Digital video clips for improved pedagogy and illustration of scientific research — with illustrative video clips on atomic spectrometry

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Abstract

This article is an electronic publication in Spectrochimica Acta Electronica (SAE), a section of Spectrochimica Acta Part B (SAB). The hardcopy text is accompanied by an electronic archive, stored on the CD-ROM accompanying this issue. The archive contains video clips. The main article discusses the scientific aspects of the subject and explains the purpose of the video files. Short, 15–30 s, digital video clips are easily controllable at the computer keyboard, which gives a speaker the ability to show fine details through the use of slow motion. Also, they are easily accessed from the computer hard drive for rapid extemporaneous presentation. In addition, they are easily transferred to the Internet for dissemination. From a pedagogical point of view, the act of making a video clip by a student allows for development of powers of observation, while the availability of the technology to make digital video clips gives a teacher the flexibility to demonstrate scientific concepts that would otherwise have to be done as ‘live’ demonstrations, with all the likely attendant misadventures. Our experience with digital video clips has been through their use in computer-based presentations by undergraduate and graduate students in analytical chemistry classes, and by high...
school and middle school teachers and their students in a variety of science and non-science classes. In physics

teaching laboratories, we have used the hardware to capture digital video clips of dynamic processes, such as

projectiles and pendulums, for later mathematical analysis. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Atomic spectrometry; Pedagogy; Video

1. Introduction

Computers have become so ubiquitous that their multitude of applications in scientific research, business, and education need not be
described. However, it is perhaps surprising that computer hardware is not used more often to present the results of scientific research or to present lectures in our schools and universities. One reason is that the lowly 35-mm or overhead transparency projectors remain cost effective for the presentation of text and images, even though the material may have been originally prepared on a computer. It is an axiom amongst educators that it is not justifiable for a computer to be used as a glorified overhead projector. Even with the aid of modern presentation software, with its sophisticated features for the production of text and still images, computers are not used habitually for the actual presentation because they are expensive, and not as portable as a fistful of 35-mm slides, a folder full of overhead slides, or a piece of chalk.

One dimension of presentation that cannot be done with an overhead or 35-mm projector is to show digital movie clips, and it is this facet of computers that will lead the computer to be ubiquitous in the presentation sphere. Desktop computers are able to digitize and manipulate short (15–60 s) movie clips, usually by addition of an expansion board. The digitized movie clip can be saved on a hard drive for manipulation like other computer files, and incorporated easily into computerized presentations. Digitized movie clips justify the use of a computer in a wide variety of scientific, business and educational situations. They can supplant the use of VCR tapes or laser discs, which have not seen universal use in presentations because their hardware and software are bulky and inflexible in use.

Digital video clips are easily controllable at the computer keyboard, which gives the presenter the

ability to show fine details through the use of slow motion. Also, they are easily accessed from the computer hard drive for rapid extemporaneous presentation. In addition, they are easily transferred to the Internet for dissemination. From a pedagogical point of view, the act of making a digital video clip by the student allows for development of powers of observation, while the availability of the technology to make digital video clips gives a teacher the flexibility to demonstrate scientific concepts that would otherwise have to be done as ‘live’ demonstrations, with all the likely attendant misadventures.

It is important to note that this paper explores the use of movie clips rather than full-length movies. A movie clip that illustrates a single scientific concept is easy to make and easy to incorporate into an electronic presentation, by use of the digital technology described here. Such clips are short, with typical lengths varying between 15 and 60 s. A clip that might be only 20 s long, and located somewhere on a tape or laser disk is not conveniently accessible during a presentation. A computer hard drive is a much more ideal random access location for such short clips.

Video material that lasts longer than 30–60 s requires more time to produce because it usually requires editing. One example of the desire by many teachers for full-length video is that of a movie that can illustrate how a student should do an experiment. This implies that the video is for introductory or review purposes when the instructor is not going to be available in person. Such movies take considerable time to produce. For example, a 2-min movie that consists of maybe 8–10 clips, taken from original footage of the experiment, might take up to a day’s work to edit into an acceptable format. This is without consideration of any importance that might be attached to accompanying sound, or added sound. Long movies, that might last from several minutes
to full-length presentations of 30 min or more, remain more conveniently presented with laser disks, or VCR, or more recently by use of the new format of digital video disk (DVD).

Our experience with digital video clips has been through their use in computer-based presentations by undergraduate and graduate students in analytical chemistry classes, and by high school and middle school teachers and their students in a variety of science and non-science classes. In physics teaching laboratories, we have used the hardware to capture digital video clips of dynamic processes, such as projectiles and pendulums, for later mathematical analysis.

Professional Development Workshops, offered through our Center for Technology Education in Math and Science, have been used to transfer the technology to the high school and middle schools.

2. Experimental

Until the advent of the practical digital video technology used in the work described here, the primary means of presentation and manipulation of scientific movie material has been by use of analog video cassette tape and laser disk players. Laser disk players have been somewhat more versatile than video tape in the presentation of short video clips, but cannot be used for recording of scientific information. Manipulation of analog video material has not been popular because it is cumbersome and difficult to produce professional looking results. In addition, if short video clips are required for scientific demonstration, tape is not practical and laser disks are not recordable by amateurs. Fig. 1 illustrates the process involved in editing clips by use of analog hardware. Various video sources, such as cameras, broadcast television, etc., are used to record original material to tape, which can then be edited by ‘rolling’ desired video clips to a master recording machine. If the resultant finished tape is to be reproduced, the copies are degraded in quality from the original. Professional videographers use automated systems that lay down successive clips after the editing sequence has been listed; the edit decision list. The equipment to do this efficiently is extraordinarily expensive.

