



## Good practice report

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# Tracking down chemical phenomena with the usage of mobile phone slow-motion videos

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**Abstract:** Some experiments in chemistry occur too fast to make out the central phenomena. Using common digital cameras or mobile phones with high-speed options, one can slow down the process and make the vital observations visible and capable for the students. This article introduces the research project *SloMoChem* and will show the benefits of using this digital technology to understand the combustion concept in a much better way.

**Keywords:** chemical education research; computer-based learning; constructivism; general public; inquiry-based/discovery learning.

“It was too fast.” – “I couldn’t see it properly.” – “Could we repeat the experiment, please?” Certainly every instructor has heard these and similar statements in the classroom when pivotal observations are demanded in exciting experiments. Shortly after an experiment has been conducted, vital observations are no longer accessible to the students and have to be reconstructed from memory. In such a context, the relevance of experimental videos as supplemental support for documentation has already been pointed out in the literature (Hoffman Laroche, Wulfsberg, & Young, 2003; Russel et al., 1997; Stieff, Werner, Fink, & Meador, 2018; Whisnant, 2000).

Whereas some years ago, one had to access films produced by teaching material manufacturers or to prepare the experiments laboriously using analogue technology, there are currently a multitude of such videos available on the Internet, which can be easily shown via webcasts. Even slow-motion videos are available (Haran & Poliakoff, 2011). However, this tempting supply of material should never replace students’ autonomous experimentation because otherwise they will be deprived of the sensual experience of conducting an experiment as well as of the opportunity to train their fine motor skills and scientific methods (Hofstein, 2015). However, (homemade) videos and images of experiments can serve as supplemental support for the documentation of pivotal experimental observations and might also be consulted for an additional analysis of the experiment in another lesson (Canal et al., 2016). Modern digital cameras and even smartphones facilitate the easy recording of experiments by students (Benedict & Pence, 2012). Here, the devices’ functions, such as slow motion and time lapse, are of special interest. In this article, the didactic potentials of slow-motion videos are presented using selective examples of chemical phenomena. In addition, details about the cameras used for recording are given, and proposals, materials, and ideas for how students might create such films and use them for analysis in their experiments are included.

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## Value of slow-motion videos by means of examples

Slow-motion videos decelerate phenomena that are too fast and enable additional observations that would otherwise remain concealed from us. Applying such films wisely might provide a better understanding of chemical phenomena, as shown below, using the example of putatively easy experiments. Moreover, this paper also demonstrates how students can analyse slow-motion videos using documentary films and other digital devices, such as notebooks or tablet computers, in class (Sieve, Struckmeier, Taubert, & Netrobenko, 2015).

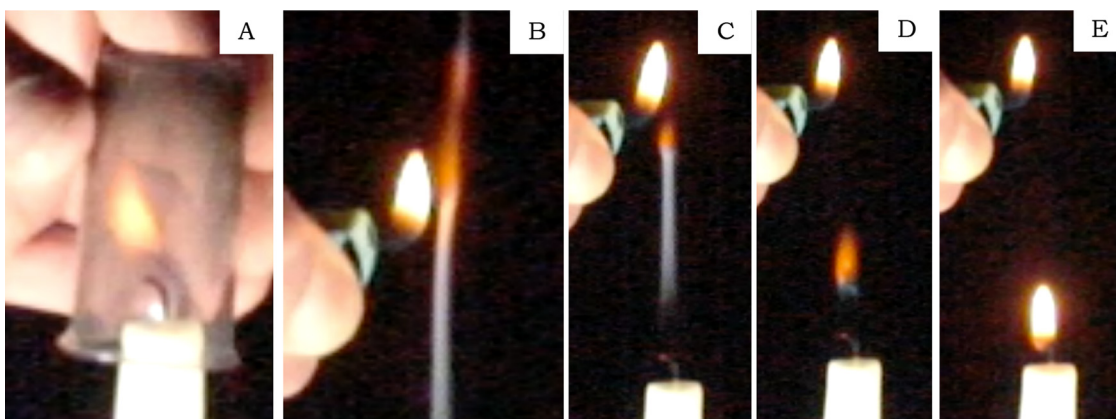
### Example #1: “Jumping flame”

A burning candle is smothered by a small beaker, the resulting white aerosol composed of wax vapour and cracking products is ignited as much as possible, and the flame “jumps” to the wick as if by miracle. However, one cannot see what exactly is happening here. Does the flame truly jump, as it seems to do? An examination of the frames of a slow-motion film of the experiment, recorded at 480 frames per second (fps), reveals the following (Figure 1):

