Multi-level videos for formal STEM learning

Stan Snijder, 6427952
Supervised by Rogier Bos
Utrecht University
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Abstract

The integration of multimedia, particularly video, in STEM (Science, Technology, Engineering & Mathematics) education has grown significantly in recent years, supported by both educators, researchers and students seeking to enhance learning experiences. Current educational videos predominantly focus on either procedural or analytical knowledge, lacking a combined approach that could potentially benefit comprehensive learning. This study addresses this gap by developing and testing guidelines for creating "multi-level" educational videos that incorporate both types of knowledge. Inspired by Wired.com's 5-level video series, this research utilizes a taxonomy-based approach to structure videos into three levels: reproduction, connections, and analysis.

Through design-based research, multiple iterations of educational videos were created and tested in Dutch secondary education settings. Each iteration involved classroom implementation, post-tests, and focus group interviews to refine the video guidelines. The study's findings indicate that multi-level videos can effectively support student learning across different taxonomical levels. The final guidelines emphasize clear and progressive complexity, explicit differentiation between levels, sequential content building, engaging elements, and promoting student autonomy.

These guidelines provide a framework for educators to create videos that enhance understanding and retention in STEM subjects, with potential applications across various educational contexts. Future research should focus on validating these guidelines in different STEM disciplines and exploring the integration of interactive elements to further engage students.

Contents

Introduction

Multimedia education, and especially the use of video in education has been growing a significant amount in the past few years. Usage of video, both guided by teachers and outside of the classroom, has increased and online channels providing educative content have grown (Lagerwey, 2024). Secondary education students, both from their own volition and when encouraged by educators, use online videos as part of their own learning of STEM subjects (Flyfield, 2022).

The rise of video in education is also accompanied by a rise of research into videos in education. When specifically looking at the usage of video in formal STEM education in Dutch secondary learning, studies already surveyed what types of videos are available for educators to use (Hove, 2014) and how they are currently used in Dutch science classrooms (Wijnker et al; 2018). As these studies find an increase in educational video usage, it is no surprise that other researchers focus on guidelines for the creation of high-quality educational videos (Kolthof, 2021).

Research from Rensaa and Vos (2018) and Wijnker et al. (2018) has pointed out that most educational videos focus exclusively on either teaching procedural, reproducible knowledge, or on speaking of concepts and analysis. Video's that provide both reproducible and more analytical knowledge are few and far between. This is an issue, as combining these two types of knowledge would be beneficial for comprehensive learning according to the previously mentioned authors. This dichotomy can further be experienced by looking at the available content on YouTube, where popular educational channels like Math with Menno (Lagerwey, 2024) and Kurzgesagt (Kurzgesagt – In a nutshell, 2023) focus on one type of knowledge and stick with it.

One method to increase the creation of these videos that teach both reproductive and analytical knowledge might be to provide more viable approaches to do so. There seems to be a gap in the knowledge base on video creation; Kolthof (2021) conducted a literature review on educational video guidelines and found no established guidelines for mixing "levels" of knowledge in videos. To address this, our research aims to develop guidelines for creating educational videos that effectively teach both types of knowledge. Our approach is based in a specific video structure; the "multi-level" approach.

This multi-level approach is inspired by the publication "Wired.com", who have produced a series of web videos detailing several stem-related subjects on different levels. These videos have an expert in their field explain a topic to five people, first to a younger child, then working their way up to another expert in a related field. Our proposed approach is similar, however instead of using different people as a basis for the levels, we used a taxonomy to create three levels.

To test the multi-level approach, we preformed design-based research. We created several videos as part of a design cycle and tested them in a classroom setting. After three iterations, we found a set of guidelines to aid in the creation of these multi-level videos, as well as an answer to whether these multi-level videos might be a useful tool for learning.

Theoretical Background

Video Segments

As explained in the introduction, this research focusses on the creation of guidelines for the multi-level approach. Of course, previous research gives many guidelines for the creation of successful educative videos. However, whilst many of these guidelines clarify things such as video quality, instructor presence or optimal ways to manage cognitive load, guidelines on how to best structure videos are few and far between. (Kolthof, 2021; Brame ,2016; Spanjers , 2012; Wouters et al, 2012)

When literature does provide guidelines on video structure, the most common advice is to segment educative videos. For example, as Spanjers et al, (2011) found that segmenting improves student understanding of video subject matter. Flyfield, et al. (2022) also show that segmenting videos improves learning gains. However, a clear understanding or set of guidelines on how to segment videos is not yet provided by literature. And segmenting videos is not a trivial manner. Whilst segments do improve learning effects of educative video, the opposite seems to be true of students' enjoyment: Research by Kolthof (2021) found that students have adverse affective reactions to segmentation, as they take away from narrative flow. This issue needs to be considered when designing multi-level videos, as they are inherently segmented, and guidelines on segmentation of the video are considered during the iterations.

Taxonomies

Another issue that necessitates addressing when creating multi-level videos is the segmentation of content into structured levels. Our proposed method is to use a taxonomy. Naturally, there are many possible taxonomies to choose from. For our approach, one such taxonomy should be selected based on perceived benefits. Prior to making such a decision, a brief (and non-exhaustive) overview of some popular taxonomies should be considered. Table N shows the analyzed taxonomies with a short argumentation for or against using these taxonomies for the multi-level video concept.

Table 1

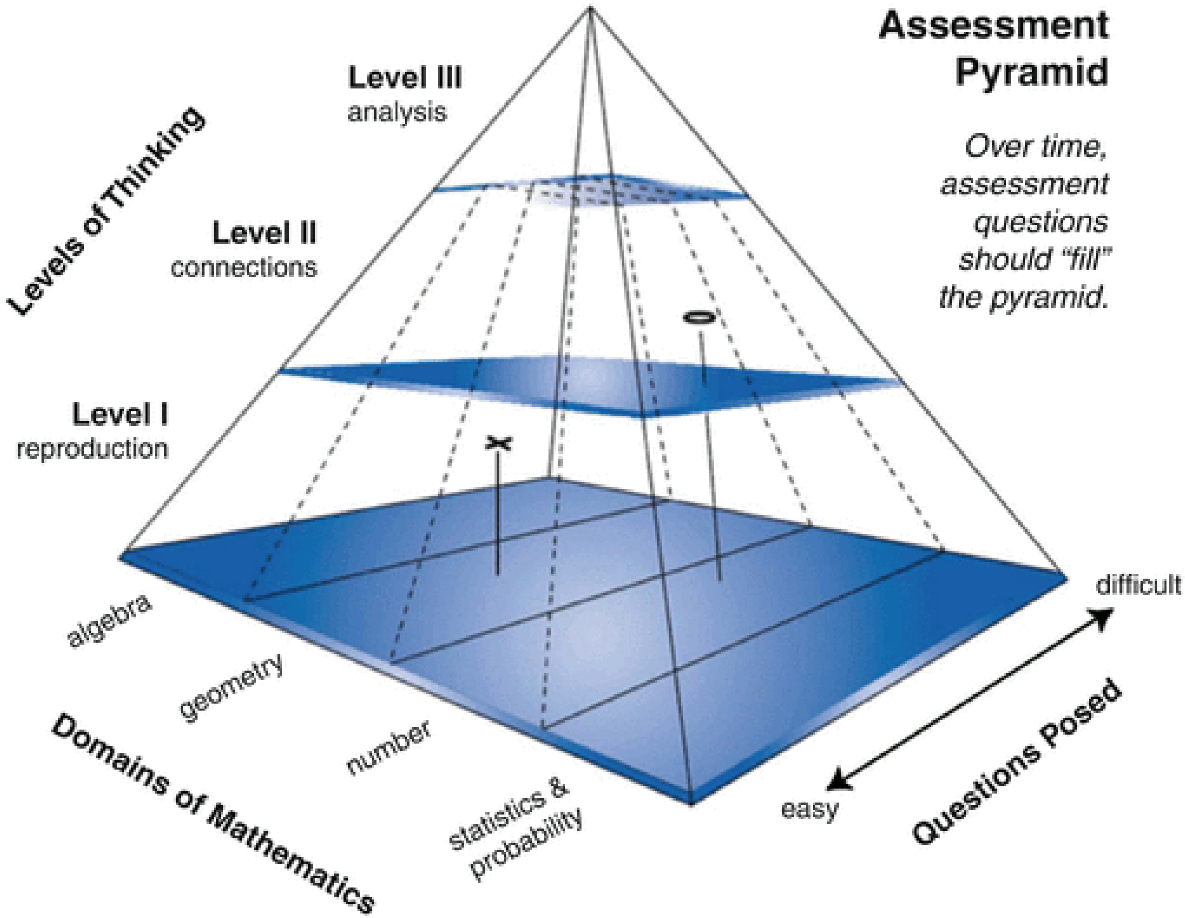
An overview of several taxonomies and considerations for their use in this research