2.1. Equipment and software

Table 1 lists the main pieces of equipment and software that were used. Routine equipment such as the computer monitor, projection equipment, etc., is not listed. The prices given in the last column are a rough guide only. They cover a range because a wide variety of products are available that produce varying levels of quality, and flexibility. However, a base system that costs approximately $3000 for the computer system, plus inexpensive versions of a VHS video cassette recorder, a VHS analog video camera, a writeable compact disk drive, and a scanner, would be capable of the work described in this paper, with only a few compromises. A multimedia personal computer is defined here as one that is powerful enough to run standard office software, plus the ability to capture and play full screen (640 × 480 pixels) full motion (30 frames s⁻¹), full field (60 fields per frame) digital video. The exact specifications of such a computer can be achieved with

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Fig. 1. The past: editing and viewing of analog movie clips with laser disk players and video cassette recorders.
many different computers on several platforms. Six computers were used here, five of which were Macintosh Quadra 950s, 68040 machines, and one was a PowerMac 8100/80.

In the classroom and lecture hall, observation of the output from the computer was by use of a LCD computer projection panel with its image projected onto a screen. The computers used had two video boards. The first was the usual built-in computer-video, while the second was for digital motion-video. The menus and windows were displayed on the built-in video, which was connected to the normal computer screen for observation by the operator, while the video clips and PowerPoint slides intended for the audience were displayed on the digital motion-video board which was connected to the LCD panel. Development work was done with the computer monitor connected to the motion-video board and the LCD panel was disconnected. Now, LCD projection panels in conjunction with an overhead projector are being replaced by LCD panels with their own built-in light source. These are brighter and more flexible than stand-alone LCD panels.

The internal hard drive was used as the storage device for the operating system software, together with a word processor, spreadsheet, image and video editing programs, and presentation programs such as Microsoft’s PowerPoint.

The recordable CD-ROM (CD-R) turned out to be the most versatile archival medium available for this project due to the low cost, $1–4 per disk,

Table 1
Multimedia computers, equipment and software

<table>
<thead>
<tr>
<th>Item</th>
<th>Company</th>
<th>Model no.</th>
<th>Notes</th>
<th>Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multimedia computer</td>
<td>Apple</td>
<td>Quadra 950 or PowerMac 8100/80</td>
<td>68040 Mac or PowerPC 601</td>
<td>1000–3000</td>
</tr>
<tr>
<td>Full motion video board</td>
<td>Radius</td>
<td>VideoVisionStudio (Nubus board)</td>
<td>Full screen, full field, video capture/playback with compression and decompression</td>
<td>500–4000</td>
</tr>
<tr>
<td>Word processor, spreadsheet, presentation software</td>
<td>Microsoft</td>
<td>Microsoft Office</td>
<td>Word, Excel, PowerPoint</td>
<td></td>
</tr>
<tr>
<td>External SCSI 2 fast, wide, hard drive array</td>
<td>FWB Corp.</td>
<td>4GB SCSI array</td>
<td>Digital movie capture</td>
<td>1000–3000</td>
</tr>
<tr>
<td>Rewritable optical drive</td>
<td>MicroNet</td>
<td>SB-TMO-1300 (Tahiti format)</td>
<td>Image and movie archives</td>
<td>500–3000</td>
</tr>
<tr>
<td>Recordable CD-ROM</td>
<td>Pinnacle Micro</td>
<td>4 × 4</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Image editing</td>
<td>Adobe</td>
<td>Photoshop</td>
<td>For use with scanner</td>
<td></td>
</tr>
<tr>
<td>Movie editing</td>
<td>Adobe</td>
<td>Premiere</td>
<td>Movie capture &amp; editing</td>
<td></td>
</tr>
<tr>
<td>Color scanner</td>
<td>Hewlett Packard</td>
<td>ScanJet Ilcx</td>
<td>Image capture</td>
<td>100–700</td>
</tr>
<tr>
<td>VCR</td>
<td>Panasonic</td>
<td>AG-1980</td>
<td>S-VHS</td>
<td>150–1800</td>
</tr>
<tr>
<td>Laser disc</td>
<td>Pioneer</td>
<td>LD-V8000</td>
<td></td>
<td>800–2000</td>
</tr>
<tr>
<td>Digital video camera</td>
<td>Panasonic</td>
<td>PV DV710</td>
<td>MiniDV</td>
<td>1400–3500</td>
</tr>
<tr>
<td>Analog video camera</td>
<td>Panasonic</td>
<td>AG55</td>
<td>S-VHS</td>
<td>300–2000</td>
</tr>
</tbody>
</table>
and high capacity, 650 MB per disk, of the medium. It was used to archive movies, which varied in size up to approximately 120 MB for 20–30-s clips, together with PowerPoint presentations and scanned images. CD-ROMs were also used to distribute materials as necessary.

