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Front-End Evaluation to Enhance the Usefulness and Adoption of Educational Materials: from Museum Education to Engineering Education*

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Summative and formative evaluation methods, adapted from the education evaluation literature, have been of tremendous value to engineering educators as they seek to assess educational materials. There is a third kind of evaluation that has a long history in the informal education realm that promises to further enhance engineering evaluation efforts. Front-end evaluation conducted in the beginning of a project provides information at the earliest stages of materials development to ensure that input from end users, faculty and students alike, is incorporated into the materials design. The benefits of front-end evaluation that have been utilized by museum exhibit evaluations and how they can be transferred across disciplines into the field of engineering education materials development are discussed. Front-end, formative, and summative evaluations combined increase the overall quality of the materials and facilitate dissemination.

Keywords: front-end evaluation; formative evaluation; summative evaluation; web-based design modules; aerosols

1. INTRODUCTION

EVALUATION OF ENGINEERING education materials is not only critical to ensure high quality of the developed materials but also is required by funding agencies. The National Science Foundation has taken a leadership role in promoting evaluation by making it an integral element of proposals and by providing engineers and scientists with guidance through the publication of several evaluation guides [1–3]. The common approach to educational materials development in the past that is still seen today is the model where the content experts develop course materials and then present them to end users [4]. Several recent examples of this approach include simulations developed for a manufacturing course [5], a web-based virtual robot task simulator (VRTS) for teaching robotics [6], and web-based simulations in a digital-filter design course [7]. In the first example, faculty recognized the benefits of providing students with self-paced, interactive learning materials. Six computer simulation projects were designed and then incorporated into the total classroom experience. In the second example, a VRTS was developed and used in an undergraduate electrical engineering course. The third example was an effort to develop a model for assessing these types of learning materials, and used modules that were a part of a digital filter design course. In all three cases, the teaching materials were developed without direct input from the ultimate end user, the students. Traditionally, anecdotal evidence or standard class evaluations would be presented as evidence of the efficacy of the materials. More commonly today, assessment is conducted after the materials have been developed to measure the degree to which the materials meet the desired goals, as was the case in the three examples mentioned above. This is an example of summative evaluation, which is an evaluation conducted at the end of a project and which provides valuable information regarding the degree to which the product has met its goals.

The rich literature produced by education researchers also points out that there are other types of evaluation that can benefit engineering education [8–14].

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Formative evaluation is another type of evaluation that assesses the product during development to maximize the effectiveness of the program, and it is exceptionally valuable in that it can identify problems that can be corrected at these early stages [4, 15–17]. This not only improves the end product but can avoid costly errors. It also provides an opportunity to generate buy-in from potential users by familiarizing them with the product and incorporating their suggestions [18].

The acceptance and adoption of project evaluation by the engineering education community is evidenced by a 2009 topic search of the articles listed in the *International Journal of Engineering Education* that produced 990 items that mention evaluation, 14 of which included "formative evaluation" and nine that mentioned "summative evaluation". A 2009 search of the *Journal of Engineering Education* produced 600 evaluation items, 21 of which mentioned "formative evaluation" and 18 that mentioned "summative evaluation".

In the previous manufacturing study [5], the summative evaluation included a survey of student attitudes and opinions of the simulations as well as an assessment of the simulations' ability to enhance content learning and the ability to apply the content to new problems. In the VRTS example, an assessment measured students' opinions of the tool after the first assignments. Coming in mid-course, this is an example of formative evaluation, if the use of the information gathered was to improve the tool as the course progressed, although it is not clear that this was the case in this instance.

Summative evaluation of the VRTS project included an instrument that measured students' self-reported perceived learning and motivation for robotics. The students' perceptions were compared to performance on a VRTS project. Anecdotal evidence of the depth of learning was noted. Summative evaluation was also conducted with the digital-filter materials. These evaluation efforts provided useful information but could be significantly enhanced by incorporating two critical stakeholder groups—students and other potential faculty users—early in the design process. Engineering educators can learn from more comprehensive evaluation efforts developed in museum education.