Taxonomy	Levels (lower to higher)	Arguments
Bloom (1956)	Remembering Understanding Applying Analyzing Evaluating Creating	Very well supported taxonomy with a large base of research. However, it does not provide a strict hierarchy as the taxonomy does not recognize "difficulty" as a variable. Furthermore, 6 differing levels might create videos with more levels than needed.
RTTI (RTTI-online, n.d.)	Reproduction Application 1 Application 2 Insight	A much-used taxonomy in the Dutch educational system, which is an advantage in ease of use for educators. However, RTTI is a commercial product, with its developers presenting little to no grounding in research.
OBIT (SLO, n.d.)	Remember Understand Integrate Apply	A taxonomy that was designed by APS, a now defunct Dutch nonprofit. It comes with a comparable ease of use as RTTI, however resources on this taxonomy seem somewhat hard to find. It is also somewhat nonhierarchical, making it less suited to the specific video approach. (SLO, n.d.)
SOLO (Biggs & Collis, 1982)	Prestructural Unistructural Multistructural Relational Extended Abstract	Biggs and Collis (1982) developed the Structure of Observed Learning Outcomes taxonomy, which orders learning outcomes in 5 steps.
Dutch Pyramid, Verhage and de Lange (1997)	z-axis: Reproduction Analysis Connections x-axis: Domain y-axis: Difficulty	A taxonomy with clear attention to hierarchy, which is achieved by giving specific attention to the variables of "difficulty" and "domain" as a part of the taxonomy. However, it is not a well-known taxonomy which might impact its familiarity and thus ease of use.

Note. When needed, levels of taxonomies are translated into English.

Figure 1

The Dutch assessment pyramid as described by Verhage and de Lange (1997)



This figure illustrates three levels of thinking in mathematics across different domains as described by Verhage and de Lange (1997). Level I involves recall and application of practiced knowledge and skills. Level II requires making connections within and between mathematical domains, using different representations, and making strategic decisions in varied contexts. Level III involves mathematizing situations, developing models, making arguments and proofs, and dealing with less familiar problem settings. The pyramid also indicates that higher-level tasks are not necessarily more difficult than Level I tasks.

Ultimately, the Dutch-pyramid taxonomy was selected as the basis for this research. Originally developed as an alternative to Bloom's taxonomy, which is more suited for teaching mathematics, Verhage and de Lange (1997) developed the Dutch assessment pyramid (figure 2), which recognizes three levels of student reasoning: Reproduction, connections, and analysis. This specific taxonomy was chosen from the many available taxonomies as it recognizes the concept of difficulty as a separate variable from the level of thinking. Thus, a video can be made as easy or difficult as is suitable for the students watching the video, while still having three clearly distinct levels.

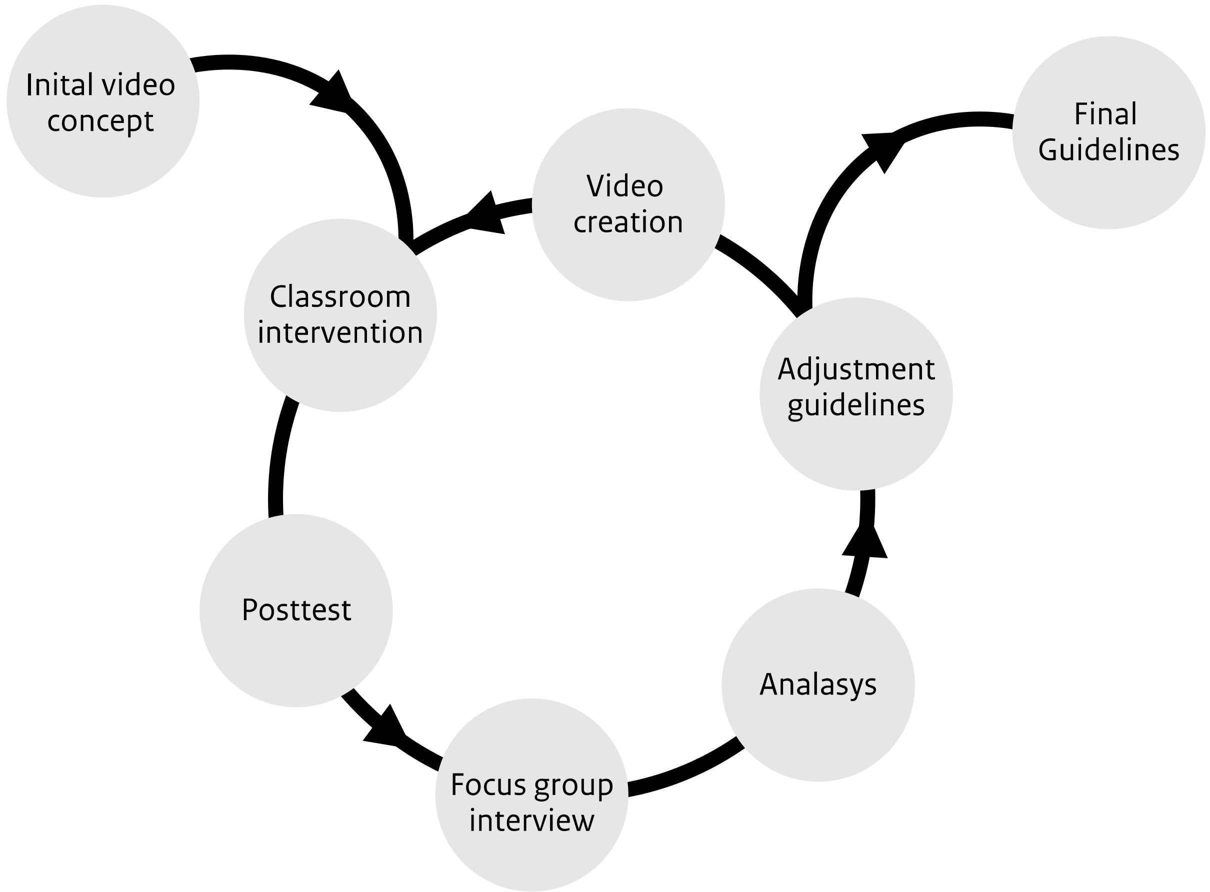
The multi-level approach will be structured in three distinct phases or “levels” , based on the three levels of the Dutch Pyramid. This proposed approach to video creation should provide an option to create videos that educate students at multiple taxonomical levels, addressing the knowledge gap identified in the existing literature on the creation of videos that teach both reproducible skills as well as analytical knowledge. The research aims to study how such videos might contribute to the learning process, as well as to provide guidelines for the creation thereof, finding an answer to the overarching research question:

“How can an educational video ordered in multiple levels according to the “Dutch pyramid” taxonomy support students’ learning in STEM education.”