The rewriteable optical disk drive used a rewriteable optical cartridge with 650 MB per side. This was used as temporary backup of extant projects. Ultimately, materials were transferred to CD-R for final archival purposes. The cartridges were 10 times more expensive than CD-R and were not practical for permanent storage of large numbers of large files. Rewriteable digital video disk drives (DVD-RAM) are just becoming available on the market at prices less than $800 per drive, and will replace CD-R before long. The DVD-RAM medium is a cartridge that holds 2.6 GB per side and costs less than $50 per cartridge. These drives can read DVD, CD, CD-R (writeable CD), CD-RW (rewriteable CD) as well as DVD-RAM and some other formats.

The motion digital video board, Radius’s Video Vision Studio (VVS), was a Macintosh NuBus expansion card (Fig. 2). It did the analog-to-digital conversion of NTSC composite or S-Video video signals from camcorders, video tape recorders, and laser disk players. The format of the resultant digital video file was Apple Computer’s Quick-Time. Additionally, the VVS board performed real time hardware compression during recording, and real time hardware decompression during playback of the digitized movies either to a computer screen or to an NTSC composite or S-Video monitor. The compression format was JPEG (Joint Photographic Experts Group) which is a spatial compression/decompression algorithm (codec) that compresses the data in each frame of a clip in order to reduce its file size for more efficient computer disk storage. Also, the VVS board was able to execute all the above functions in the European PAL format. Once the video clip was digitized and saved to computer disk, the video hardware such as the video cassette recorder (VCR) did not need to be part of the presentation hardware. There are a variety of motion video boards available on the market that may use a variety of movie formats other than QuickTime and a variety of codecs other than JPEG. Presently, the MPEG codec (Motion Picture Experts Group) and DVD formats are becoming popular for computer generated and manipulated movie clips and full length video. MPEG motion digital video boards for compression and decompression have become relatively inexpensive, and MPEG decompression has been built into some computer video boards. The latest MPEG format, called MPEG-4, is a version of QuickTime.

Without compression, digital video files are very large, because they include 30 picture frames s⁻¹, each frame of which could be as much as 20–30 MB. This amount of information is reduced by

Fig. 2. The present: digitization of analog video clips, with editing and viewing of digital video clips with a computer.
JPEG compression to approximately 100 MB for a 20–30-s clip, but even this requires high data transfer rates for capture and playback. In order to save this amount of information as fast as it is being processed by the VVS board, a hard drive array is necessary (Fig. 2). This is a pair of conventional hard drives in one portable housing. A normal hard drive is not usually fast enough to keep up with the information flow, but an array drive has two drives onto which information is saved simultaneously. The effective access time is improved by a factor of two from approximately 10 ms to approximately 5 ms, and the data flow rate, for QuickTime Movies, is between 2.8 and 10 MB s⁻¹. The drives used here had a SCSI (Small Computer Systems Interface) board in either the processor direct slot of the Macintosh computer (Quadra 950) or a Nubus slot (PowerMac). We used 2–4-GB array drives which were adequate to capture multiple movie clips of 20–30 s in length that we found to be useful to illustrate scientific principles. The array drives were portable to facilitate the transportation of presentations from an office computer to one in a lecture hall.

It is possible to minimize the cost of the required digital video hardware by choosing less capable but adequate hardware. The compromises in capability are primarily focussed on capturing video clips at slower data rates. This is done by reducing the size of each frame of the movie from 640 × 480 pixels to as low as 320 × 240 pixels or 160 × 120, and by reducing the frame rate to as low as 15 frames s⁻¹. The amount of reduction depends on the speed of the hard drive in use. Older internal hard drives can not usually be used to capture movies, but modern fast internal hard drives designed for multimedia (AV drives) can be used. In addition, for higher data rates, it is possible to buy computers with an internal array drive; at considerable savings in cost over an add-on external array drive.

The color scanner was used for acquisition of images, and is a routine adjunct to any multimedia computer.

The video cassette recorder was a high quality device capable of VHS and S-Video formats. The purpose of the VCR, and laser disk, was to play commercial tapes and disks that illustrate scientific principles, and the VCR was used to play recordings of scientific experiments and field trips obtained with camcorders by teachers and students. Once the video clips had been chosen and digitized, neither the VCR nor laser disk were necessary to show the clips because they had been saved on the array drive. This means that these devices did not need to be in the classroom or lecture hall for presentations.

Analog video camcorder: We have been able to move the computer and the camera close to a scientific experiment, and capture movies directly onto the hard drive of the computer and we have also recorded movies on tape for later digitization at the computer. Both approaches work well. Some photoflood lighting was useful for some experiments, although good daylight often worked well. Two golden rules of video making are important for scientific movie clips. The first is to move the camera as close to the subject as possible, which is a common recommendation for good photography. The second is to use manual focusing rather than automatic focusing. Automatic focusing of video cameras often leads to ‘hunting’ by the camera for the correct focus point, especially if there is a confusing background.

Digital video camcorder: Almost any camera will do the job of making acceptable movies for computer display. The computer hardware described above does not degrade the image significantly, unless the movies are made smaller and reformatted to play on less capable computers. However, the very best quality video is now made on digital camcorders that use one of the several new digital video formats. The consumer level format that is presently becoming important is called Mini-Digital Video or MiniDV, and the camcorders save the video onto a tape that is not much bigger than a matchbox. The quality of the movies in this format is better than all current consumer formats by a significant margin. Some of this quality cannot be appreciated on a normal analog TV screen, but can be appreciated on a computer screen that has higher resolution.

