Multimedia Cone of Abstraction – Process Burners Case Study

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Abstract

Advanced multimedia techniques offer significant potential for enhancing engineering education, but there has been little discussion of how to use them effectively in specific learning contexts. Dale developed an iconic Cone of Experience (CoE) which is a hierarchy of learning experiences ranging from direct participation to abstract symbolic expression. This CoE has been updated by the authors for today's technology and learning context, specifically focused on the use of multimedia. This new hierarchy, called the Multimedia Cone of Abstraction (MCoA), can be used as a guide to help engineering educators select appropriate multimedia for specific learning contexts. For example, the learner with little if any knowledge in a subject needs more concrete multimedia such as animations and virtual reality, while the experienced learner may prefer symbols and text. A case study will show an example of how the MCoA can be used to select multimedia including symbols, text, drawings, photographs, videos, animations, and virtual reality. In this example, the subject area is process burners which are used in refineries and petrochemical plants and the typical learners are engineers and plant operators.

Introduction

Dale's Cone of Experience (CoE) is an icon of instructional design theory.[1-3] The CoE shown in Figure 1 is a visual analogy to illustrate the progression of learning experiences from direct, firsthand participation to purely abstract, symbolic expression. Ausburn and Ausburn (2008) asserted that Dale's CoE is based in the proposition in Piagetian psychology of concrete versus abstract reason.[4] They provided the following description of the CoE (p. 62):

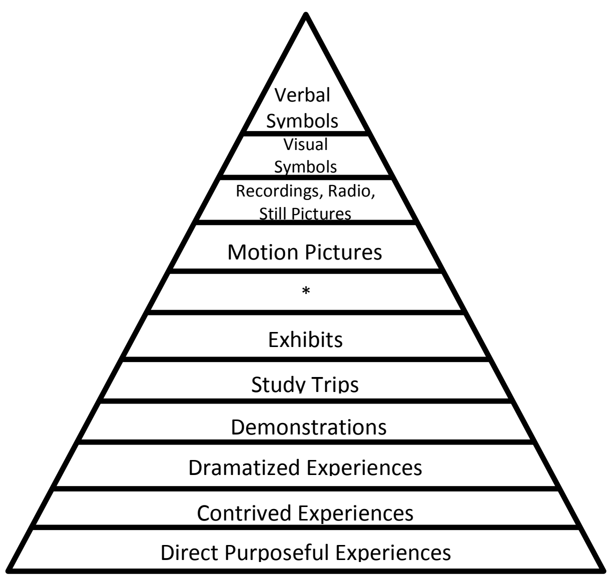


Figure 1. Dale's Cone of Experience (* Not in 1946 version, "Television" in 1954 version, and "Educational TV" in 1969 version.)

> [It] . . . proposed that (a) various types of learning experiences and media representations vary in their "concreteness," (b) more concrete forms of experience and media are truer and more complete representations of reality, and (c) media representations that are more concrete can facilitate learning, particularly when reality is complex and unfamiliar to learners.

Dale's CoE, originally developed for K-12 teachers, shows the level of abstraction for various types of learning activities to help educators design appropriate instructional materials using audiovisuals. The base of the CoE or lowest and least abstract level is "Direct Purposeful Experiences" where students participate directly in an activity and use their senses to help them learn. This level is sometimes referred to as "the real world." The highest and most abstract level of experience is "Verbal Symbols" where students use written symbols to express a concept. For example, H_2O represents the chemical compound for water which shows that water consists of two hydrogen atoms bonded with one oxygen atom. H_2O is a symbolic representation of water.

Some current forms of multimedia were not readily available to teachers when Dale proposed his CoE. For example, virtual reality (VR) is a relatively new element of multimedia available to educators today which has the potential to show very realistic simulations of things like airplane cockpits and operating rooms.[5] Some of the elements in the original CoE are not as relevant today as they were at the time the CoE was first developed. These include, for example, contrived experiences, study trips, exhibits, and educational television. Dale's CoE needed to be updated for today's technology and learning context.

Multimedia

Multimedia has become an important element in instructional design and is increasingly used in engineering curricula. Multimedia instruction can be defined as "the presentation of material using both words and pictures, with the intention of promoting learning" (ref. 6, p. 5). Multimedia can be used to effectively communicate complex technical concepts that are common in engineering programs. It has become easier to develop and use multimedia technologies due to the advancements in both hardware and software.

