Work in Progress: Development of Web-based Pre-laboratory Modules to Increase Motivation and Reduce Cognitive Load

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Work-in-Progress: A Framework for Development of Web-based Multimedia Pre-laboratory Exercises

Introduction

Engineering is an applied discipline, and therefore, undergraduate laboratories are considered an essential part of engineering curriculum [1], [2]. Laboratories help reinforce theoretical concepts [3], and improve skills such as problem solving, analytical thinking and technical skills [4]-[6]. Other benefits include learning professional skills such as time management, teamwork, effective writing and oral communication skills [7]-[11].

Despite the potential value of undergraduate laboratories, there is a general agreement that the actual learning outcomes often do not balance the time, effort, and money invested in them [12]-[15]. One contributing factor to this imbalance is high cognitive loads as students are given too much information all at once [13], [16]. Therefore, students tend to concentrate solely on acquiring procedural knowledge by treating experimental procedures like recipes from a “cook book” to get the results/product [13], [16], [17]. In other words, they are usually not critically engaged with what they are doing, and rather than connecting theories to the experiment, they only focus on executing the experiment to obtain a correct result [12], [13], [18]-[20].

Past research has indicated that pre-laboratory (henceforth, pre-lab) exercises can reduce cognitive overload [19], [21], [22], and help facilitate student learning and understanding [13], [23]-[25]. Pre-laboratory preparation usually involves a short task to be completed before performing or attending the laboratory [19]. The fundamental purpose of pre-lab exercises is to prepare students for experiments by clarifying the expected work, asking students to read and understand the procedures, and encouraging them to learn or recall the related theories [16], [19], [26]. Being prepared for laboratory can result in less time being wasted, more productive work being completed [16], and reduced anxiety level [24].

There have been many pre-lab preparation methods proposed, such as small groups discussion [27], writing a summary of experimental procedures [28], answering procedural questions [21], and using simulations [29]. However, the majority of pre-lab assignments focus heavily on explaining procedural steps, describing the manipulation of apparatus/instruments, safety information [30], or practicing experiments using simulations [29]. While understanding experimental procedure is a crucial step to prepare for an experiment, there is still a lack of emphasis placed on integration between theories and experiments in pre-lab exercises [30], [31]. Laboratory sessions also do not usually coincide with the relevant concepts being taught in class [20], [32]. As a result, it might be hard for students to construct meaning and knowledge from laboratory experiences, since they cannot bridge the gap between theories and experiments, or become familiar with the underlying theory [13], [16], [21], [29].

Too often, students are not given adequate explanations as to why an experiment is performed, why they should care about the experiment and its relevance to the real-world practice [33]. This is unfortunate, as the lack of utility value can detract from students’ motivation to engage in a task [34].
A research project is currently being conducted to enhance the learning experience of students in chemical engineering laboratories at the University of Toronto by developing web-based multimedia pre-lab exercises to complement the laboratory manual. The goals of these multimedia pre-labs are to help the students construct knowledge by building connections between theory and experiment, and to understand the relevance and utility value of the experiments. This work-in-progress paper describes a theoretical framework for the development of multimedia pre-lab modules.

**Web-based multimedia pre-laboratory exercises**

Multimedia learning objects include multiple forms of media such as words and pictures. Examples of multimedia learning objects include, but are not limited to, videos with narrations, animations with narrations, and simulations [35]. According to the multimedia principle, “people learn more deeply from words and pictures than from words alone” [35, p. 43]. For example, it has been shown that students viewing a narrated animation of bicycle tire pump operation performed better on retention and transfer tests, compared to those either listening to an explanation or viewing an animation with out narration [36]. Visual representations can especially be helpful for making abstract chemical concepts more concrete, as hands-on laboratories cannot allow direct observation for unseen and unobservable phenomena [37]. However, simply adding pictures to words does not necessarily result in an effective multimedia presentation. Rather, the multimedia learning objects should be designed in accordance with how the human mind works [35].

Web-based multimedia learning objects can be accessed by students at any time, and hence allow a flexible and cost-effective means of delivery [16]. This is particularly important for pre-labs, as it allows students the flexibility of preparing for the laboratory at their own pace [16]. Web-based multimedia learning objects can also enable formative assessment with instant feedback, so as to address or clarify misconceptions [16]. Therefore, web-based pre-lab exercises are now a popular format of pre-labs [for examples, see 29,38].

Figure 1 represents a framework for developing web-based multimedia pre-labs. These pre-labs are meant to complement already existing laboratory manuals, which provide step-by-step procedures. The next sections describe the content, context and design of these web-based multimedia pre-labs.
Figure 1. A theoretical framework for the development of web-based multimedia pre-labs.