Fig. 3 shows the principles of the digital camcorder. The A/D and compression/decompres-
ion hardware is done in the camera, instead of in the motion video board described above. Hence, digital video is saved directly on the tape instead of being translated from the charge coupled detector (CCD) into analog form as is done in traditional camcorders. This means that an expensive motion video board is not required in the computer. The VVS board, above, costs approximately $3400 although less expensive ones down to less than $1000 have become available, albeit at some reduction in quality of the results. The connection between the digital video camcorder and computer is now standardized to use the IEEE 1394 interface, commonly known as ‘firewire’, which requires an inexpensive board, $400–$500, with the correct connector. Some recent computers now have ‘firewire’ as standard equipment. The present disadvantage of this technology is that the movies cannot be played on the computer screen at full resolution and full size directly from the hard drive because the hardware in the camcorder is required to decompress the video. Present computers are not yet fast enough to decompress in software at the same speed as the camcorder’s hardware. Hence, the digital video can be transferred to the hard drive array, edited by use of the computer, and then played back at very high quality through the camera to the TV monitor and saved to tape. Alternatively, the video clip can be played back at smaller size and resolution onto the computer screen. For playing on normal computers, the video can be reformatted to smaller screen sizes and different compression codecs, just as in the case of the VVS type of board described above. If the full size and resolution of the digital video is required, the camera, or MiniDV cassette player, is always needed for decompression, but it still reduces the cost of the technology because it is not necessary to purchase both an analog camera and motion video board. Our laboratory has a number of these types of camera and firewire equipped computers, but none of the work reported here was done with them.

Software for the preparation of materials by teachers and researchers should be easy to use and should not have a steep learning curve. The multimedia approach discussed here uses standard office software such as a word processor, spreadsheet, and presentation software that are easy to use compared to authoring software. The digitization of video clips in software such as Adobe’s Premiere, is as trivial as pressing the record button on the screen followed by a press

![Diagram](image)

Fig. 3. The immediate future: direct digitization of video in the camcorder followed by transfer to a computer hard drive for editing and viewing.
of the mouse button to stop the recording at the appropriate place. This is all that is required to save the clips on the hard drive for later retrieval and inclusion into a presentation. If the movie is to be converted to a smaller size and compressed differently, a little more facility with software is necessary.

3. Discussion

Digitized movie clips have a wide range of possible applications in research, business and education. Here, emphasis is on the pedagogical applications and scientific illustration that we have developed in our laboratory.

3.1. Digital video as an integral component of student multimedia reports

Traditionally, student's laboratory reports are composed of text and figures drawn by the student. The written laboratory report can be translated into overheads of text and images for oral presentation, which increases communication skills. Students have long been trained to give oral presentations, at both the graduate and undergraduate levels, and to an increasing extent at the high school level.

With a computer, the ability to easily incorporate video clips into the presentation allows the student to make traditional decisions about the choice of figures, but also about whether or not a digital video clip would convey more information than a still image. The latter skill is a function of the observational powers of a student. Some students, when faced with this decision, will simply make a movie that lacks motion information from their experiment. For example, movies of an essentially static benchtop instrument, from a distance! Others will intuitively see movement in a scientific experiment, whether it is through a movie of the progress of some feature of the experiment, or one of the techniques used to enable the experiment.

The use of digital video clips in a student's presentation opens up fresh opportunities for discussion amongst students and teacher that do not exist in a paper laboratory report or in a presentation that only uses an overhead projector.

3.2. Digital video clips as an important part of inquiry-based learning

Digital video clips in students' presentations can be an important part of inquiry-based learning by students. Inquiry-based teaching assumes that students are involved in initiation of problems to investigate, searching for alternative solutions to the problems, collection and tabulation of data, reporting conclusions, and suggestion of new, related problems for further investigation. Digital video clips incorporated into students' reports can open new perspectives for their understanding of science concepts, because students need to think about whether or not a video clip is appropriate to explain a concept, and exactly what should be recorded in order to explain that concept. All of which is integral to the tenets of inquiry-based learning.

Another condition of effective inquiry-based learning is that teachers need to experience inquiry-based science themselves [1]. Accordingly, our Professional Development Workshops on digital video for teachers have been based on an inquiry-based learning approach in which teachers explored the effectiveness of digital video by working with real experiments from the classroom, and by making multimedia reports that contained digital video.

3.3. Digital video for reports on field trips

Field trips by students, such as for environmental sampling, are often recorded on videotape as part of the exercise. Many sampling techniques contain motion that cannot be recorded by a still image. For example, it is difficult to illustrate the exact appearance of a riffle in a river without resort to a movie clip. Hence, it is useful to record on videotape many activities of a field trip for future digitization into short clips that might illustrate sampling techniques, or methods of on-site analysis. Such clips can then be incorporated.
into a multimedia presentation by the students, which might replace or accompany the written report of the field trip.

3.4. Digital video clips as precursors to student laboratory experiments or instead of laboratory demonstrations

One of the best ways to introduce a student to an experiment is to demonstrate it first. A digital video clip is easier to use as a demonstration and often more effective than the real experiment. Each clip is always short in duration, because the main points of most scientific experiments are almost always quick to illustrate. Complex details can be rapidly shown and re-shown in a few seconds, while keyboard control of the clip is so facile that the teachers can step slowly through individual features of the experiment, in minute detail, to ensure understanding. One example might be individual steps in the dissection of an animal in a biology experiment. Exact placement of the scalpel could be illustrated with ease.