Because of the ubiquity of using computers to display instructional content, it is assumed here that multimedia specifically refers to materials that can be displayed on a computer. That assumption necessarily limits the senses that can be used in materials delivered by computer to visual and auditory. This means some of the elements in Dale's CoE are not appropriate in a computer-based learning environment. For example, a study trip where students physically travel to another location is not included in the updated CoE for the specific context defined here. However, VR, which is included in the updated CoE, makes it possible to virtually travel to other locations.

Some studies have shown no significant difference between learning with and without multimedia (e.g., [7]). In some cases, a reduction was actually found in learning with multimedia compared to learning without multimedia (e.g., [9]). Conversely, there is considerable research that shows learning is enhanced by well-designed multimedia presentations compared to text-only.[8]

Not all forms of multimedia are equally preferred in instructional settings. For example, it is often assumed that dynamic visuals such as videos and animations are superior to static visuals such as photographs and drawings because of their ability to show temporal relationships (*dynamic media hypothesis*).[9,10] The transient nature of dynamic visuals can help learners develop dynamic mental models.[11] Many studies have found that students prefer dynamic over static visuals (e.g., [12]), and there is a small but statistically significant improvement in learning (e.g., [13]). Höffler and Leutner (2007) did a meta-analysis of 26 primary studies that compared dynamic and static visualizations and found a statistically significant advantage for animations over static pictures.[14] Lin and Dwyer (2010) found a statistically significant learning advantage measured with four different types of tests for students viewing animations compared to those viewing static pictures.[15] These studies supported the dynamic media hypothesis by demonstrating the superiority of dynamic over static visuals.

Some researchers found static multimedia may be preferable to dynamic multimedia. Mayer et al. (2005) conducted four experiments on technical topics (e.g., lightning formation) in which one group of learners had annotated illustrations and the other group had narrated animations.[16] The annotated illustration group did as well as, if not better than, the narrated animation groups, which supported the *static media hypothesis* that static media are superior to dynamic media for learning. Tversky et al. (2002) questioned those studies showing an advantage for dynamic over static visuals because the visuals may not have been informationally equivalent or there may have been some confounding variables.[17]

In other studies, mixed results were found in comparing static and dynamic visuals. For example, Schnotz et al. (1999) empirically found that animations aided learning in one type of learning, but that static pictures provided superior learning in most conditions tested.[18] This can be explained by the increased extraneous cognitive load on the learner caused by the animations compared to static pictures.[19]

There is currently no consensus among media researchers that dynamic visuals such as animations enhance learning compared to static visuals.[20] This may be at least partially explained by the increased cognitive load on the learner caused by dynamic visuals compared to static visuals within a given (usually short) time period.[10,7] Viewers may look at a static visual for as long as they want, while non-interactive dynamic visuals such as videos are transitory and play automatically at a predefined rate.[21] Here, *interactive* dynamic visual means more than the ability to merely start and stop the visual; it also includes the capability to move to a specific frame, change the playing speed (i.e., slower or faster), and to zoom in or out. While viewers may replay a dynamic visual, they often do not take advantage of that capability, which means they may miss some details. An important advantage of interactive dynamic visuals such as VR compared to non-interactive dynamic visuals such as animations is the learner controls how the visual is displayed. A possible explanation why dynamic visuals may not be superior to static visuals is related to the viewer's previous knowledge of the subject, where novices often lack sufficient background to process complex information from animations quickly enough. A further possible explanation why dynamic visuals may not be superior to static visuals is a reduction in the degree to which learners engage in processing activities.[22]

Based on current research, there is no clearly superior multimedia type that enhances learning more than other types. This is a complex issue requiring further research. It may be that learner characteristics or prior knowledge have a large influence on what type of multimedia enhances learning for a particular individual. Therefore, it appears that *level of abstraction* is a valid approach for ranking different types of multimedia, in the absence of clear differences for enhancing learning. Since there is currently no hierarchy of multimedia for enhancing learning, level of abstraction was used as the ranking basis for placing various media formats in the MCoA presented here.