Method

Figure 2

A representation of the iterative steps taken during this research



This figure illustrates the iterative process of developing and refining educational videos. The process begins with an initial video concept and proceeds through several stages: video creation, classroom intervention, post-test, focus group interview, analysis, and adjustment of guidelines. These stages are repeated until final guidelines are achieved.

General description

As previously described, we employed a design-based approach focusing on the creation of guidelines for multi-level videos as one of the main research goals. An overview of this approach can be seen in figure 2. For this approach, videos were created and then tested in a classroom setting, where approximately 25-30 students watched the video at their own pace using individual devices. Subsequently, students were asked to complete a post-test. Both the video and post-test combined were designed to fit into a standard class period of 50 minutes to minimize disruptions to normal lessons. After post-test results were collected, eight people were randomly selected using an online name-picker and asked to participate in a focus group interview.

These interviews took approximately 40 minutes and were recorded for analysis. During analysis, the post-tests were graded with each question receiving a score of 0 or 1 (correct/incorrect ad the interviews were analyzed for specific quotes pertaining to the video. More information on these steps can be found further in this chapter. Based on these results, guidelines were created or adapted and then used to create a new video. This cycle was performed three times to complete data collection and form the final set of guidelines.

Videos

Several videos were made during this research. Some core information on these videos can be found in table 2 and 3 For the first iteration, 2 videos were made as guidelines were at that time unclear. The lack of guidelines made the creation of first iteration videos a less guided and unclear process. Creating and analyzing two videos might offset these unfavorable conditions somewhat, allowing us to still gather usable data. Furthermore, on video (the video on the Pythagorean theorem) was created by a more experienced video creator, hopefully further offsetting the issue of lacking guidelines during the first iteration.

Table 2

An overview of the learning goals per level

Video topic	Learning goals per level
Redox Chemistry	1: Students know how to use half reactions to find a given redox reaction 2: Students can predict how redox reactions occur using the potential difference. 3: Students can make connections between concepts of redox chemistry and electromechanics.
Pythagorean theorem	1. Student can recognize the Pythagorean theorem and verify its correctness in simple right-angle triangles. 2. Students can use the Pythagorean theorem to find the length of the hypotenuse of a right triangle. 2+. Students can use the Pythagorean theorem to find the length of any side of a right triangle, as well as the distance between point on a grid. 3. Students can use and recognize the need for the Pythagorean theorem when solving mathematical problems.
Chemical Bonds	1: Students can recognize and describe molecular, ionic, and metallic bonds. 2. Students can recognize and describe polar and apolar bonds 3. Students can use polarity to reason on molecular interactions on micro and macro scale.
Acid-base chemistry	1.Students can recognize and describe acid-base reactions. 2. Students can predict if acid-base reactions occur fully or reach equilibrium.

Table 3

Links and further information on the videos

Video topic	Target audience	Length	Post test appendix	Link to video
Redox Chemistry	16-17-year-old pre university students (5VWO)	3:23	3	https://youtu.be/l2CVTWq0p-A
Pythagorean theorem	12-13-year old pre university students (2VWO)	25:23	4	https://www.youtube.com/@freudenthalinstituut1432
Chemical Bonds	15-16-year-old pre university students (4VWO)	19:09	5	https://youtu.be/Aa07uh4Gc-k
Acid-base chemistry	15-16-year-old pre university students (4VWO)	20:58	6	https://youtu.be/85VJUt_UUyY

Classroom "intervention"

As stated previously, interventions were designed so they fit within a standard 50-minute lesson period, so as not to disturb the normal running of lessons. The focus of this research is the design of the videos, and not the surrounding intervention. Therefore, a simple intervention, and even simpler HLT should keep extraneous influences to a minimum. For this simple HLT, the learning goals are as described in table P and differ for each video. The subsequent learning activity is individually watching the video made for that specific iteration. The hypothesis is that by watching these video, students will learn at all three levels as described by the Dutch assessment pyramid. To test this hypothesis, the focus-group and post-test were used.

Post-test

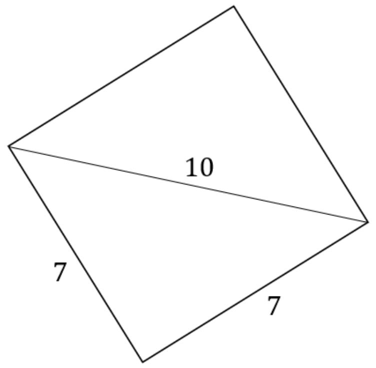
One of the two instruments to collect data on the videos was the posttest. The post-tests were designed to provide insight into students learning at the different levels as described by the Dutch Pyramid taxonomy. Importantly, no pre-test was performed. This approach was deemed suitable as topics for video-creation were selected such that we can assume that students did not have any topic-specific knowledge. To validate this assumption, both students and their teacher will be asked about this beforehand.

For the post-test, questions were created to cover al three levels. Based on the approximation of the researcher, as many questions as possible for the students in the available time (approximately 20 minutes) were created. Unfortunately, for most video this meant the creation of 1 to 2 questions per level, which is suboptimal for test reliability. An example question of a post test can be found below. The following question hails from the post test on the Pythagorean theorem and tests at the first level of the Dutch Pyramid taxonomy. The question and grading model are translated into English from the original Dutch.

Exercise 1.

Jip says: “The diagonal for a square with sides 7 is 10 !”. Janneke replies: “No its not!”

Use the Pythagorean theorem to prove that Janneke is right.



The grading model for this question was as follows:

Exercise 1.

Any answer according to the following logic:

$$7^2 + 7^2 = 98$$
$$\sqrt{98} = 9{,}9$$

9,9 is not 10, therefore Janneke is right

For the full posttests as well as the grading-models, please see appendix 3 through 6.

Post-tests are graded to give a single point score on each question to provide some measure of consistency. These results are analyzed via a Test-Item Analysis (TIA) model to test reliability and most importantly obtain percentage scores. (Quaigrain & Arhin, 2017) The analysis of post-test results will be interpretative as post test results are primarily used to give a qualitative idea of student understanding and to corroborate on focus group results. Furthermore, the post-test does not provide comparative data, as the questions are not normalized for difficulty. Therefore, the posttest mostly serves as proof that learning occurred during the video.

Focus-group interview

After the posttest concludes, 8 students are randomly selected after completion of the post-test. This led to post-test with approximately 5 to 7 students, as students could of course freely refuse participation. These students participate in a semi-structured focus group interview, where they are encouraged to provide feedback on the video. The interview protocol for these focus groups can be found in appendix 2. The interview schema is designed to get students talking about the video, while still providing room for students own input so all issues with the video and thus possible improvements for the guidelines can be found.

The audio recordings of these focus group interviews are replayed, with notes taken to capture the general conclusions and key points relevant to the study. Transcription was selectively applied to portions of the recordings that provided particularly illustrative quotes or significant insights. This selective transcription approach aligns with Denscombe's "The good research guide's" recommendation for descriptive accounts, where only small extracts are transcribed as quotes to illustrate points when writing up the findings (Denscombe, 2017). To guide the selection of quotes, specific attention is given to statements pertaining to engagement, interest and (perceived) understanding. Next to this, quotes mentioning any of the guidelines were also of particular interest.

Results

Iteration 1

Video 1a: Experimental setting.

