2006). As summarized by Ward and Sweller (1990), "A heavy cognitive load is imposed because of the need to simultaneously consider and make decisions about the current problem state, the goal state, differences between states, and problem solving operators that can be used to reduce such differences. When non-automated operators are being used, the process becomes even more difficult."

Guided examples that are paired with self-explanation prompts are known as *worked examples*, and aim to demonstrate an expert's solution to a given problem by explicitly describing concepts and problem-solving methods. Implementing worked examples in the classroom has proven to be effective in enhancing learning and problem solving skills in a variety of scientific disciplines, including mathematics (e.g., Sweller and Cooper 1985), physics (e.g., Chi and Bassok 1989; Atkinson et al. 2000), engineering (e.g., Moreno et al. 2013), chemistry (e.g., Crippen and Brooks 2009), and statistics (e.g., Paas 1992). Given the strong desire for students to learn from examples, as well as the abundance of real-world applications in the field of meteorology, such a

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successful pedagogical method should be embraced and implemented in the classroom.

2. CONSTRUCTING WORKED EXAMPLES

The evidence is quite clear that using examples is recommended and beneficial for students. However, these examples must be carefully constructed to ensure that their structure and composition work to reduce cognitive load to allow learning to take place. For instance, examples that require students to split their attention between different sources of information and mentally integrate them are much less effective (e.g., Tarmizi and Sweller 1988; Ward and Sweller 1990; Fig. 1a). Instead, it is recommended to visually integrate problem statements, equations, and diagrams (e.g., Ward and Sweller 1990; Sweller 1994; Atkinson et al. 2000; Fig. 1b).

Additionally, the concept(s) that are being tested in the problem should be explicitly identified to prevent inaccurate assumptions, and students should be given prompts that encourage self-explanation and target common misconceptions. It is also recommended to provide opportunities for students to complete small steps of the problem (i.e., leave example problems partially unfinished to foster additional self-explanation), as well as offer multiple examples of each concept that contain varying degrees of complexity, paired with practice problems to solve on their own (e.g., Reed and Bolstad 1991; Atkinson et al. 2000).

3. IMPLEMENTING WORKED EXAMPLES

As an instructional tool, worked examples are typically given as a pre-class assignment where students examine and analyze a problem involving an application of upcoming lesson material. The goal is for students to construct a basic understanding of concepts and how they are used; in-class time is then spent on solidifying the key concept and providing additional depth using lecture, peer learning, solving additional problems, or other activities. (Atkinson et al. 2000). However, the worked examples approach does not specify the manner in which it is incorporated in the classroom; thus, instructors have latitude in the manner in which the examples are implemented. One possibility includes having students work through a guided example as an in-class activity;

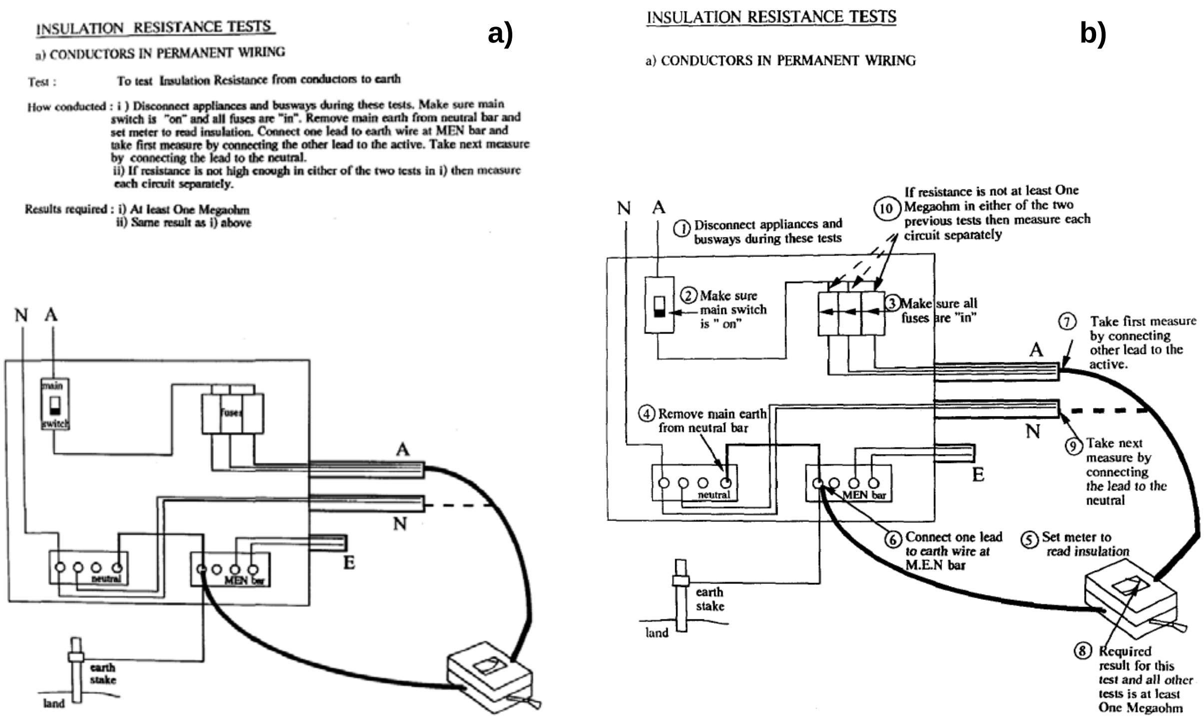

Figure 1: a) Example that separates problem statements and different sources of information versus b) an example that integrates the necessary information to solve a problem. Images taken from Chandler and Sweller (1991).

students could work individually or in small groups to promote peer learning. Alternatively, worked examples could simply be assigned as homework problems to complete after introducing a concept in class. Another possibility would be to have students create their own worked examples as preparation for an upcoming exam.

4. DISCUSSION AND FUTURE WORK

There is significant evidence of the power of learning from real-world applications and examples, particularly for novices (e.g., Pirolli and Anderson 1985; Cooper and Sweller 1987; Anderson et al. 1997). Given the positive influence of examples, and the richness of learning opportunities provided by the atmosphere, it is argued here that the atmospheric science community should embrace and implement the worked examples pedagogy. This approach would likely be most helpful for math-intensive courses such as atmospheric dynamics, which are typically more challenging for students given their theoretical basis and complexity (Persson 2010). However, this approach may also be of use in directly addressing misconceptions that students bring in with them at the start of the meteorology curriculum (e.g., Davenport et al. 2015).

The author is currently working to develop a set of worked examples for the atmospheric dynamics course sequence, and plans to test the examples within the next year. While refinement and assessment will be needed to ensure their effectiveness in enhancing student learning, the examples are nevertheless anticipated to be a valuable resource for all.

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