Multimedia Cone of Abstraction

Figure 2 shows the proposed MCoA designed to update Dale's CoE specifically for the use of multimedia in a learning context. A detailed discussion of the proposed MCoA is given in ref. [23]. The closer to the bottom of the cone, the more realistic the media representation; the closer to the top, the more abstract the representation. The triangular shape indicates that more abstract levels near the narrower top will appeal to relatively fewer experts, while less abstract levels near the wider bottom will appeal to relatively more novices. The levels chosen are consistent with Mayer's Cognitive Theory of Multimedia Learning. There are some relationships among some of the levels which could potentially have been combined but have been purposely separated. For example, nonverbal audio and narration both involve sound, and symbols are a specific subset of images and text. However, they are considered by educational media researchers to be distinct forms of multimedia and therefore have been kept separate here. A case study will be used to show examples of some of the levels within the MCoA. It will also be shown that there are many potential sublevels within some of the levels.

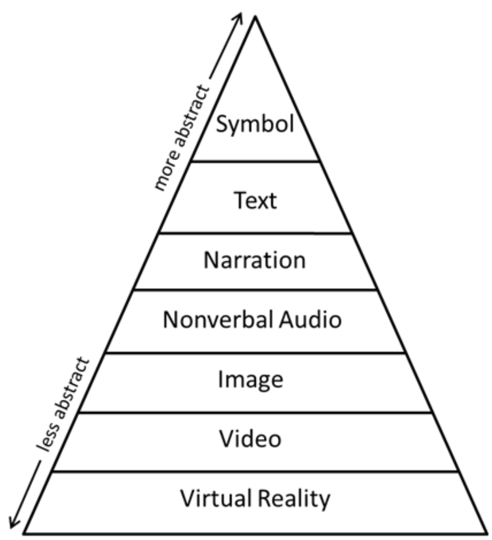


Figure 2. Proposed Multimedia Cone of Abstraction.

Process Burners Case Study

Process burners are used in refineries and chemical plants to heat hydrocarbon fluids to make a wide range of products such as gasoline, diesel, and ethylene.[24] Engineers and operators who work with heaters need to get training on these burners.[25] One element of this training is learning to identify the various parts of a burner. This element will be used here to show how different types of multimedia could be used to teach students how to identify burner parts.

The lowest and least abstract level on the MCoA is *Virtual Reality*. There are two basic types of VR: real and simulated. Real VR is a user-controllable virtual reality simulation using actual images such as photographs of things like objects or scenes. Simulated VR is also a user-controllable virtual reality simulation, but using simulated graphics such as computer-aided images (e.g., drawings) instead of actual photo-real images. There are multiple types of VR used in education, such as immersive simulations, interactive simulations, interactive scenes, and object movies. These require varying amounts of hardware, software, and expertise. Immersive VR requires special hardware (e.g., tactile gloves) worn by the learner to actually sense things in the simulation. Interactive simulations are computerized representations of something, similar to video games, where the learner interacts virtually with the environment. These simulations require special software and expertise, often beyond the level of most educators. Interactive scenes are relatively easy and inexpensive to make with a camera, tripod, and stitching software to merge images together to make a continuous scene. The tripod is usually fixed in one place and the camera is panned horizontally and sometimes also panned vertically to generate photographs of the scene. The learner interacts with the virtual scene by panning and zooming to view areas of interest. Object movies are similarly made except that the camera stays fixed while the object is rotated. The learner can virtually rotate the object and zoom to areas of interest. The latter two types of VR can be reasonably created by most engineering educators. Figure 3 shows a setup used to take photographs of a burner, which was rotated 360° horizontally in 10° increments using a carousel. The photographs were then stitched together using special software to make an object movie.