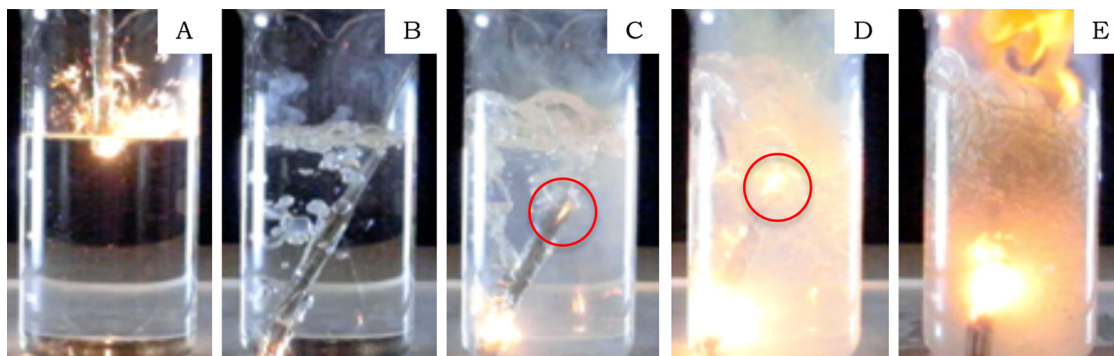
The “jump” of the flame that we see during the experimentation is revealed to be a “migration” along the trail of wax-containing aerosol and cracking products when the slow-motion pictures are analysed. Watching the slow-motion film and thus gaining the ability to dissect the observed process into single frames—using, for example, the screen shot tool of the interactive whiteboard or operating software on the students’ computers and tablets—turns the putative miracle into an observable phenomenon. Through such means, the observations can be related to the conditions of combustion (fuel, aerial oxygen and ignition temperature), and it thus becomes possible to counteract improper conceptions.

### Example #2: Underwater sparkler fire

In the subject area of oxygen transfer reactions, the underwater sparkler fire experiment can be used to expound whether the atoms of base metals are able to react with oxygen atoms in water molecules and whether the water molecules consequently serve as donors of oxygen atoms (oxidizing agents). For this purpose, a



**Figure 1:** Observations during the “jumping flame” experiment. (A) The candle’s light is extinguished. Here, the oxygen is already consumed. (B) The white aerosol ignites at the top of the lighter flame, which is the hottest zone of the flame. (C) – (E) The flame migrates along the trail of smoke towards the wick, while the wax aerosol burns. The flame grows when it approaches the wick and gains its previous size and light intensity only at the wick because more fuel is provided there.



**Figure 2:** Observations during the underwater sparkler fire experiment. (A) The burning sparklers are immersed in water and (B) continue to burn underwater. Gas bubbles rise to the surface of the water. (C) The gas flows upwards through the tape casing, it ignites and a spark of burning gas “shoots” upwards through the casing. (D) The stronger the reaction becomes, the more the sparks shoot upwards. However, the gas above the water surface does not yet ignite. (E) The gas mixture above the surface ignites after a continuous spark gap has been formed.

bundle of seven sparklers are wrapped together with adhesive tape and ignited at the unsealed top. Then, the burning sparklers are placed into a large beaker filled with water. The sparklers continue to burn underwater, and gas bubbles are formed (mainly hydrogen). Shortly after, the gas above the water surface ignites in the form of an explosive flame. The question arises as to how it is possible that the gas above the water surface is able to ignite, as it does not encounter the underwater flames. It is frequently assumed that the gas is already ignited underwater and that the bubbles containing that burning gas rise to the surface. Slow-motion pictures of that experiment again provide deeper insights (Figure 2). Here, the film was also recorded at 480 fps.

The slow-motion film shows that the emerging hydrogen above the water surface is not already ignited underwater but is ignited by the upwards shooting sparks formed in the tape casing, which are generated by the burning hydrogen. Here, again, the conditions of combustion can be discussed.