Content: explanation of related theories

Students require adequate time for interaction and reflection in order to enable meaningful learning [21]. However, when executing an experiment, students have to carry out many tasks within a set limited time, leaving no time for reflection [23], [31]. One method to overcome this limitation is to prepare students conceptually through pre-labs before they attend the laboratory. Thus, pre-labs should focus on theory in addition to procedure by explaining the related theory, connecting theory to procedural steps, providing a rational for each step, and explaining what is happening at the molecular level. This can provide an opportunity for students to interact and reflect upon underlying theories before performing the experiment, which in turn can improve prerequisite knowledge [14], [30]. Being prepared both procedurally and conceptually is an important factor contributing to the effectiveness of laboratories [28].

Context: utility value and real world relevance

Achievement motivation relates to performance on a task so as to achieve a standard of excellence [39]. One of the well-known achievement motivation theories is the expectancy-value theory [39]. According to this model, students are motivated for a task based on their expectations of success, and the value they assign for completing it. Expectancy for success is defined as student beliefs regarding their competencies in regards to the tasks [34]. Task value has four components. Attainment value is the personal importance of doing well on the task. Intrinsic value refers to the enjoyment, which is a result of performing the activity. Utility value is the relevance of the task to current and future goals, such as career goals. Cost refers to the negative aspects of performing a task. This could entail the degree of effort required, anxiety and fear, and the lost opportunities that result from performing that task [34].
Utility value is an important factor contributing to student motivation, which is often missing in undergraduate laboratory experiments. Students are usually not given explanations as to why they should perform the laboratory, why they should care about learning the material [33], and how it might be relevant to current and future goals, such as career goals. If students cannot see the usefulness of what they are learning, they will not be motivated to actively learn from performing experiments [40]. Pre-labs could provide a context for experiments by explaining real-world application, relevance of the material to industry and future careers, and knowledge transfer. This in turn could help increase student motivation to perform and engage with the laboratories, which is important as motivation is a key factor determining the amount of time students devote to learning [40].

**Design: multimedia principles to reduce cognitive load**

The cognitive theory of multimedia learning is based on three assumptions. First, humans have separate channels to process visual/spatial and auditory/verbal information. Second, each channel has a limited processing capacity. Lastly, active engagement in cognitive processing is required to construct mental representations of experiences [35]. Considering these assumptions is important when designing effective multimedia learning objects, as multimedia learning is associated with substantial cognitive processing, and learning can diminish if the tasks require cognitive processing exceeding that of the learner’s cognitive system [41]. Mayer and Moreno [41] have outlined general recommendations of multimedia instruction to reduce cognitive overload in multimedia learning, taking into account how the information processing system works. Some of the guidelines more relevant to the design of multimedia pre-labs are [41], [42]:

1. **Off-loading effect**: Words should be presented as narration rather than as on-screen texts.
2. **Redundancy effect**: Words should be presented as narration rather than as both narration and on-screen text.
3. **Segmenting effect**: Content should be presented in learner-controlled segments.
4. **Coherence effect**: Interesting but extraneous material should be eliminated.
5. **Signaling effect**: Cues should be provided for how to process the material.
6. **Feedback effect**: Explanatory feedback should be provided especially for novice learners.

Designing multimedia instruction based on these guidelines has been shown to enhance learning by reducing the cognitive overload [41], [42], and should be considered when designing multimedia pre-labs.

**Conclusion and Future work**

Web-based multimedia pre-labs provide a valuable method of preparation by offering advantages such as combining words and pictures, being interactive, and being available to students at any time. A framework has been proposed to develop web-based multimedia pre-labs for undergraduate students to complement the laboratory manuals. This framework is currently being used to develop pre-lab modules for a second year chemical engineering laboratory class at the University of Toronto. White-board animation videos are being developed to provide students with the content and context of the experiments by explaining related theories, utility value and relevance of the experiments to the real world or engineering practice.
As an example, a pre-lab module has been developed for a second year chemical engineering experiment involving the synthesis of the active ingredient in Aspirin. The module has five videos with a total duration of approximately twelve minutes. The videos explain the reaction mechanism of ester hydrolysis and acetylation, and provide a justification for procedural steps by explaining what is happening at the molecular level. For example, it is explained why cold water is added at one step, or why sulfuric acid is needed. Examples of various applications of some of the techniques and reactions are also given. For instance, it is mentioned that recrystallization is used in pharmaceutical industry to purify drugs, and ester hydrolysis is used in industry to make soaps. This helps students understand the usefulness of the techniques and reactions they will learn. The videos are being designed according to the guidelines of the cognitive theory of multimedia learning to reduce cognitive overload. Students can also re-watch the videos or pause if necessary. The module is interactive, with students responding to questions after each video, before moving to the next segment. Explanatory feedback is provided as to why the answer is correct or incorrect, and so as to help address misconceptions. User activities such as answers to the questions, video view counts and time on task can be tracked. A survey is being developed to determine the effectiveness of these web-based multimedia pre-labs through student perceived learning and motivation.

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References