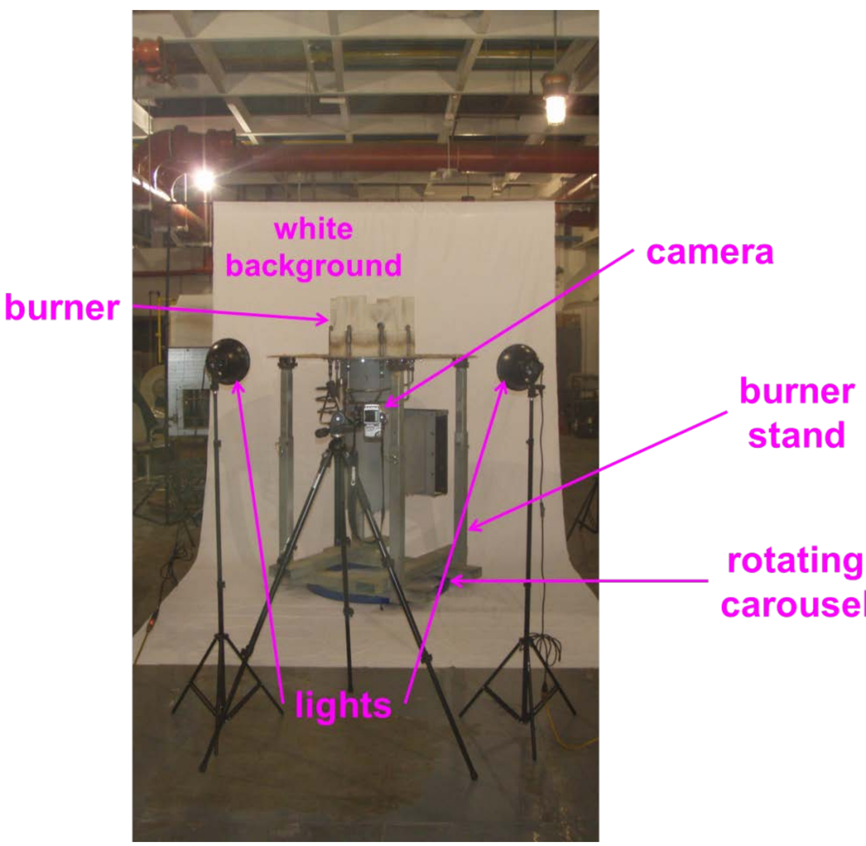


Figure 3. Setup for taking burner photos to make an object movie.

It might be argued that *Video* should be considered less abstract than VR. However, user-controllability makes VR less abstract than video in a learning environment. With video, the user generally only controls the speed and time sequence of the display (e.g., start, stop, rewind, fast forward), but not the location being viewed (i.e., it has no pan or zoom capability). VR has the added feature that the learner not only controls the speed and time sequence, but also the location being viewed (e.g., zoom in, zoom out, pan left, pan right, pan up, pan down). Further, while learners control the speed and time sequence of a video, in actual practice these capabilities are rarely used. However, in VR the user must control those functions or the image will not move, so learners are forced to control what they are viewing which typically means they will move at a pace they are most comfortable with and not at the preset pace (e.g., 30 frames per second) of a typical video. Videos can be easily made using video cameras and even most cell phones. Inexpensive software is available for editing videos to make them more professional. Powerful instructional videos can be relatively easily made by most engineering educators. Figure 4 shows a setup used to make a video of a burner by manually rotating it on a carousel.