The museum education community has been involved in exhibit evaluation for over 100 years. Museums are considered informal learning environments, as opposed to formal, generally school-based, environments. Museum exhibit developers have unique challenges because unlike formal settings, learning takes place outside the classroom, materials are visually oriented and often involve manipulation, learners are self-directed, can proceed at their own pace, may select their own sequence to go through the materials, and have different backgrounds and ages [19, 20].

Similar to engineering education, early museum efforts focused on summative evaluation of exhibits after they were installed [21]. If a problem was discovered at this stage, it could be costly to remedy. In the 1960s, exhibit developers began promoting a new type of evaluation that was conducted on mock-ups of proposed exhibits, to identify areas in need of modification before the expense of creating the full exhibit. This came to be known as formative evaluation [22]. In the 1970s, museum exhibit evaluators borrowed what was called front-end analysis from J.H. Harless who did a needs assessment before developing training materials, recognizing the value of involving potential audience members very early in the development process [23]. Museums now routinely conduct front-end evaluation as the first step in a comprehensive evaluation program that includes assessing the target audience to uncover their perceptions and prior knowledge of the concepts that will be included by the materials, as well as their interests and attitudes. In the absence of this type of evaluation, materials developers are operating with a set of assumptions about what their target audience's level of knowledge is and what they are able to learn about a given topic. This was the model used in the three examples described above, in which materials were developed based on assumptions of developers and without direct input from students. Front-end evaluation allows developers to test these assumptions. It can provide information that can help developers refine their goals and message [23, 24]. Depending on the scope and complexity of the project, front-end evaluation may involve large studies or smaller surveys of selected people. It can also be seen as a type of market research.

Computer visualization teaching modules that are designed as engineering education materials have many characteristics in common with museum exhibits. The materials are visual, allow the students to manipulate concepts through simulations, and students may complete the modules outside the classroom, direct their own progression through the materials, proceed at their own pace, may select their own sequence to go through the materials, and may have different backgrounds and ages. These commonalities with a museum exhibit suggest that similar evaluation methods can serve the development of both.

Front-end evaluation can be very useful to engineering materials developers to ensure the materials meet their goals. Proper front-end development will help ensure that the materials have been designed with input from all potential users, increasing their usefulness to others and therefore increasing dissemination [25]. Another benefit of front-end evaluation is that it helps identify misconceptions that the students may have. Identifying these misconceptions is an important step in the development of any educational materials. Studies have demonstrated that undergraduate students often have misconceptions about scientific concepts, and that these are persistent in spite of classroom teaching unless the instructor directly challenges the misconception [26]. In the following example, front-end evaluation was employed in the development of web-based aerosol engineering teaching materials.

2. METHODOLOGY

Front-end evaluation was employed in an NSF CCLI project to design seven web-based modules that teach undergraduate students aerosol science and engineering at a research-extensive institution that would also be appropriate for the community college level and undergraduate minority teaching institutions, adding heterogeneity to the student population of potential users of the materials. The modules developed were Aerosol Basics, Aerosol Transport, Aerosol Instrumentation, Particle Control/Collection Devices, Nanoparticle Synthesis, Health Care Related Aerosol, and Atmospheric Aerosols (http://aerosol.ees.ufl.edu/).

Formative and summative evaluation was used in a previous pilot project that produced three aerosol modules, and demonstrated that students learned the content that was intended. The evaluation team decided to borrow from the museum literature and add a front-end evaluation component to the second, more extensive project, to provide developers with added user input. This was included to enhance dissemination and uncover misconceptions that students may have about the topics. Evaluations representing all stakeholders are vital to creating better learning modules and are helpful in the implementation of the modules. A two-pronged approach was designed with two short, online surveys, one for students and one for faculty. The primary goal of evaluating the faculty responses was to elicit suggestions of content that they would find useful thereby ensuring that the materials will meet their needs and maximizing module utilization. As another critical stakeholder, students were also included in the front-end evaluation effort. Students were asked what they knew about each module topic, what they would like to see in the module, and what would make the module more useful for their learning. In addition to assessing the level of prior knowledge, another purpose of this step was to identify any misconceptions that students may hold.