The video on redox chemistry (see table 2) is shown to a classroom of 27 5 VWO students at the CLZ in Zeist. Due to a lapse in instructions, some students worked together on the posttest; others worked alone. Results for the posttest and TIA analysis can be found in table 4. 7 students participated in the focus group interview. The interviewer and instructor in the videos was also the regular chemistry teacher for these students.

Results posttest video 1a

Table 4

Results for post-test 1a

Results per question							
Question	1	2	3	4	5	6	7
p-value	0,06	0,76	0,47	0,71	0,47	0,06	0,29
variance	0,06	0,18	0,25	0,21	0,25	0,06	0,21
rit	0,51	0,66	0,49	0,51	0,57	0,51	0,58
rir	0,389	0,45	0,19	0,24	0,28	0,39	0,32

Results averaged per level			
Level	L1	L2	L3
p-value	0,43	0,59	0,18
variance	0,16	0,23	0,13
rit	0,55	0,54	0,55
rir	0,34	0,26	0,36

The post-test indicates that the video leaves room for improvement, as students struggled at all three levels. Cronbachs alpha for the reliability of the posttest was 0,61, which is low, but a low alpha is expected for such a short test. As seen in table 4, RIT and RIR values for individual questions show that all questions should be about equally reliable, although of course this is only an estimate as the number of items is so low.

Students score low on question one, with only one student giving a correct answer. For this question, students are asked to give a half-reaction for the reduction of oxygen. Most students give an answer as follows:

$$O_2 + H_2O + 4e^- \rightarrow 4OH^-$$

This is the reaction for oxygen found in BINAS, however, it also involves water, which is incorrect. However, the correct answer cannot be found in BINAS, and therefore requires more than just procedural knowledge. Perhaps this is an issue with post-test design.

For the second level the p-value is 0.59, showing that this learning goal has been achieved for more than half of the students (assuming the test reliably tests for the learning goal). Students mostly answered correctly, with most incorrect answers coming from students who just not provided an answer at all. Whether this is due to some fault of the video, or an extraneous factor is currently unclear.

For the third level, students are asked to make connections between their chemical knowledge and knowledge on electricity (physics) One of the questions had students compose a formula for energy output of a redox reaction, substituting dE for the potential-difference between reactants. A typical answer to this question looked something like this:

$$P=U*dE$$

Showing that students do use the equation P=U*I, which was also used in the video, showing some transfer of ideas occurred here. However, they subsequently substitute dE at the wrong part, showing their understanding of the connections between redox chemistry and electromechanics needs more work.

Overall, we saw that level 1 and 2 show similar results, with level 3 trailing behind in score. When the assumption is made that all questions are equally difficult, this implies that the creation of new guidelines needed to be focused on improving the learning outcome at level 3.

Results focus group video 1a
Students show interest in the multi-leveled video concept and report they believe it could be useful, as shown in the following (translated) quote:

"The visual distinction between levels made it easy to see what part was about what."

Students were however quite critical on the video, with a major issue being the duration of the video:

"The video was very short and felt hurried which made it a bit chaotic to understand"

Student reported on their motivation troughout the levels, with one student saying:

"At level one I was already thinking "I don't understand", so I figured the other levels would get even more difficult."

The group sentiment indeed reflected that level one was too hard, which students found demotivating. This can also be seen in the post-test results. Next to this, they found some incongruencies in buildup. Specifically, level 1 became much more understandable after watching level 2, as it explained a part of the first level, as can be seen from the following statement:

"Yeah it only became clear what we had to do for level one after level 2, because you showed the BINAS table there"

Students also report their engagement started to wane, especially during the end of the video:

"I missed some stimuli, especially at the end of the video"

Video 1b: Experimental setting

The video on the Pythagorean theorem (see table 2) was shown to two groups. One group was a 2 VWO/HAVO class of 26 students at the Erasmus College in Zoetermeer. The second group was a VMBO 3 class of 29 students at the Christelijk Lyceum Zeist. Results for the posttests can be found in tables 5 and 6. Both groups watched the video as a whole classroom on a smartboard before making the posttest. Due to circumstances, scope of the curriculum, and observed student response the video was cut short after level 2+ at the VMBO class. Respectively 6 and 5 students participated in the post-test interviews. For both groups, instructor and interviewer where not the regular teacher. The HAVO/VWO group had already received a single lesson on the Pythagorean theorem at the point of watching the video.

Results posttest video 1b (HAVO/VWO)

Students are assessed at levels 1 through 3 according to the Dutch pyramid taxonomy. The post-tests held one question at each assessment level, with level 2 slit up in 2 levels (2 and 2+) as we were unclear on exactly how level 2 and 3 should be defined.

Table 5

Results for post-test 1b VWO

question	Level 1	Level 2	Level 2+	Level 3
p-value	0,95	0,73	0,45	0,00
variantie	0,04	0,20	0,25	0,00
rit	0,51	0,87	0,86	-
rir	0,310	0,61	0,52	-

Table 6

Results for post-test 1b VMBO

question	Level 1	Level 2	Level 2+
p-value	0,95	0,73	0,45
variantie	0,04	0,20	0,25
rit	0,51	0,87	0,86
rir	0,310	0,61	0,52

Post test results clearly differ between groups. The VMBO group was only asked to make questions on levels 1 trough 2+. They show a less strong understanding after watching the video as the HAVO/VWO (A) group, which can at least partially be explained by the fact that the A-group already received a lesson on the Pythagorean theorem. Overall, there seems to be a correlation between level and score, where score declines as the level increases. This decline implies that guidelines to improve level 3 will be required, just as we saw during the redox video. This does come with a caveat: the high performance for level one can also be explained by students having some previous experience at this level.

Results focus group video 1b

The focus group results for both groups showed a large variance. The HAVO/VWO group is relatively enthusiastic about both the video and the concept. The enthusiasm about the concept is shown for example by one student, who said the levels made them more curious about what was coming next:

"I felt curious about the next level, like, ooh, if this was level one, what would be level two?"

Next to this, enthusiasm about the video in general seemed high. Several students asked whether this video would be shared with them, and all interviewed students indicate they would like to watch this video at some point during their learning process. One student for example said the following:

"I would really like to watch this video just before the test, because it's just like a handy summary"

However, students do have some critique to the video. The main point is the long duration of the video being detrimental, as students report losing interest as the levels go on. Interestingly, the point where they lose interest differs, as some found level one to be boring as they exclaimed it was "too easy" and others lost interest at level 3 because they thought it too difficult. Students asked if it was possible to add interactive elements to the video, such as the ability to skip ahead for repeat exercises.

The VMBO group had an almost directly opposite response. Students saw little use to the ordering in levels, and all interviewed students found the video boring and only one student reported they would rewatch the video during their learning process. The main point these students made was that watching a video during a lesson felt like a waste of time:

"When were in the classroom we might as well listen to the teacher, because then we can ask questions"

When asked whether they would find a video like this useful as aid when doing their homework, students reported they don't really do their homework, or ask relatives for help.

After this iteration, a set of guidelines was created based on the feedback. These guidelines are designed to circumvent problems found in the initial test based on the results. The full set of guidelines created in the first iteration can be found in in appendix 1.

Iteration 2

Video 2: Different bonds in chemistry
The video on chemical bonding (see table 2) was shown to a group of 31 4 VWO students at the Christelijk Lyceeum Zeist. Results for the posttest can be found in table 7. 6 students participated in the focus group interview. The interviewer and instructor in the videos was also the regular chemistry teacher for these students.

Post-test results
Students are assessed at levels 1 through 3 according to the Dutch pyramid taxonomy. The post-tests held one question at each assessment level.