In summary, the introduction of scientific concepts in the form of digitized video clips can help students to more clearly visualize concepts and deal with their misconceptions. The clips can provide an additional vehicle for observation and allow more concepts to be highlighted [2].

3.5. Digital video for use by the student during laboratory work in class

Students during their experiment can review the same digital video clip on the hard drive that may have been used in an introductory presentation by the teacher. The high degree of control exercised by the teacher is also equally accessible by the student, as an aid to doing the laboratory experiment. The act of making a digital video of a scientific experiment encourages students to use their powers of observation, and discovery, because they know that in order to explain their subject in a subsequent multimedia report they must have illustrations of their experiment. This can only be obtained by careful observation in order to make a clear movie. Careful observation leads to scientific discovery and understanding.

It turns out that the experiment can be taped normally with a camcorder, or the camcorder can be connected directly to the multimedia computer, without video tape, and movies of an experiment can be recorded directly onto the hard drive. In the case of video tape, it does not matter how much of the recorded material later proves to be useless. Important video clips can be digitized onto the hard drive for use in a presentation, while the rest can be left on the tape for archival purposes, or the tape can be reused. If the experiment is recorded directly onto the hard drive, without going through tape, additional discipline is imposed on the experimenter. It is necessary to plan the digitization of short segments of important material; otherwise indiscriminate video material will soon fill up the hard drive. Indeed, the use of a camcorder tethered to a computer during an experiment is rather clumsy. The complexity of the computer is added to the complexity of the science being done. Ultimately, the portability of a camcorder used with tape is the most useful. For professional looking results, it is always important to use a tripod with the camcorder.

3.6. Measurements on digitized video

Students can make measurements from a digitized video clip, and thus perform experiments in time and space. Software packages exist that can be used to set axes in the software window of the movie. The axes can be calibrated with a length scale that was recorded during the movie. As the movie plays, several points can be marked by clicking with the mouse. Coordinates are recorded for each point, and angles can be measured for rotational measurements. In addition, physical phenomena that cannot be brought into the laboratory can be taped for future experiments. Some phenomena are much easier to measure on the video clip than on the equipment itself. Examples include dynamic physics experiments such as a dropping ball, wave motion of a rope or spring, and a diver jumping off a diving board. This technology works fine for time scales encompassed by the 30 frames s⁻¹ of consumer camcorders, but is clearly inadequate for many scien-
tic processes on faster time scales, for which more sophisticated scientific equipment becomes mandatory.

Redish et al. [3] surveyed 1500 students at the beginning and end of their introductory, calculus-based, physics course at six colleges and universities. Four questions were asked to probe whether students felt their physics course was relevant to their life's experience, and vice versa. At the beginning of the course, the students had the strong impression that physics is related to their life, but they were less sure by the end of the course. To counter this problem, video clips can be used to bring ‘real’ phenomena such as automobile collisions, athletic events, and the launch of a space shuttle, into the teaching laboratory. After digitization, these events can be examined for their physics and chemistry content.

3.7. Digital video in teachers’ multimedia lecture notes

Multimedia materials are a modern way to make lecture notes. No longer are lecture notes merely a text-based synthesis of material from a wide variety of printed sources and experience, but now can include video clips of the teacher’s experience with scientific experiments. Also, the teacher can include images and video clips from a wide variety of resources, including those directly scanned from the students’ textbooks, images and video clips taken from the Internet, laser discs, compact discs, etc. Significant time is required on the first occasion that a set of traditional lecture notes are made, but the time to make multimedia lecture notes is approximately the same, assuming that mastery of the software has already been achieved. Indeed, for many teachers, software mastery is the main energy barrier to implementation of multimedia technology.

3.8. Presentation software as part of teachers’ lecture presentations

While presentation software can be misused in that the teacher or lecturer can present material too rapidly, or use the computer only as a complex overhead projector, there are important pedagogical implications of lectures with presentation software. Handouts that reproduce the computer-based materials are easy to generate with software. This has two implications. First, the images that are used in class and reproduced in the handouts can be richer in detail, more informative, and more numerous than images normally drawn on the blackboard. Second, the existence of handouts means that students do not spend inordinate lengths of time to copy material from the blackboard into their notes. This should not result in a deluge of material for the students, but in greater interaction time between the teacher and students. Images instantly projected on a screen and distributed on a student handout can be discussed at length during class time. Images that don’t need extensive discussion, but that illustrate a small point, can be used with very little cost in time. The result is more discussion of concepts. Probably, paper handouts are only temporary. Electronic handouts on the Internet, or portable disc media are the inevitable successor. This is particularly true when digital video clips are part of the presentation [4], as the only way to view them would be to display them on the computer screen. Video tape is not an option. Teachers don’t normally distribute video tapes now, even though the technology has been around for a long time.