3. RESULTS

Samples of the faculty responses are shown in Tables 1, 2, and 3. Twenty-two faculty from across the country participated in the survey. The interdisciplinary nature of the field is illustrated by the range of departments represented by these respondents: respiratory care, environmental engineering, environmental management, paper engineering, environmental health, chemical engineering, chemistry, occupational health, cardiorespiratory technologies, civil engineering, mechanical engineering, allied health sciences, mechanical and aeronautical engineering. Each provided a list of the undergraduate classes they taught. Faculty were asked what they would like to see included in each module and what would make it useful to them when they were teaching. The survey provided developers with comprehensive information about what these potential users of the modules would like to see incorporated into the modules. Faculty were also asked what other module topics they would like to see and what in their opinion was the hardest concept in aerosol engineering for undergraduate students to understand, as well as an open ended opportunity to add additional comments.

Students' responses to Module 1 questions are shown in Tables 4, 5, and 6. Materials development faculty initially expressed concern to the evaluator that the process would not be useful as they assumed that students would have no prior knowledge of the subjects. Twenty-nine students

Table 1. Sample faculty survey responses to module 1 question 1

Module 1: Aerosol Basics

What topic(s) would you like to see included in this computer module?

- Demonstration of the forces on particles, comparison between physics of visible things vs aerosols—students find it difficult to understand that particles are affected by the air they are moving through.
- Principles of aerosol generation. Deposition of aerosol particles in the lung.
- Differences in aerodynamic diameter, Stokes diameter, volume diameter, projected area diameter, etc.
- What is an aerosol? (How is it different from a particle?) Examples of aerosols in daily life, methods of characterizing aerosols (general), aerosol composition—organic and inorganic details and how it varies with source type, region in US (i.e., pie charts), aerosol size distributions—factors affecting indoor vs. outdoor differences.
- Physiologic water principles; RH, Absolute humidity, triple point. Cell dynamic in water such as osmolality, osmosis, cranation, normality, any water principles in regard to temperature and pressure (universal gas law). Then specifics of driving gas, pneumatics, atomization and baffling, wet MDI and DPI function, dautrebands baffles/filters, piezoelectric cell function, vibrating mesh technology. Specifics of electricity and water for safety.
- Deposition of particles within the lung parachyma. Factors that increase or decrease penetration. Simulations of particles entering the lungs and how disease states alter their penetration.
- Discussion on the important parameters relevant to the study of aerosols (size, density, size distributions, etc.). Also, a good discussion on the various nondimensional numbers important to aerosols (e.g., Re, Kn). General discussion on everyday aerosols and how they impact our lives.

Table 2. Sample faculty survey responses to module 1 question 2

Module 1: Aerosol Basics

What would make such a computer module useful for you when teaching this topic?

- User-friendly and informative with practical examples.
- Interaction branching logic, critical thinking applications.
- Something interactive where students can work independently and then come to class with questions or submit them in the module itself.
- Remedial study for students taking a class that require the material as a prereq.
- Visualization tools, computational tools.
- Visualization/animation of the above topics.
- Relevance to civil engineers and public eye-catching interactive graphics quizzes to get their attention; make students think first!

Table 3. Sample faculty comments.

Additional comments:

- I think this is a GREAT resource! Based on my quick look at what is up so far, I commend you for your efforts to date!
- I think your ideas and the work you have done are very useful. Thanks.
- I did not repeat myself for each of the questions, but any tools that help a student "see" the process, or that allows a student input an important parameter (e.g. particle diameter) and then visual the change in particle collection/deposition properties is wonderful!
- This is a tough basic area of respiratory care and this would be most helpful.

participated, and as expected, the majority had no prior knowledge of the topics and left most of the questions blank. However, significant information of value to the developers was uncovered from those who responded to the survey.