Table 7

Results for post-test 2

question	Level 1	Level 2	Level 3
p-value	0,33	0,71	0,38
variantie	0,22	0,21	0,23
rit	0,58	0,63	0,62
rir	0,042	0,13	0,08

The post-test was made quite poorly overall, with level 2 getting the highest score of all three levels. The low scores on the post-test do not paint the full picture however, as many students gave half-correct answers. For example, the first question was to identify the substances that could conduct electricity in the liquid phase. Many students answered comparable to the following:

> NaCl which is a salt.

> NaCl and HCl which are salts

Which shows that they do understand that liquid salts conduct electricity, but they misidentify the substances, leading to an incorrect answer.

The most common mistake on question 2, which asked students to decide whether the bond between oxygen and Sulphur is polar, had people forget to subtract electronegativity values, giving answers such as the following:

> The electronegativity of S is 2,6 and that of O is 3,4 so they are both above 1,6 making it an ion

However almost all students did use electronegativity in their reasoning, showing that at least some learning occurred during phase 2 of the video, as this concept was introduced here. For phase 3, a big issue seemed to be time constraints, as many students indicated this on their answer sheets. If only looking at the non-blank answers, performance on this level is much better as table 7 suggests. The most common mistake at this question, where students had to identify which molecule would stick to a given polymer, was misidentifying the polymer as an apolar molecule, leading students to match it with the other apolar molecule, giving answers like:

The polymer is apolar so the right molecule, as it is also apolar.

These answers, whilst wrong, do show reasoning with the correct concepts, implying that the conceptual knowledge was at least to a certain extend transferred. However, as the video teaches these concepts with a similar example, it might also be guesswork. Overall, we see results that indicate learning did occur at all three levels.

Results focus group.

The focus group mostly underpins the previously made guidelines. For example, on student reports that organization in levels is helpful with finding motivation to watch the video, stating:

"At one point I thought: 'Oh were already at level three, just a little longer' which did help me keep my motivation."

Paying extra attention to the accessibility of level one seems fruitful, as students reported they felt like they would be able to handle the rest of the video more easily. One student remarked:

"I'm not very good at chemistry but I figure I understood it quite well."

The largest discussion point for the focus group was again the waning interest for the third level. Interestingly, the video differs greatly in length from the previous video's, implying that it is not necessarily an issue of length. The focus group does provide a new insight into a reason for losing interest, which is the perceived difficulty of level 3 being too low. Students made statements like:

"The difference in level between 2 and 3 wasn't all that big."

"At level 3 I found it less interesting as I already heard it all."

Which summarizes the general impression from the focus group that level 3 was too easy. Perhaps giving students more room to struggle on their own will increase retention. Interestingly, this perceived ease is not visible in the post-test results, instead showing less than stellar results. Although there are some doubts as to the reliability of the post-test results, this is still a signal that for a yet undetermined reason learning at the third level is difficult.

To corroborate, students still show that engagement waned for level 3, shown with statements like:

“I thought at the end it got a little boring.”

One other interesting statement was that students greatly appreciated autonomy in watching the video. As one student said:

“If you missed a certain part, you could play it back.”

Next to this, students report that they feel like it would be useful to have exercises in between levels, both to break up the video to make it more interesting and to verify that they understood the previous level.

Feedback on video creation

Of course, usability of guidelines is also an important factor. Therefore, we also evaluated our own usage of the previous set of guidelines. It became apparent that the definitions of separate levels were not clear enough in the previous set of guidelines, so a more accurate set of descriptions was warranted.
To further increase usability of the guidelines, we reformulated guidelines to be more actionable, using the works of Bakker (2019) as a basis to developing better guidelines. The guidelines were adjusted based on the results. This gives us the changed guidelines as seen for iteration 2 as seen in appendix 1.

Iteration 3

Video 4: Acid-base chemistry

The video on acid-base chemistry (see table 2) was tested with two groups of students at the Christelijk Lyceum Zeist, with one group consisting of 17 students and the other of 28 students. Respectively 7 and 5 students participated in the focus group interview. The interviewer and instructor in the videos was also the regular chemistry teacher for only the second group of students.

Post-test results

Students are assessed at levels 1 through 3 according to the Dutch pyramid taxonomy. The post-tests held 3 separate 1-point questions on level 1, 4 questions on level 2, and a single question on level 3. This structure is chosen to provide insight into learning whilst considering the time limit for the post-test. However, as was found out during the classroom test, these concerns were relatively unfounded. Perhaps adding an extra level-3 question would provide better insight into students learning. Results for the posttest can be found in table 8.

Table 8

Results for post-test 1a

Results per question									
Question	Item 1a	Item 1b	Item 1c	Item 1d	Item 2a	Item 2b	Item 2c	Item 2d	Item 3
p-value	0.82	0.94	0.88	0.94	0.76	0.53	0.18	0.35	0.35
variance	0.15	0.06	0.10	0.06	0.18	0.25	0.15	0.23	0.23
rit	0.67	0.68	0.65	0.68	0.72	0.73	0.41	0.43	0.66
rir	0.556	0.61	0.54	0.61	0.60	0.58	0.25	0.22	0.50

Results averaged per level			
Level	1	2	3
p-value	0.90	0.46	0.35
variance	0.09	0.20	0.23
rit	0.67	0.57	0.66
rir	0.58	0.41	0.50

The post-test results show that learning did occur at all three levels. Students' performance on test items again seems to be declining at higher taxonomical levels (as reflected by the p-value). Cronbach alpha for the post-test is 0.80, which is reasonable especially considering the low number of items on the posttest.

Effects of video on student answers

Most students were successful in identifying acids for the first question. The second question was to give reactions between several acids and bases. Here, the most common mistake was to forget that weak acids and bases react as equilibrium, forgetting the double arrow and giving answers like:

$H_2O + HIO \text{ -> } IO^- + H_3O^+$

This shows that students do understand the aspects of proton transfer, but the idea of equilibrium is still difficult. However, sub-questions 2b, 2c and 2d require students to use equilibria, and about a third of students make these correctly. Sub questions 2a and 2b are reactions between water and an acid, which was also the case for all the examples used in the video. This might explain why students perform better on these questions than on sub questions 2c and 2d, where examples differ from those in the video, as 2c is about a base reacting with water, and 2d is about a weak acid reacting with a weak base.

The question on level 3 was made correctly by 35% of the students. This shows an improved performance at level three when compared to previous iterations. Especially when we consider that quite a few students gave correct insights on acid-base reactivity but failed to answer the question correctly. For example:

A base attracts H, whilst an acid gives it away (correct) Red has the most H+ (correct), therefore, the environment for red is basic (incorrect)

Results focus group.

About a third of the incorrect answers for question three followed this, or a similar logic, showing again that most students understand underlying concepts but still have difficulty with reasoning using that understanding.

This is in and of itself a positive result: One of the goals for this research was to teach concepts. The video uses a similar example as the one used in the question to talk about the concept of acidic or basic environments but focuses mainly on the underlying concepts. The fact that successful learning at a conceptual level has occurred is therefore a notable result.

Focus group results test 1

The focus group mostly underpins the previously made guidelines. Students report an increase in difficulty with each level, without feeling to demotivated by the difficulty at level 1. Some students do report that they lost some interest during level three:

"Yes, I thought it just got really hard to follow at that point, but that might be because I was getting bored."

However, as you can see from the statement, students self-report that the issue herein lies with the duration of the video. Students claim that watching a 20-minute video was difficult, and that they would rather watch a 10 to 15-minute video. This also comes up when asked if they would watch this video on their own, or as part of the homework.