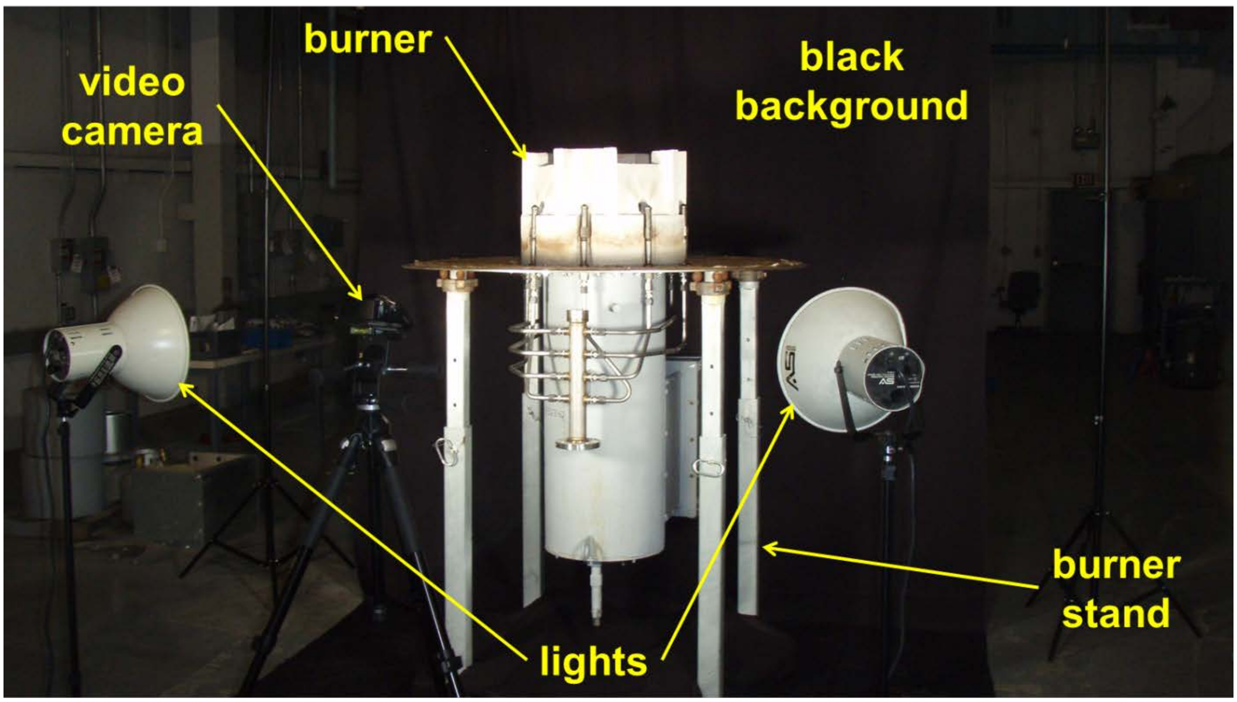
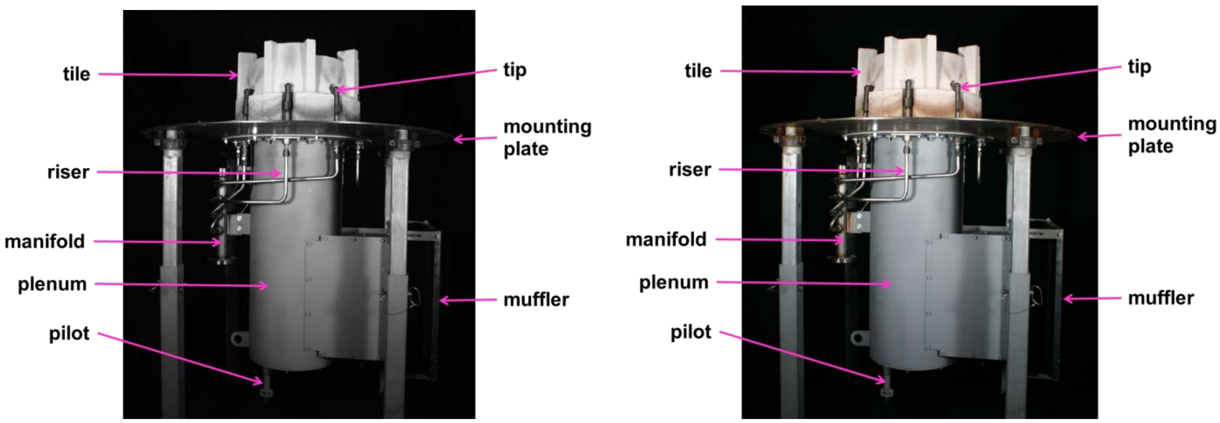