The most significant result of this study is that three of the seven students who responded to the first question admitted that they knew little about the topic, but they were convinced that aerosols were bad for the environment. As mentioned earlier, student held misconceptions can be very resistant to change unless directly confronted. Front-end evaluation identified a potential misconception about aerosols that developers could directly address in the modules. These students' concept of aerosols consisted of products in aerosol cans and the connection to the ozone layer. Having identified this narrow understanding of aerosols, materials developers' could directly address this and provide students with a broader perspective and understanding of the field.

In addition, the responses from community

Table 4. Sample student responses to module 1 question 1

Module 1: Aerosol Basics

What do you know about the topic?

Of the nine who responded to this question, one knew "Nothing," one "Very little," and the responses of the seven others are shown below.

- My knowledge of basic aerosols has expanded from "bug spray" to a particle and fluid combination. I feel that the most important part of an aerosol is the size distribution with respect to time (not just size or concentration, etc.). Also, I feel that I have a good idea of the life cycle of an aerosol. For example, the cycle begins with how aerosols are formed to their transport with or without external forces, to collisions, and to deposition, etc.
- There are aerosols *that damage the ozone layer* and some do not. Not much really)
- Aerosols are used for spray cans and *can be hazardous in the environment.*
- What they are and how they are formed.
- Very little. Only that aerosol is found in many products and *negatively affects the environment*
- Basic properties and fundamental behavior of aerosols
- "Aerosol" = particles of a liquid or solid suspended in a gas. As such, they can fall out of suspension. Fall-out is based on particle type, size, and weight and type of gas and physical parameters such as temperature, % moisture (humidity) and flow. When an aerosol is used as medication, density also becomes important. Density is the ratio of the number of particles to the volume of gas. Particle size plays an important role in delivering medication to the appropriate site. Aerosol therapy is effective because it can be applied to the intended site directly. It is safer than systemic delivery of medication for that very reason and because lower doses can be used effectively and because the medication does not have to be filtrated through the kidneys and/or the liver before reaching the intended site (i.e. upper airway, lower airway, parenchyma), and because the surface of our lungs is actually on the outer surface of us but protected by its central location within the body, the tissues are thin and easily capable of diffusion of medication delivered by aerosol therapy.

Table 5. Sample student responses to module 1 question 2

What would you like to see in this module?

Eight participants responded to this item. Only one responded with an "I don't know," and another wanted "more information." Responses from the other six are shown below:

- Something that would combine the theory to a real world application (such as an analysis of household sprays, looking at the size distribution, etc).
- The mechanics of compressed air or vapor used to propel the content. Types of aerosols containers, hazards, recycling.
- Information on how they move with respect to other types of flow.
- Information to educate people
- Basic examples and practical references
- 1. Name what it is 2. tell what it does 3. tell how it does it 4. with what does it do it? 5. some history 6. some pictures 7. how the parts of delivery devices go together 8. proper administration 9. cautions & best way.

Table 6. Student responses to module 1 question 3

How could we make this module more useful for your learning?
• Of the eight who responded to this question, one had "No opinion" and the seven others made various suggestions:
• The mechanics of compressed air or vapor used to propel the content. Types of aerosols containers, hazards, recycling
• Diagrams, visual animations, interactivity with the material.
• Funny, humor is really nice.
• I have very limited information on this topic, any information would be useful.
• 1. In the beginning of the module, state the learning objectives 2. During the text of the module, have the subject matter reflect the same format as the list of learning objectives 3. Pictures, drawings, illustrations 4. If math is involved, use units, show step-by-step method and then if there is a short-cut show the short cut. 5. If there are known neumonic devices to help in memorization of essential facts, pass them on to us. 6. Places to look for advice: a. cognitive psychology books b. how-to-study books 7. I want questions with answers to follow quickly. Instant gratification is very good. That way, I know I am on track. Then I want questions that follow up on what we learned and link what we learned. 8...

college students showed developers that the respiratory therapy students have different levels of understanding than engineering students. An example of this phenomenon is that "aerosol transport" to one student meant the process of transporting gas canisters, clearly an appropriate response given her field, but a different concept from what was intended by engineers. This points out to materials developers the differences in perspectives used by different potential user groups, and the need to address this to be sure all concepts are clearly defined for all potential users. Students also provided developers with suggestions on what types of information and formatting they feel would be beneficial.