When asked if they would watch this video as preparation on a classroom lesson, one student said:

"Well to be honest I if the video was 21 minutes, I would just not watch it"

Which was a statement immediately echoed by most of the group. Students believe the cutoff for a video they would still watch would be approximately 10 minutes, or about 20 minutes when they knew that they were allowed to skip parts of the video. The skipping of content was something that students were enthusiastic about, with one student reporting:

"It was really nice that we could skip ahead if we understood the level. Although I didn't use it because I didn't understand it yet"

This statement brings to light another issue: Telling students to skip parts of the video requires them to be confident enough to do so. Of course, it might not be the goal to have all students skip parts, however, more attention should be given to the difficulty of the video with or without skips. Other interactive elements, like pausing the video to make questions, were appreciated as well. Adding a self-review question at the end of a level was something students appreciated, stating:

"It was nice to have a sort of test to see if you are ready for the next level"

When asked whether students would prefer a multi-level video over a normal video, students mostly said they would prefer the multi-level video. When asked to clarify why, one student said:

"The levels make it really nice and ordered which I would like when I need to study for a test".

Out of the 6 students participating in this focus group, 5 agreed with this statement. One student said they would prefer a regular video.

Feedback on video creation

The improvements in usability since the previous iteration showed, as definitions of separate levels were clearer as in previous iterations. This resulted in it being easier to create the video in separate levels. The new guideline on creating interactions could use some work from a creator's perspective. The guideline does not hook into the multi-level concept and does not specify how much interaction is appropriate, or when it is appropriate.

Next to this, some terminology might require changing, as many different terms are used to describe the same thing and some general issues were found in the guidelines. This should be corrected to improve the usability and clarity of the guidelines.

Final guidelines

Considering the results for the last iteration, the following set of guidelines was finalized:

Phase 1: Reproduction

In the first phase, fundamental concepts or transparent procedures are presented, connecting to expected pre-knowledge. When using examples, make them as clear cut as possible.

Next to this cognitive dimension, the envisioned outcome for the first level has an affective dimension, which is inducing curiosity concerning the subject and garnering confidence in being able to follow the rest of the video.

Phase 2: Connections

Design the second phase of the video to present the topic so that students need to make connections within and between different domains of the topic This should help students to develop the ability to see beyond isolated concepts and procedures, understanding the interconnectedness of concepts.

Phase 3: Analysis

In the third phase, present the topic so it requires students to analyze situations, develop models, or create generalizations. When presenting examples, showcase avenues for problem resolution. By engaging with situations that demand analysis and critical thinking, students are required to synthesize their knowledge and apply it in innovative ways. This process hopefully leads to a more comprehensive understanding of the topic.

Structure phases and levels

Design the video content in distinct, progressively more complex phases aligned with specific taxonomical levels, as described in guidelines 1 trough 3. Utilize various means (text, visuals, verbal explanation) to make each video phase and its corresponding level explicit to the viewer. This approach should provide a clear learning pathway for students which should enhance engagement due to the sense of progression and achievement.

Build content sequentially.

Introduce necessary information at the outset of the video, ensuring that each level builds upon the previous one. Only building upon that which is provided in earlier levels allows students to follow along without confusion. This should allow students of sufficiently high level to watch separate phases without having to watch the whole video to gain the whole picture.

Consider engagement.

Adjust the use of engagement techniques such as visual aids or quick transitions based on the complexity of the content, with a focus on maintaining interest in later levels. Use engagement strategies to keep the material captivating to address the tendency for self-reported attention and interest to wane during the video.

Promote Autonomy

Make the multi-level approach interactive by offering students the option to pause, replay, or skip segments during each phase. For example, end phases on a self-test question with a suggestion to rewatch the level if the self-test proves too difficult, or provide a second optional example that students can skip. Ensure that the video still explains all concepts when students skip all parts that can be skipped. By suggesting moments for active interaction with the content, engagement should be enhanced as students can tailor their experience by skipping ahead, rewatching, or pausing for exercises.

Conclusion and discussion

Several multi-level videos were made and analyzed in an iterative manner. During the iterations, average post-test results improved, and student responses during post-test interviews became more positive. Generally, students were positive about the multi-level concept during all iterations, especially the last.

Research Question

The research question—How can an educational video ordered in multiple levels according to the "Dutch pyramid" taxonomy support students' learning in formal STEM education? —has been explored. Our findings indicate that multi-level videos, structured according to the Dutch pyramid taxonomy, support student learning at multiple taxonomical levels.

Contributions to the learning process

The aim of this research was partially to study how multi-leveled videos might contribute to the learning process. We set out to create videos that teach both reproductive knowledge and more analytical "high level" thinking. We used the Dutch pyramid taxonomy to define these levels and analyze whether our approach was successful. Our results have shown that the guidelines we developed lead to videos capable of teaching at all three levels. However, our videos still seem more suited to teaching the more reproductive knowledge as found in levels 1 and 2, as post-tests show the highest performance at these levels. These findings align with previous studies highlighting the challenges in balancing content difficulty in educational videos (Kay, 2012). However, it is important to reiterate that the post-test results are not normalized for difficulty. To make a definite statement on the comparative effectiveness at different levels, more research is required.

Guidelines

In addition to answering the research question, we have identified several guidelines to guide the creation of such videos. The relative change in guidelines can be seen in Appendix 2. As seen here, the guidelines were drastically changed after the second iteration, with smaller changes during the third iteration. However, whilst the last changes are small, these guidelines should still be far from set in stone. For example, an interesting change to the approach taken could be to change the taxonomy on which guidelines are based. While the choice for the Dutch pyramid was not arbitrary, another taxonomy, such as Bloom, might provide an interesting avenue to creating videos with six levels.

Furthermore, the guidelines derived in our study have not yet been rigorously tested. While preliminary data suggests these guidelines are likely to be effective, further empirical validation is necessary to confirm their efficacy. This study primarily focused on chemistry education, raising questions about the generalizability of our findings to other STEM disciplines. However, there is no inherent reason to believe that the multi-level video approach would not be effective in broader STEM contexts. Future research could focus on validating the proposed guidelines across various STEM disciplines. Another interesting point would be the selection of topics for these videos. Perhaps, some topics lend themselves better to the multi-level approach than others.

Interactive Elements

A positive aspect of multi-level videos lies in creating videos meant to be paused and replayed by students. Research by Kolthof (2021) found that pauses, skips, and other interactive elements increase the educative performance of videos. However, students watching videos with such elements report decreased engagement, as they break the flow of the narrative. Our research found no such adverse effects in multi-level videos, perhaps because the phases for each level already break up the video, giving a natural moment for such interactive elements in the video. Conversely, our focus group results at all three iterations show students asking for more of these interactive elements. As these interactive elements are shown to improve learning outcomes, the inclusion of such elements into multi-level videos might provide an interesting topic for future research.

Integration into Teaching Practice

Future research could explore the integration of these multi-level videos into teaching practice. As can be seen in the focus group interviews, most students report that they would like to watch these videos as test preparation. Some students report they would like to watch similar videos as a preparation for a lesson, if the videos would not be too long. However, we did not further study best practices for integrating multi-level videos into the curriculum.

Implications for Instructional Design

Our study demonstrates that educational taxonomies traditionally used for assessment, such as the Dutch pyramid taxonomy, can be effectively repurposed to guide instructional design. This aligns with the principles of constructive alignment (Biggs and Tang, 2011), where learning activities and assessments are systematically aligned with learning outcomes. By structuring educational videos according to these taxonomies, we can create more effective learning tools that promote deeper understanding and engagement.

Data accessibility

Data for this research was collected and stored in accordance with the guidelines as described by the Science Faculty of Utrecht University. Inquiries to collected data not shared in this paper can be directed to s.r.h.snijder@students.uu.nl

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Appendix 1: Guidelines per iteration

Appendix table 1
Table showing different guidelines at iterations 1 and 2.