3.9. Digital video in interactive learning projects

It is possible to use HyperCard or similar types of software for interactive, learning projects. The ultimate goal might be a document that allows student-centered learning without constant teacher involvement. The software provides an interface that allows access to text, images, digital video clips, and databases through buttons, or ‘hot-spots’ on the computer screen. More sophisticated software exists that is generically known as ‘Authoring’ software. Macromedia’s ‘Director’ is one of these. Additionally, these types of software tend to incorporate basic animation tools that could allow scientists to animate their concepts as a function of their own creativity and abilities with computer illustration. This approach is also becoming available on the Internet,
through web pages, although most teachers use web pages only to post assignments and answers to homework or examinations, or to post illustrated reading material, because it is not yet trivial for a teacher to provide effective pedagogical feedback on web pages.

The term ‘authoring’ is an apt description for this type of software because it is a major undertaking to produce a finished product. The software learning curve is steep, and many teachers and scientists do not have the time to master the software. A useful analogy is with the world of textbooks. Not many teachers write textbooks because of the major time commitment involved. The same holds true for ‘authoring’ software. Therefore, it is a valid viewpoint that authoring software should not be considered for routine use by students and teachers. On the other hand, the production of multimedia lecture notes, multimedia scientific presentations, and multimedia student presentations are facilitated by software that is easy to use. This need is fulfilled by current presentation software and software for digitization of video clips, which are almost trivial to use. Indeed, it takes no longer than one traditional laboratory period for a high school, undergraduate or graduate student to learn how to make a multimedia presentation with these types of software. The subsequent production of the multimedia presentation then takes about as long as a traditional written laboratory report. The learning curve is somewhat steeper for those teachers who have little experience with computers, but this can be addressed by carefully designed, hands-on, professional development workshops. This is becoming less of a problem as the present crop of young teachers enter the system.

3.10. Applications to the presentation of research results

Scientists are so familiar with the transcription of the inherent dynamics of science into static tables and figures, that it is easy to forget that many scientific principles are better illustrated in a dynamic way. According to Kozma [5–7] the advantage of any video is in its use of dynamic, visual symbolic systems that allow scientists to view any scientific experiment or discovery from multiple or different perspectives. The advent of digital video on the desktop computer allows us to reverse engineer the mindset that causes us to translate dynamic science onto static paper. Most scientists, given a few moments thought, can easily see the power of this new digital medium. The video clips provided with this paper, on CD-ROM, attempt to illustrate this principle and are discussed below. In general, it has become possible to use the camcorder as an adjunct to the laboratory notebook to record important dynamic parts of research experiments. The natural extension is that the resultant digitized video clips can be published electronically, as well as used in scientific presentations at conferences and in group meetings at the research site. Indeed, the concept can be extended quite generally, for example, to salesmen who wish to illustrate their product by use of digital video clips of an operating product.

4. Examples of scientific concepts illustrated with digital video

Fourteen movie clips are provided on a CD-ROM that accompanies this issue of Spectrochimica Acta Electronica. The CD-ROM is in ISO 9660 format and can be read on both IBM-PC compatible and Macintosh computers. Each clip is simple, short, at 15–45 s, and usually was designed to illustrate one scientific concept. Digital video clips of this nature contain at least one additional concept, other than that originally intended, because motion has a way of illustrating points that may not have been apparent when the original recording was made. In the discussion below, this is brought out for each Figure.

The original QuickTime digital video clips on the CD-ROM cannot be played on a normal computer, because the compression/decompression algorithms were done in the VideoVision Studio hardware, which is not found on many computers due to the high cost. Hence, for this publication, these QuickTime movies were made smaller in screen size from the original 640 × 480 pixels to 320 × 240 pixels, and recompressed with an algorithm that is software-based and can oper-
ate on any computer. The Cinepak codec was used, which can be found on many IBM-PC compatible or Macintosh computers. The smaller screen size is necessary because most of today’s computers, although improving rapidly, are still not quite powerful enough to play 640 × 480 movies entirely with software. The advent of new MPEG and DVD standards may change this over the next year or two. Meanwhile, for those readers who attempt to view these video clips, Macintosh users should use Apple Computer’s Movie Player that comes with the Macintosh operating system along with QuickTime, while IBM-PC compatible users should use or install QuickTime for Windows. Macintosh users should have QuickTime installed on their computer already. The latest version for Mac or Windows can be on the CD-ROM QuickTime for Windows contains the Cinepak decompressor. The reformatting of the movies from the larger to the smaller size and different codec causes a degradation in quality from the original movies, which were about S-VHS quality or better depending upon whether they were captured to tape on an S-VHS VCR or directly to the hard drive.

Readers should copy the clips to their hard drive, unless they have a fast CD-ROM player. Ideally, the movie clips should play smoothly with no jerkiness from frame to frame. Smoothness of play depends upon the speed of the computer, and the rate at which data can be retrieved from the hard drive. Typically, the data rate of the movies provided is approximately 600 kB s⁻¹, which is fine for a computer hard drive. If a reader finds the movie to play jerkily, then a number of compromises can be made. The first is to switch the computer’s monitor and its video board, to a lower color depth. The movies were made in 24-bit color which allows the movie to be played with millions of colors. However, if the computer screen is switched to 8- or 16-bit color depth, it will be likely to play more smoothly with fewer colors. In addition, menu items in the movie player allow the movie to play at a smaller size, say 240 × 180, which should also play more smoothly. A modern fast computer with a fast hard drive should have no trouble to play the movies at their full 320 × 240 size and 24-bit color depth.