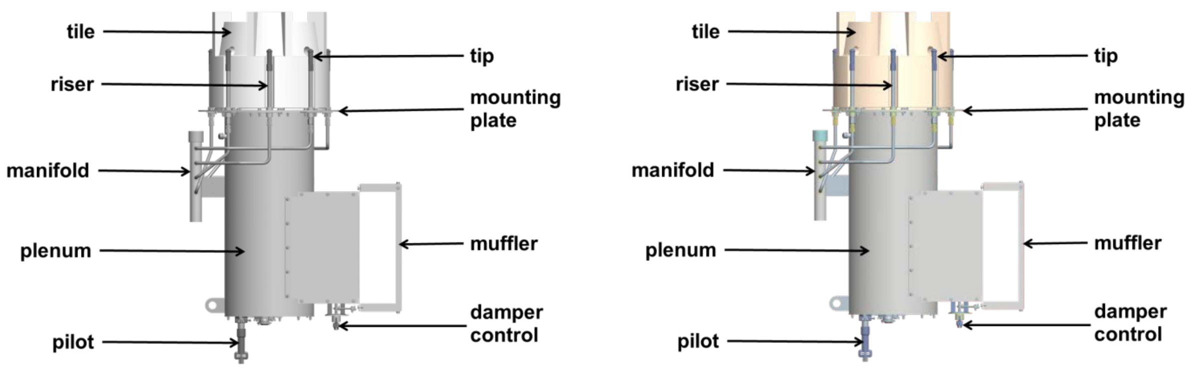
Figure 4. Setup for taking a video of the burner.

Image is a static graphic that can be in multiple formats. Real images are static graphics (e.g., photographs) of an actual object or scene. Figures 5a and b show black-and-white and color photographs (real images) of a process burner. The photographs have been annotated with arrows and labels to delineate the parts. Simulated images, such as drawings, are representations of real images. Images also have dimensionality and can be 2D or 3D. Figures 6a and b show 2D black-and-white and color drawings of a process burner, respectively. Figures 7a and b show 3D black-and-white and color drawings of a process burner, respectively. These are examples of the multiple sublevels possible in a given level, in this case the Image level.



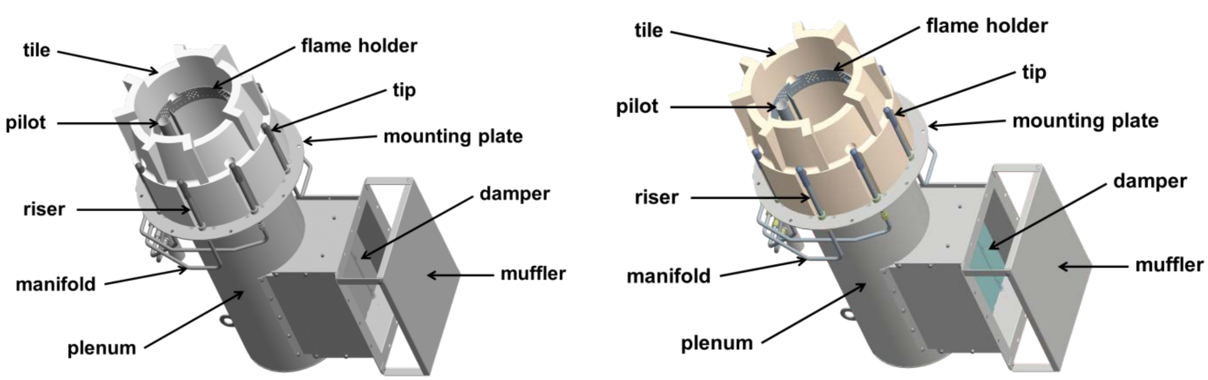
(a) (b)

Figure 5. Photographs of a process burner: (a) black-and-white and (b) color.



(a) (b)

Figure 6. 2D drawings of a process burner: (a) black-and-white and (b) color.



(a) (b)

Figure 7. 3D drawings of a process burner: (a) black-and-white and (b) color.

In the proposed MCoA, *Nonverbal Audio* refers to sound other than narration, which is treated here as a verbal form at a higher level of abstraction. Nonverbal audio could, for example, be produced during burner operation such as the sound of a burner firing in a heater. There are two types of audio: real and simulated. Real audio is a recording of actual sound, while simulated audio is produced, for example, by a computer which can be used to recreate sounds such as electronic instruments or voices. Nonverbal audio has the added feature of dimensionality where the sound could be mono (1 channel), stereo (2 channels), or surround-sound (multiple channels). Making audio recordings is relatively simple using sound from: videos taken with cameras or cell phones, microphones, or electronic files that can be downloaded from the Internet.

Narration is a specific verbal (auditory) form using spoken language with no images or text. In the case of a process burner, this could be an instructor verbally describing the various parts of a burner. Narration is less abstract than the next level "Text" because the spoken language includes changes in volume and tone that contain additional meaning compared to written words. While narration can be easily recorded with a microphone, educators may prefer to narrate other forms of multimedia (e.g., videos or images) live in the classroom, unless a particular narrator other than the instructor is desired.