Iteration 1	Iteration 2
Levels and phases of the video: The first level should be a clear introduction and very accessible to the target audience. Each following level should progress through the levels of the chosen taxonomy. Ensuring that the starting point is easy enough to be accessible to all learners is vital, as students report feeling demotivated when faced with a first level they don't fully understand as was the case in the chemistry video. Conversely, when the first level is understandable and clear, students report curiosity to later levels and feel more secure in their ability to follow along with the video, as was the case for the mathematics video.	**Phase 1: Reproduction** In the first phase, fundamental concepts or instruction of transparent procedures are introduced, connecting to expected pre-knowledge. When using examples, make them as clear cut as possible. Next to this cognitive dimension, the envisioned outcome for the first level has an affective dimension, which is inducing curiosity concerning the subject and garnering confidence in being able to follow the rest of the video. **Phase 2: Connections** Design the second phase of the video to present the topic so that students need to make connections within and between different domains of the subject matter. Introduce more practical problems, for example by providing worked examples. This should help students to develop the ability to see beyond isolated facts and procedures, understanding the interconnectedness of concepts. **Phase 3: Analysis** In the third phase, incorporate complex, open-ended problems that require students to analyze situations, develop models or strategies, or create generalizations. Provide worked examples or showcase avenues for problem resolution. By engaging with tasks that demand analysis and critical thinking, students are required to synthesize their knowledge and apply it in innovative ways. This process hopefully leads to a more comprehensive understanding of the topic.

Explicit Differentiation Between Levels: It is essential to the concept of multi-leveld videos to distinguish explicitly between different learning levels within the video. Explicitly showing what level students are on shows students what to expect, which students report as helpful. Both videos achieve this differently. Students report a clear understanding of when levels change, implying the way of communicating level change is not that important.	**Structure phases and levels** Design the video content in distinct, progressively more complex phases aligned with specific taxonomy levels. Utilize various means (text, visuals, verbal explanation) to make each video phase and its corresponding level explicit to the viewer. This approach should provide a clear learning pathway for students. This should enhance engagement due to the sense of progression and achievement, whilst also improving watchability.
Levels should only build "up": Later levels can build on previous levels, but not the other way around. The completeness of previous levels should not depend on the following levels. Ensure that technical aspects, like tool usage such as BINAS, are introduced at appropriate stages in the video. For example, if a tool is required in Level 1, it should be introduced in that level itself, not in a later level.	**Build content sequentially.** Introduce necessary tools and concepts at the outset, ensuring that each level builds upon the previous one. Only building upon the tools and concepts provided in earlier levels allows students to follow along without confusion. This should allow students to watch separate phases without having to watch the whole video.

Later levels should grab the attention: Later levels of the video need specifically to be designed to keep students' attention. The number of attention-grabbing elements, such as visual aids but also jump-cuts, quick transitions between scenes, and other intentionally captivating imagery, should be adapted according to the content. Use more engaging elements when conveying information of a broader, less directly applicable level, as students note that here attention starts to wander. Conversely, use fewer attention-grabbing techniques for more straightforward explanations. Also make sure to watch content duration. Do not make video's overly short as students noticed a lack of information in the previous video. The students noted a lack of engaging elements and suggested that later levels could incorporate more to maintain interest. Particularly for first-time viewers, the initial presence of engaging content is crucial for engagement	**Consider engagement.** Adjust the use of engagement techniques such as visual aids or quick transitions based on the complexity of the content, with a focus on maintaining interest in later levels. Use engagement strategies to keep the material captivating to address the tendency for self-reported attention and interest to wane during the video.
	Promote Autonomy Guide students to interact with the video content actively by pausing, replaying, or skipping segments based on their understanding. By suggesting moments for active interaction with the content, engagement should be enhanced as students can tailor their experience by skipping ahead, rewatching, or pausing for exercises.

Note. This table shows guidelines as they were developed during the design process. Guidelines that evolved into other guidelines are placed next to each other to describe differences between levels.

Appendix 2: Guideline for focus-group interviews

Appendix table 2
Table showing guidelines and reminders used during all focus-group interviews

Topics	Questions
Intro	Start with a brief introduction and explain the purpose of the focus group (Research on a way to make videos). Emphasize the importance of specific and detailed answers. Encourage participants to provide concrete examples to support their answers. Indicate that criticism is welcome, as it is essential for improvement! Mention that the focus group will last about 20 to 30 minutes.
General impression	- What were your overall impressions of the video? Did you find the video interesting to watch? If necessary, ask why or why not.
	- How did you find the clarity and comprehensibility of the 1st part
	- Was it easy to tell when the video changed levels? Why or why not, ask about specific elements.
	- How did you feel after the 1st level? Did you feel motivated or eager for the rest of the video? How did you feel after the 2nd level? Repeat question for each level, ensure each level is discussed individually)
Video elements	- Were all parts equally interesting? Ask why or why not. What made it interesting or not, and how could we adjust that?
Levels	Did you experience differences in difficulty or accessibility between the levels? *Discuss all levels at least.* - Did the division into levels affect your motivation? *If yes, ask how!* - Would you watch this video? Probe further, on YouTube? While learning? On your own? When would you watch the video, or not at all
	- Were you able to concentrate well while watching the video? *Was this different for different parts of the video?*
Affect	- How did you find the video compared to normal instruction? What was useful, what less so?
Closing	Do you have any other feedback or comments about the video that you would like to share with us? Thank the participants!

Appendix 3: Posttest redox and grading model

Maak de vragen op een apart antwoordblad. Schrijf hierop NIET je naam! Lever dit antwoordblad aan het eind van de les in.

Level-1 vragen:

(Gebruik ook je BiNaS om op de juiste antwoorden te komen)

Geef de half-reactie voor de reductie van zuurstof

Geef de half reactie voor de oxidatie van ijzer naar Fe2+ (zonder zuur)

Geef de redoxreactie tussen ijzer en zuurstof.

Level 2 vragen:

Is de redoxreactie tussen ijzer en zuurstof een aflopende redoxreactie, of ontstaat er een evenwicht?

Kunnen Lithium en Fluor samen reageren in een redoxreactie? Welke stof is dan de oxidator en welke stof de reductor?

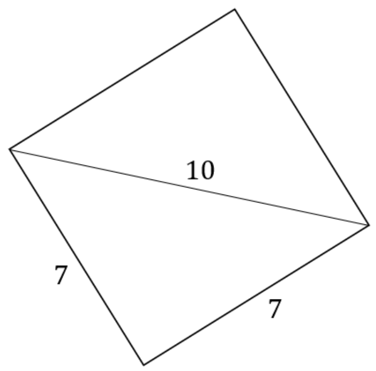
Level 3 vragen:

Geef een formule voor de energieopbrengst van een bepaalde redoxreactie. Ga er van uit dat 1 Ampère gelijk is aan 1 mol elektronen per seconde. Gebruik dE als variabele voor het verschil in electronegativiteit.

Waarom kan een redoxreactie die bestaat uit halfreacties die 2 elektronen per mol opleveren (bijvoorbeeld $Zn^{2+}+2e^{-}$ -> Zn)**,** per mol reactanten meer energie opleveren dan een redoxreactie met halfreacties die 1 elektron per mol oplevert? (Bijvoorbeeld Ag^{+}+ e → Ag)

Appendix 4: Posttest Pythagorean theorem and grading model

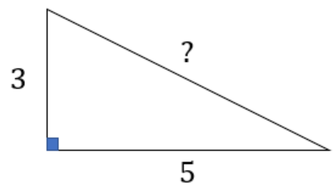
Opgave 1.
Jip zegt: “De diagonaal van een vierkant met zijde 7 is 10”. Janneke reageert: “Mooi niet!”