The examples below are primarily, but not exclusively derived from atomic spectrometry, and they cover undergraduate and graduate level analytical chemistry. The last two clips are from a high school biology class, and were obtained during one of our professional development workshops for high school and middle school teachers.

There are two ways to play these movies. The first is to just press the play button which appears underneath the movie window when the movie is opened in the QuickTime player. The second is to stop the movie, and use the mouse to drag the scroll bar. This allows the user to slow down the movie to play it frame by frame, or to speed it up, to reveal more information as outlined in each clip described below. Also, the arrow keys can be used to move through the movie frame by frame.

5. Descriptions of the video clips provided on the CD-ROM

5.1. Flame.mov

This is a movie clip that shows an air–acetylene flame. The movie proceeds by illustration of the variation in fuel flows. A fuel lean flame changes into a stoichiometric flame followed by a fuel rich flame. This started out as a clip to be shown in undergraduate analytical chemistry classes as a simple illustration of the appearance of an air–acetylene flame. A bonus, which rapidly became evident when the movie was played in slow motion, arose from some dirt that passed into the flame and traveled with the flame gases. The dirt broke down to a visible plume of sodium emission that illustrated the point at which the sodium atoms became free from the original particle, and the diffusion of the atoms while traveling upwards with the flame gases. A classic diffusion plume is seen at various times during the clip, with the best example being at the end of the clip. These diffusion plumes last for approximately one frame, which illustrates the time scale of the movement of flame gases and particles in the flame. This diffusion concept was not in-
tended when the movie was made. Serendipity provided the pieces of dirt in the flame during the recording.

5.2. Burette.mov

This is a video clip of the way to read a burette and illustrates the principle of no-parallax. Here, the camcorder was moved up and down, close-up to a burette and opposite a water meniscus. In slow motion, the marks on the burette can clearly be seen going in and out of parallax, and the correct point of no parallax can be trivially illustrated. This clip is useful in high school or lower level undergraduate courses. It is rather like moving a student's head up and down in front of a burette and being able to know exactly what the student is seeing. Another advantage of this clip is that when projected in the classroom or laboratory, the burette image is at least one foot across, which is a big improvement over the half-inch size of the real device.

5.3. Sprayneb.mov

This is a clip to illustrate the inner construction and operation of a spray chamber for atomic absorption flame spectrometry. It is composed of two clips that have been joined together by use of movie editing software (Adobe Premiere). The first part of the clip shows a student disassembling the spray chamber of an atomic absorption burner to reveal the nebulizer nozzle and the spoilers inside. The second part of the clip shows the appearance of water spraying from the nebulizer. This was a relatively difficult movie to make because it was necessary to ensure plenty of reflected light from the droplets so that they could be easily seen on the final movie.

5.4. Spectro.mov

This is a video clip of a small spectroscope that is commonly used in general science laboratories to illustrate dispersion at a grating and the existence of line spectra in gases. This is probably one of the more ambitious edited movies that were done for this project. It is composed of several important basic concepts of spectroscopy. First is shown an overview of the outside of the spectroscope, and then a series of colored lines is overlaid on the image of the instrument to illustrate the white light path passing into the device, and the dispersion of colors onto the exit plane. Then the spectroscope is shown looking at a gas discharge light source followed by a clip of the slit width being manipulated by a student’s fingers that turn the slit width control. This part of the clip is close-up, and the slit variation fills the whole screen. Then a view with the camera looking into the eyepiece shows the white light coming into the spectroscope, and then the dispersed light at the exit plane. This is shown while the entrance slit width is being varied in order to illustrate how the resolution of the spectrum is affected by slit width. This sequence of edited clips took some hours of undergraduate time, and was unusual. Normally, short clips were made for this project, with no editing at all.

5.5. Filter.mov

This is a video sequence of the filtering of a sample of soda, which is colored in the usual way with caramel. The soda is being filtered with a small particulate filter on the end of a syringe prior to a liquid chromatography experiment. The clip was made by an undergraduate during a routine analytical chemistry laboratory. It illustrates the basic filtering operation, but it becomes evident that the liquid droplet that exits the filter appears to be clear rather than caramel colored. As the filter was not capable of removing caramel, only particulates, this is something of a puzzle. Questions of a student audience should eventually elicit the observation that this is Beer's law in operation, as the path length through the apparently clear droplet is much less than the path length through the original sample of soda in the beaker. This clip also illustrates that it is important to turn off the automatic focus of the camcorder during close-up observations, because this feature causes distracting ‘hunting’ for the focal point.
5.6. OPOscan.mov

This clip shows the internal operation of an optical parametric oscillator (OPO)-based tunable laser. This type of laser is tunable throughout the visible and near-infrared spectrum by rotation of a beta-barium borate (BBO) crystal through which is passed a laser beam at 355 nm. The 355 nm photon is split into two photons one in the visible and one in the near infrared. The movie shows the changes in the color of the visible laser radiation as the crystal is rotated. The crystal is at the center of the frame where all the bright colors emanate, and during the wavelength scan it can be seen rocking in conjunction with the housing that holds it. Also, in the top right-hand corner, the movement of a grating can be seen which selects the seed wavelength for the OPO oscillator. This was a rather convenient movie to illustrate the basic principles of OPO laser operation in research seminars. The bonus in this movie was the movement of the grating in synchronization with the angle of the BBO crystal. The original tape of the laser in operation was approximately 2 h long, and could not be used directly for this clip because the 10 Hz repetition rate of the laser was not synchronized with the 30 frames s\(^{-1}\) of the camcorder. Instead, selected frames were taken from the tape and reassembled into the 13-s movie that is presented here. In many ways, this 13-s movie clip misrepresents the laser because it takes much longer to tune through the visible at the true rate of approximately 0.25 nm s\(^{-1}\).