Text is a verbal form that refers to written words. This may be as simple as a bulleted list on a PowerPoint slide or as complicated as a textbook. The assumption is that the language is familiar to the learner, although advanced vocabulary or a language that is not the primary language of the learner can make text even more abstract. The challenge with pure text is that the learner has fewer cues, such as facial expressions or voice inflections, to determine what the author means. This generally makes it more abstract than images and narration. Figure 8 shows labels plus text used to describe the parts of a process burner. Figure 9 shows a simple bulleted list of the parts. This would not likely be used by itself, but could be used by an instructor who describes each part (i.e., narrates).

• **tile**	**ceramic part which shapes flame**
• **pilot**	**small premix burner to ignite main flame**
• **riser**	**tube connecting manifold to tip**
• **manifold**	**distributes incoming fuel to tips**
• **plenum**	**delivers uniform air flow to outlet**
• **muffler**	**reduces noise**
• **damper**	**adjusts incoming air flow**
• **mounting plate**	**used to attach burner to heater**
• **tip**	**injects fuel into flame zones**
• **flame holder**	**anchors and stabilizes flame**

Figure 8. Labels + text describing process burner parts.

- **tile**
- **pilot**
- **riser**
- **manifold**
- **plenum**
- **muffler**
- **damper**
- **mounting plate**
- **tip**
- **flame holder**

Figure 9. Labels of process burner parts.

Symbol is the most abstract level and requires special knowledge by the learner for interpretation. There are two primary types of symbols: visual and verbal. A visual symbol refers to a graphic that is often short-hand notation for something else. For example, a circle with a slash diagonally across it on top of an image is a universal symbol that means do not do whatever is in the image. Figure 10 shows an image of a plant operator holding a stick with a rag on the end. This is improperly and unsafely used at some refineries to light burners by dipping the rag into a flammable fluid like gasoline and lighting the end. The flaming torch is then inserted into each burner through the back. Then the fuel gas to the burner is turned on and the burner should light. The proper way to light a burner is with either a pilot (see Figures 5-7) that is permanently part of the burner or with a gas-fired torch designed for lighting burners. The learner must be familiar with the symbol for it to be meaningful which is why it is considered more abstract than a non-symbolic image. A verbal symbol is usually short-hand notation for something more complex. For example, FGR refers to *furnace gas recirculation* which is one of the design principles used in the process burner shown in Figures 5-7 to minimize pollution emissions.[26] Someone skilled in this art would know what FGR means, but the novice learner would not.

Figure 10. Photograph of an operator holding a rag on a stick, which is improperly used to light a process burner.