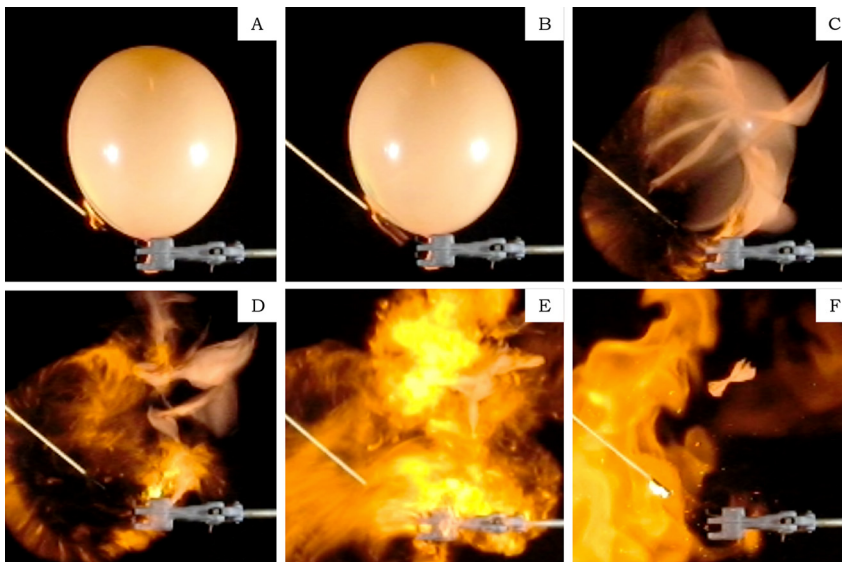
### Example #3: The exploding hydrogen balloon

The flammability of hydrogen gas is often demonstrated by igniting a balloon filled with hydrogen gas. The reaction is so fast that only a hollow pop and a fireball are noticed. Again, a slow-motion picture facilitates a deeper understanding of the combustion concept (Figure 3).

This example shows again—like the previous experiments—that a profound discussion about the conditions of combustion reactions is only possible on the basis of the generated frames. In addition, the knowledge about the time lags between the frames allows an estimation of the chemical reaction’s time dependency. Thus, images B–E of example #3 depict time lags of approximately 1/500 of a second.

## Working with high-speed cameras in chemistry lessons

Slow-motion pictures of experiments can be used to supplement the demonstration of experiments in order to collect pivotal observations in an initial evaluation phase directly after the demonstration as well as to try to form an initial interpretation, ask questions and hypothesize. Subsequently, the film can be presented to the whole class, stopped at vital points and replayed as often as desired, so that the aforementioned observations can be confirmed and additional phenomena can be written down. Methodically, it is useful to show the slow-motion videos of an experiment twice in a class, first in their entirety, and students should be given the task to memorize key scenes. The second time, the students should determine where to stop the film. Using the screen



**Figure 3:** Observations during the ignition of a hydrogen-filled balloon. (A) The flame of a glowing splint melts a hole into the shell of the filled balloon. (B) Hydrogen escapes through that hole and ignites, generating a tongue of fire. (C) One 480th of a second later, the tensioned balloon shell bursts. As a result of the generated convection, the hydrogen mingles with the air. Only where there is an inflammable mixture does the hydrogen burn. (D) Another 480th of a second later, a “ring” of flames can be observed. Hydrogen burns only in the outer area, where enough aerial oxygen is provided for an inflammable mixture. (E) Another 480th of a second later, an inflammable mixture arises through convection wherever the former balloon was. (F) One 10th of a second later, the reaction declines because most of the fuel is used up. Only the tatters of the balloon are left flying.

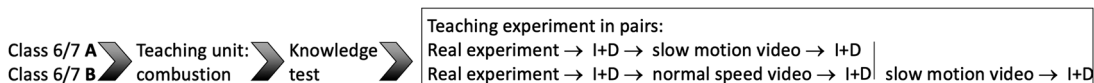
shot tool, the key scenes can be excerpted and integrated into a digital protocol on, for example, an interactive whiteboard.

The high-speed cameras described in this article are of interest, and especially those in smartphones (Supporting Information) are particularly so for students because of their easy handling. Using smartphones, students are able to record slow-motion films of their own experiments (e.g. the “jumping flame”, the ignition and burning of a sparkler, etc.) and use them to create their own digital protocols. As mentioned before, key scenes can be extracted using a screen shot tool and can be complemented by additional notes.

## Are high-speed cameras effective for learning?

In science subjects, slow-motion pictures are already acknowledged tools for the thorough analysis of processes. For science subjects, this kind of deceleration supports learning on different levels. However, the extent to which digital slow-motion films of fast processes are able to support concept development by students is still open to debate. In the pilot project *SloMoChem* we analysed experiments regarding to their potential for the development of the combustion concept.