5.7. Furnace.mov

This movie shows the operation of a Zeeman graphite furnace in an atomic absorption instrument. An undergraduate student placed a fairly high concentration of common salt solution into the furnace, and then put the furnace through a dry, char and atomization cycle. The atomization cycle is the most evident, but the bonus in this clip comes when it was played in slow motion. Under these conditions it becomes very apparent that the right-hand electrode moves during the atomization cycle to compensate for expansion of the graphite furnace. This movement is not easily noticed on the real instrument by the casual observer. Indeed, it surprised one of our graduate students upon seeing the movie for the first time.

5.8. Autosamp.mov

This clip simply illustrates how an autosampler operates to put a sample into a graphite furnace atomic absorption instrument. There is nothing more to this clip, and it can be shown quickly and efficiently in an undergraduate lecture.

5.9. Opamp.mov

Principles of electronics are a key component of undergraduate and graduate teaching of analytical chemistry. This clip was made by a graduate student, and is a movie of an oscilloscope screen during gain changes of an operational amplifier with a sine wave at the input. Electronics is often difficult for students to take from the lecture to the laboratory, because it is tough to illustrate the operation of an oscilloscope with a piece of chalk or with still images. The dynamic nature of the oscilloscope is clear in this clip.

5.10. Fringe.mov

This clip shows the fringes obtained when an étalon was used to measure the spectral linewidth of the OPO laser of OPOscan.mov. The movie was taken in a darkened room, with no light other than that of the interference fringes reflected from white paper. The nearly monochromatic radiation from the OPO laser passed through the étalon to produce constructive and destructive interference patterns. The width of the individual fringes and the distance between the fringes allows for an estimate of the spectral linewidth, or monochromaticity, of the laser beam. This clip has been useful in teaching graduate laser spectroscopy, as well as in research seminars.

5.11. Ablation.mov

Laser ablation is a topic of current research interest in analytical atomic spectrometry. This
video clip illustrates one of the primary problems, which is the sometimes poor precision of the ablation process. The clip shows showers of large glowing ablated particles that are the result of the somewhat irreproducible way in which sample is ablated under some conditions. Some of these particles give tracks of radiation over two frames, which indicates the speed of the heavier particles as they leave the sample surface. In addition, the clip shows the shape of the ablation plasma from shot to shot. Both these phenomena are best seen by playing the clip in slow motion. In the classroom this movie links the normal still images to a real ablation plasma, and gives the student a better feel for laser ablation.

5.12. Cleanopt.mov

The operations required for successful cleaning of optics are critical for protection of optical components in high power lasers. This simple clip shows, close-up, a cleaning operation of an infrared reflector, and is useful for training of graduate students of laser spectroscopy.

5.13. Tomato.mov, and Pollen.mov

High school biology education is full of dynamic processes that lend themselves very well to the production of illustrative movie clips. These clips were made by a teacher who produced a CD-ROM full of short clips digitized from tapes made by students during a long-term experiment to grow various plants. Figure 16 shows a simple planting operation of a small tomato plant, while Figure 17 shows how to take pollen from a zucchini flower for pollination purposes. The teacher’s students eventually incorporated the clips into scientific presentations.

5.14. Copyright issues

All text, images, and movie clips are subject to copyright protection, with the same rules that apply to traditional printed materials. For example, if it is a legitimate use of a commercial compact disc, laser disc or video-tape of scientific experiments to digitize a clip and present it in a lecture, assuming that the material was bought from the copyright owner in the first place. However, it is not a legitimate use to distribute that clip within a handout or on the Internet without paying the appropriate copyright fees. The only exception might be if the only audience is composed of students who have bought the textbook that is accompanied by the laser disc, etc. It is also important that a teacher’s students sign a copyright release if a teacher intends to distribute materials made by students.

6. Conclusion

Video clips are easy to capture onto a hard drive, and trivial to present alongside images, text, equations, etc., in the classroom, teaching laboratory, or lecture hall. It is inevitable that this technology will become as commonplace as word processing and spreadsheets in teaching and research. The learning curve is not steep, unless an author attempts to become a professional videographer to make full-length video productions. Those of today’s teachers who have little experience with computers generally find the learning curve to be a bit steeper than found by their own students. Our experience at high school, undergraduate and graduate levels indicates that the technology is useful for illustration of scientific principles by both teachers and students. Indeed, students find this approach to the presentation of scientific reports to be as challenging as paper reports, but usually more fun. One of the impediments is the availability of hardware to digitize the movies. Many schools have hardware that is capable of playing the smaller movies described earlier, and only one station is needed that is capable of digitization of the movies. The same station can be used to convert the movies to a smaller recompressed format, or for playing back the full screen, high quality, movies for class presentations by teachers and students. For scientific presentations, at distant places, the only practical solution is to use a conventional portable computer and small 320 × 240 clips. Alternatively,
a desktop computer with a digitizer and array drive can be transported by car, although this is not practical over very long distances.

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References