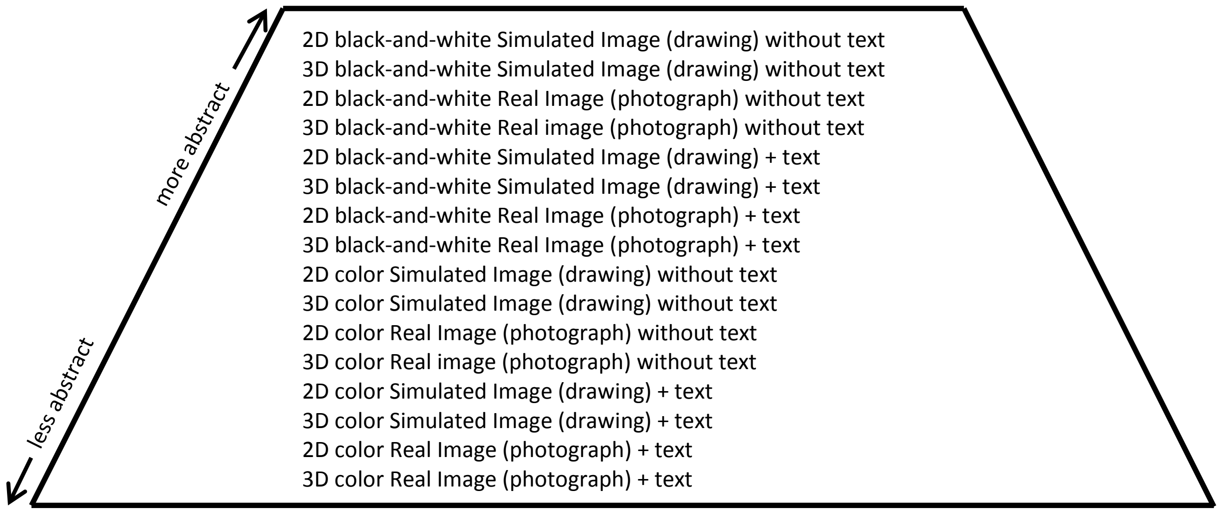


Figure 11. Possible sublevels within the "Image" level of MCoA listed from most abstract (top) to least abstract (bottom).

Within a given level of the MCoA, there may be many sublevels. For example, possible sublevels for the Image level are shown in Figure 11. The Image sublevels are combinations of image type (simulated or real), dimensionality (2D or 3D), verbal type (none, text), and color (black-and-white, color). *Simulated image* (better known as a drawing) is a static representation often created with computer-aided software. *Real image* (better known as a photograph) is a static representation of an actual image, usually taken with a camera. A verbal component in the form of text may or may not be present. Similarly, the image could be in black-and-white or in color. Figures 5-7 show examples of six of these sublevels.

The MCoA discussed in this paper demonstrates the many levels of abstraction that are available to the instructional designer of engineering content. The appropriate amount of abstraction depends on both the subject matter and on the prior knowledge of the learners. For example, students with no prior experience in a subject area will likely need less abstract multimedia initially, but will be capable of more abstract multimedia as their knowledge of the subject increases. The less experienced students might benefit from virtual reality simulations, animations, and videos to enhance their learning. Instructors might use less abstract multimedia for new topics and more abstract multimedia for topics that were already covered earlier in the course. No single level will be appropriate for all topics, but some levels may be more appropriate than others for particular topics. For example, a video that includes audio of a process burner flashing back would be much more effective than a drawing, photo, or verbal description of a burner flashing back as the sound is a key component of this phenomenon. In addition, some levels may not be appropriate for all learners. For example, more visually-oriented learners may prefer virtual reality, while more verbally-oriented learners may prefer narration and text. The MCoA is not intended to rank multimedia types from best to worst, because no single level is best for all learners and all topics. It is intended to give some guidance to instructional designers of engineering education content. Further considerations include the time and cost to make suitable multimedia where, for example, text is very quick and easy to produce while virtual reality can be time consuming and somewhat costly initially to acquire the proper hardware and software.

Conclusions and Recommendations

The purpose of this paper was to give engineering educators some tools to consider when developing course content. A Multimedia Cone of Abstraction was presented which lists broad categories of multimedia ranked hierarchically according to their approximate level of abstraction. The subject of process burners was used to illustrate how multimedia might be used to teach learners about this technology. However, it was shown the MCoA is not intended to rank multimedia types from best to worst, nor was it intended to be a rigid ranking as levels of abstraction can change depending on the specific content. It was also shown there can be many sublevels within a given level. Some variety is recommended as using only a handful of multimedia types could become boring and reduce learner interest. Other factors that were not included in this analysis are the time to develop the content and the cost to make the content. These can vary widely depending on the content and the equipment used to develop the content.

A further element only briefly mentioned here is learning preferences where some learners are more verbal and others are more visual. It will not usually be possible to satisfy the needs of every learner with one particular type of multimedia because a given class usually has students with a range of subject knowledge (sometimes from novice to expert) and learning preferences (visual to verbal). Therefore, it is recommended that engineering educators use a range of multimedia types to teach technical content. However, the range can often be narrowed somewhat depending on the type of class. For example, a lower level or beginner's class will not usually, at least at the beginning, include many symbols because the students have not learned them yet. In an upper level class on a more advanced version of the same topic, symbols can be effectively and efficiently used since the learners are familiar with them.

The appropriate multimedia should be selected according to the subject matter and the needs of the learner. Further research in this area is recommended to quantitatively measure differences in student performance as a function of many variables such as student multimedia preference, student learning style, student experience level, and multimedia type.

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