In a primarily qualitative research approach, teaching experiments were conducted in pairs in four classes from the first two years of chemical education ( $N = 98$ ) (Figure 4). The “jumping flame” experiment was



**Figure 4:** Research design for the “jumping flame” experiment (I: interview, D: drawings).

“[...] the *fume* just switched on the candle *automatically*.” (GS2BL)  
 “[...] then suddenly *something jumped down*.” (CD3AD)

“And like a *fuse of a firecracker* the fire went down and ignited the wick.” (PS8KT)  
 “The *smoke is flammable*, caught fire and *migrated further* [...].” (KD2HH)

Figure 5: Example comments from students in (left) B-classes and (right) A-classes.

selected for this pilot study. Students often cannot interpret this experiment sufficiently, because they do not recognize the wax-containing aerosol as fuel. The “jumping” of the flame does not fit to the sub-concept “fuel” of the combustion concept (Schmidt & Volke, 2003).

In all classes, a specially designed 6 hour teaching unit for the introduction of the combustion concept was executed and concluded with a knowledge test. That test served as a control for the comparability of the four classes. The actual teaching experiment was as follows in the A-classes (Figure 4): The students conducted the “jumping flame” experiment (see above) in pairs and interpreted it by thinking aloud. Their statements were videotaped, and their drawings served as additional artifacts. After to the analysis, the students watched a slow-motion film of the experiment, which showed an approximately 20-fold slow-down of the “jumping flame”. As before, the evaluation was videotaped and complemented by illustrative drawings. The students in the B-classes conducted the “jumping flame” experiment as well. Afterwards the students watched the film at normal speed and finally the slow-motion film of the experiment. After each step the students interpreted their observations as in the A-classes. Thus, the effect of using slow-motion videos could be distinguished from that of using films with a normal speed.

After watching the experiment in person, most of the students in all groups described a “jump” of the flame to the wick (88%). Explanatory approaches (e.g. by mentioning the fuel) were hardly observed (Figure 5). Those students who watched the recording at normal speed (B-classes) stuck to the aforementioned description, which was occasionally more differentiated. The latter phenomenon was probably attributed to the repeated watching of the video. However, the analysis of the slow-motion video revealed a higher proportion of explanatory approaches (A-classes). Approximately half of the students in the A-classes (42%) drew an analogy by describing a “migration” of the flame due to the combustibility of the wax vapour, which was reasoned by more than one third of the students. Similar explanatory approaches were observed when the



Figure 6: Drawings from the Group (KD2HH) (above) before and (below) after watching the slow-motion video.



B-classes had also watched the slow-motion videos. Four groups stated the wick as the fuel before watching the slow-motion video. Three of these groups corrected this after the slow-motion video and stated the wax vapour as fuel (Figure 5).

The analysis of the drawings confirms these findings in both subgroups. After conducting the “jumping flame” experiment respectively watching the recorded experiment in normal speed 39 of the groups drew a candle with a smoke plume and another candle with a flame. Twelve groups added the beaker in their drawings (Figure 6). The other groups did not provide a drawing or sketch. After watching the slow-motion video nine groups drew sequences of frames with a downward moving flame (Figure 6). Seventeen groups outlined the “migration” of the flame with arrows. Only four groups did not change their drawings. All these findings revealed that the slow-motion video of the “jumping flame” seems to permit a better connection between the students’ explanations and the combustion concept, especially in the sub-concept fuel.

## Conclusion

The examples shown here illustrate that experiments recorded using a digital camera or smartphone with a slow-motion option allow a better understanding of chemical processes and thus have an additional high didactic value as a supplemental tool for real experiments. The issue of the project *SloMoChem* is to examine the potential of slow-motion videos for the development of the combustion concept. The pilot study has shown that after watching the slow-motion video of the “jumping flame” experiment a larger number of students pictured a “migration” of the flame instead of a “jumping” and stated wax vapour as fuel for the combustion. This reveals a better understanding of the sub-concept fuel (Schmidt & Volke, 2003).

## Associated content - Supporting Information

Useful links to further slow-motion and time-lapse films of chemical experiments; details about cameras and smartphones, which can be used for slow-motion pictures; tips and tricks for the recording of chemistry experiments are offered in the online version of this article.

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**Supplementary Material:** The online version of this article offers supplementary material (<https://doi.org/10.1515/cti-2019-0018>).