4. DISCUSSION

The developers of the aerosols modules used information gathered by front-end evaluation to guide them, rather than rely on assumptions. Formative and summative evaluations were also included in the comprehensive evaluation of the materials. There are several recent examples where front-end evaluation would have enhanced materials developed and student adoption. In one example of materials developed to teach the concepts of diffusion and drift, interactive animations were developed to illustrate semiconductor devices. They were developed without student input, then formatively tested and integrated into a curriculum. The formative evaluation with three students uncovered very valuable information for developers—of the three students tested, all had different conceptions of diffusion, only one of which was consistent with that of the developers [27]. This is a good illustration of the problems with making assumptions about students' prior knowledge and developing the materials before testing for this, and like the previously cited example when evaluators discovered that students had widely varying prior conceptions about aerosols transport. Only in this case, as a result of front-end evaluation, developers knew this before the development stage, and therefore could address it before the materials were developed. Additionally, it was noted that using the materials did not change one of the students' incomplete conceptualizations—given what is known about the intractability of misconceptions, this is not a surprise. Had the misconception been directly addressed in the materials, the probability of correcting it would have been significantly better, and front-end evaluation uncovered such misconceptions. Statements that show a disconnect between the developers and end users are shown in the following comments: "what was thought to be more or less obvious parts of the animation expression were actually hard to perceive or not perceived at all" [27, p 10] and "we can conclude that what is intended to be shown in the animation . . . was not at all obvious to the user" [27, p. 13]. Prior knowledge assessment would have benefited these materials developers.

A second group developed computer-based modules for introductory thermodynamics, then tested them with students. The developers recognized that assessment can help identify areas for improvement or components to delete [28] but these changes would involve additional cost as they would have to be altered after the materials were produced. Developers assumed that voice over would be useful, much like the use of clicks and music in the previous example, when in fact summative evaluation uncovered the suggestion that students wanted an option to turn off the sound. Summative evaluation determined that 80% of the students encountered technical difficulties with the materials and this discouraged their use. Again, beginning the evaluation process early in the materials development process and including students at the beginning would avoid mistakes that would need to be corrected later on.

A third project that followed the model of "expert development of materials followed by testing with students" measured web-based materials designed to teach the measurement of hardness in metals and to meet specific goals. The developers concluded that while several of their objectives were met, others could be met with "slight adjustments" or "more intensive programming", all of which would require additional resources and which might have been avoided if more intensive early evaluation including students was conducted before and during materials development [29].

5. CONCLUSIONS

Front-end evaluation can help materials developers make informed decisions about what concepts/features to include. The faculty participants in the front-end evaluation effort have provided module developers with a rich picture of the types of content that they would find useful. They represent a wide range of departments and teach a variety of courses. By collecting this type of information, module developers can ensure that the content included will meet the needs of this range of potential users of the final product, which will enhance dissemination of the final products. By including students in the aerosol modules development process, it was clear that as expected, the majority of the students did not have significant knowledge of the topics. However, there was evidence that aerosols have a negative connotation to some students and it was important for the modules to address this issue directly. Additionally, respiratory therapy students had a different understanding of the concepts and vocabulary of aerosols. Module designers could use the information provided by students to address their interests, such as the request for real-world applications and content they would find useful. This comprehensive model of materials assessment included all stakeholders from the outset, identified levels of prior knowledge and misconceptions, and identified concepts and topics that potential users wanted included. Input at the earliest stages of product development helped improve the materials that were ultimately developed.

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