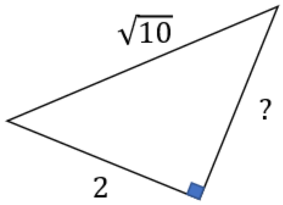


Laat met de Stelling van Pythagoras zien dat Janneke gelijk heeft.

Antwoord:
Redenatie in de vorm van:
$7^2 + 7^2 = 98$
$\sqrt{98} = 9,9$
9,9 is niet 10, dus Janneke heeft gelijk (1p)

Opgave 2. Bereken de onbekende lengte van de zijden van de rechthoekige driehoeken hieronder.





Antwoord 2:
Redenatie in de vorm van:
$3^2 + 5^2 = 34$
Geeft $\sqrt{34}$ *(ongeveer 5.8 ook goed rekenen) voor 1p*

Antwoord 2+:
Redenatie in de vorm van:
$2^2 + x^2 = 10$ (of $\sqrt{10^2}$)
Geeft $x^2 = 5$
Geeft $x = \sqrt{5}$ *(ongeveer 2,2 ook goed rekenen) voor 1p*

Opgave 3. De afstand tussen de punten $(1,2)$ en $(x, 4)$ is 5, Wat zijn de mogelijke waarden van de onbekende coördinaat x?

Antwoord 3:
Redenatie in de vorm van:
Situatie geeft $(x-1)^2 + (4-2)^2 = 5^2$ *(Liefst inclusief tekening)*
Geeft $(x-1)^2+4=25$
Geeft $(x-1)^2=21$
Geeft $x = 1+\sqrt{21}$ *of* $x = -(1+\sqrt{21})$ *(Numeriek antwoord ook goed rekenen) voor 1p*

Appendix 5: Posttest chemical bonding and grading model

Opdracht 1

Welk van de onderstaande stoffen kan of kunnen er stroom geleiden in de vloeibare fase?

Antwoord:
Hg en NaCl, dit zijn een metaal en een zout (1p)

Opdracht 2

Is de binding tussen zwavel en zuurstof polair? Gebruik de onderstaande tabellen:

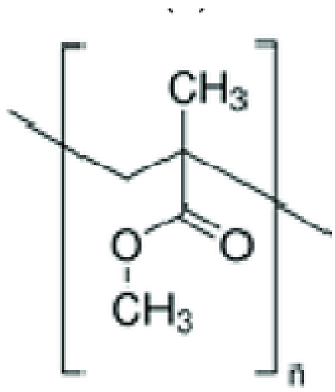
Informatie Zwavel	
Atoomnummer	16
Atoommassa (u)	32,0
Atoomradius (pm)	103
Aantal valentie-elektronen	6
Electronegativiteit (Pauling)	2,58
Reeks	Niet metaal

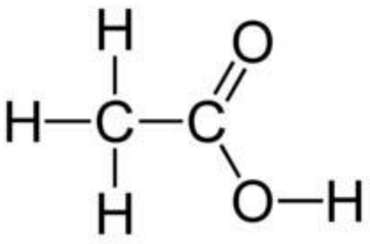
Informatie Zuurstof	
Atoomnummer	8
Atoommassa (u)	16,0
Atoomradius (pm)	73
Aantal valentie-elektronen	6
Electronegativiteit (Pauling)	3,44
Reeks	Niet metaal

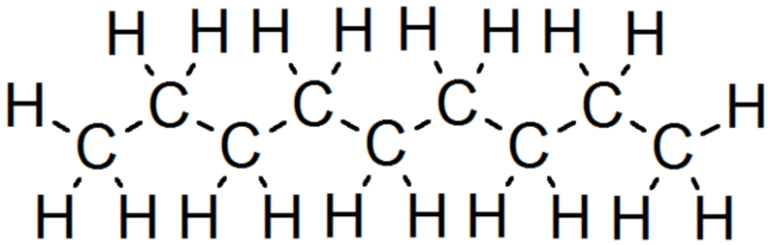
Antwoord:
Gebruik verschil in electronegativiteit, geeft 3,44-2,58=0.86, dit valt binnen het "polaire" gebied, dus binding is polair. (1p)

Opdracht 3

Het molecuul hiernaast is onderdeel van een polymeer (Een lange keten van hetzelfde onderdeel dat steeds herhaald wordt). Dit polymeer wordt in kleine bolletjes gebruikt om water te filteren. Welke van de onderstaande stoffen kan er met dit specifieke polymeer uit water gefilterd worden?







Antwoord

Redenatie in de trend: polymeer bevat een $COOCCH_3$ groep, met polaire bindingen. Deze willen binden aan de polaire bindingen in het linker molecuul, dus dit kan gefilterd worden (1p)

Een goed antwoord bevat een referentie naar polaire bindingen in het polymeer, polaire bindingen in het te filteren molecuul, en de juiste conclusie.

Appendix 6: Posttest acid-base chemistry and grading model

Vraag 1: Geef van ieder van de onderstaande moleculen aan of ze wel of niet als zuur zouden kunnen reageren.

$KMNO_4$
H_2O
H_2SO_4
$AlNO_3$

Antwoorden:
1a *Nee 1p*
1b *Ja 1p*
1c *Ja 1p*
1d *Nee 1p*

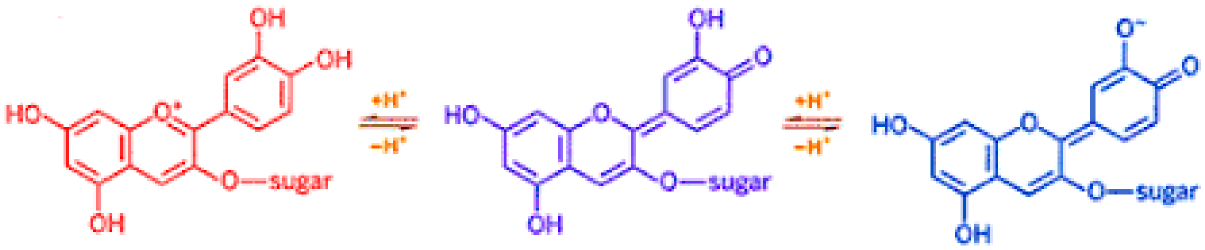
Vraag 2
Geef de reactie die optreedt wanneer de volgende stoffen gemengd worden

H_2O en H_2SO_4
H_2O en HIO
H_2O en $CO3^{2-}$
NH_3 en H_3PO_4

Antwoorden:
2a $2H_2O + H_2SO_4 \rightarrow 2H_3O^+ + SO_4^{2-}$ (Enkelwaardige reactie ook goedkeuren)
2b $H_2O + HIO \leftrightarrow H_3O^+ + IO^-$
2c $H_2O + CO3^{2-} \leftrightarrow HCO_3^- + OH^-$
2d $NH_3 + H_3PO_4 \leftrightarrow NH_4^+ + H_2PO_4^-$

1p per vraag. Noot bij alle vragen, een goed antwoord moet de juiste pijl (evenwicht of aflopend) gebruiken.

Vraag 3 Indicatormoleculen kunnen van kleur veranderen afhankelijk van de omgeving. Bij een zure omgeving krijgen ze de ene kleur, en bij een basische omgeving de andere. Welke kleur heeft dit molecuul hieronder bij zure omstandigheden, en welke kleur heeft het molecuul bij basische omstandigheden?



Antwoord:
In zure omstandigheden wordt het molecuul rood, want als de omgeving zuur is, staat de omgeving H+ af, en bevat dit molecuul dus ook maximaal H+. Het omgekeerde is waar in basische omgevingen, dus dan is het blauw. (1p)

Een goed antwoord geeft minstens de correcte conclusie en een verwijzing naar de protonerende omgeving in zuur of deprotonerende omgeving bij base.