Using Videos to Elicit Self-Explanations of Emergent Electromagnetic Concepts

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It is well documented that students have more difficulty comprehending and mastering emergent schemas in comparison to direct-causal schemas or concepts. Compared to some other disciplines, electrical engineering tends to have many emergent concepts, particularly in electromagnetics where most phenomena are not directly observable by humans and many observed behaviors arise from spatially distributed charge and field distributions. One method that has been shown to help students understand emergent concepts is to elicit self-explanations of these concepts. This paper reports on the use of student-produced videos for self-explanation of concepts in a required junior electromagnetics class. As part of a requisite fourth hour meeting each week students produced two videos one year and three videos a second year that explained a basic concept in electromagnetics. Each video was to incorporate at least four different representations—images, formulas, examples, etc.—to help students explore the concept in multiple ways. Prior work in mathematics education has shown learning improves when concepts are expressed in more than one representation. Over the two-year period in which this experiment was run the course instructors made several improvements to the way videos were integrated into the course including: training in video-production techniques including editing, use of a sound booth, stop-motion, and a "green screen"; developing a three step iterative process for videos based on story boards; and changing how concepts were identified. In the first year students selected from a list of relevant concepts, in the second year concepts were represented mathematically. During both years the videos were scored using rubrics on both accuracy of conceptual understanding and production values, and were also peer-evaluated. Comparisons of video scores to performance on standard exams and the results of concept inventories are presented. We also reflect on the value of videos for self-explanation and for engaging with conceptually difficult material. Example student videos will be used to illustrate both correct and incorrect conceptual explanations.

Introduction and Background

Not all learning is the same. In other words there are different types of knowledge as there are different ways of learning. This is the idea underlying the 2001 revision of Bloom's Taxonomy [1] that identified factual, conceptual, procedural, and metacognitive forms of knowledge. Furthermore effective means to promote student learning are dependent upon the type of knowledge. For example techniques used to teach factual knowledge—the basic elements that students must know to be acquainted with a discipline or solve problems in it [1]—may not work to master conceptual or procedural knowledge. A third way that learning is not uniform is that different forms of knowledge may be harder to acquire than others. This paper results on an attempt to have students better master conceptual learning of difficult knowledge, termed in educational literature *emergent schemas*. Conceptual knowledge has been defined as “understanding of principles governing a domain and the interrelations between units of knowledge in a domain” [2].

A schema is a mental representation, or picture, that is used to organize knowledge. The schemas we hold strongly influence later knowledge. For example you likely hold a mental schema classified as “dog” that influences you perception of canines. Work by Chi and colleagues [3, 4] have classified schemas into direct-causal and emergent. Direct schemas are those for which a simple mental pictures suffices to accurately represent the concept. Typical examples are many simple physical phenomena such as balls or a ramp or weights suspended by pulleys. For direct schemas it is possible to develop a mental picture from one’s own experiences that lead to adequate explanations of how the phenomena works. Such direct schema allows causal predictions; let go of ball, it rolls down ramp. Make ramp steeper, ball accelerates more quickly.

In contrast emergent schemas are those in which phenomena arise from many interacting bodies or forces for which human, lived experience cannot adequately explain the phenomenon. An example is heat flow which is caused by vibrational interactions among the atoms or molecules of a material as well as transport and radiative effects. Another example is diffusion. To adequately understand such phenomena the student must develop a mental representation that goes beyond lived experience. Given the complex nature of emergent schemas they are typically more difficult top master than direct-causal schemas or concepts [3]. Furthermore if students develop misconceptions, such as the water in a pipe model of electrical current, they can be more difficult to correct.

Compared to some other engineering disciplines, electrical engineering tends to have many emergent concepts. It is a truism that if you can feel electricity something has gone seriously wrong. At the undergraduate level, one of the courses that is built almost entirely on emergent schemas is electromagnetics where most phenomena are not directly observable by humans and many observed behaviors arise from spatially distributed charge and field distributions. Thus many treatments of electromagnetics are highly canonical and rely on theoretical/mathematical representations of phenomena. If the goal of the electromagnetics course is to have students improve their procedural understanding—how to solve an integral or set up a problem—then such approaches may be effective. If, on the other hand, the goal of the course is to better understand the concepts underlying electromagnetic phenomena then other methods should be used in addition given the highly emergent nature of typical course material. In electromagnetics as in other areas where tests of conceptual understanding are given in pre-post formats, students show relatively small gains [5] with forms of active and participatory learning leading to larger gains.

In this work we did an exploratory study of ways to get students to better understand emergent concepts. One method that has been shown to help students understand emergent concepts is to elicit self-explanations of these concepts [4]. The majority of work has been done on procedural learning, where there is a significant difference in learning gains when students engage in more self-explanation. In mathematics education there has been considerable work on the use of multiple representations to improve conceptual learning. Similarly in engineering design representations have been shown to improve overall outcomes [6]. Students who use multiple representations in creating models perform better; the use of multiple representations has been termed "representational fluency" [7]. Such representations can be classified as concrete (hands-on), pictorial, symbolic (mathematical), language, and realistic (metaphors and analogies). Multiple representations have been shown to help people with different backgrounds or learning styles understand an idea. In other words, some people understand formulas better, others find diagrams, animations, or a spoken representation more helpful.

This paper reports on the use of student-produced videos for self-explanation of concepts in a required junior electromagnetics class. The idea behind having students create videos was to engage them in more self-explanation of concepts in electromagnetics they would use to form schemas. The instructions for creating videos asked students to use multiple representations with the intention they schema they developed would be more robust. The remainder of the paper discusses how the video project was structured over two semester, and reports on the evaluation of the videos.

Course and Video Assignment Structure

The student produced videos were integrated into a required third year course in electromagnetics (EM) offered in an electrical and computer engineering department at a private, non-profit liberal arts university in the northeastern United States. At Bucknell University the number of electrical and computer engineers in a given class year is limited to 35. Thus classes tend to be small, around 15-20 students. The course was taught from a common text, Ulaby's *Fundamentals of Applied Electromagnetics*, with material introduced in the order of the text: transmission lines, vector calculus, static electric fields, magnetic fields, time dependent fields and Maxwell's equations, wave propagation, and antenna theory. The course met three times per week for approximately one hour. In Pennsylvania it is required by law that for the credit offered for this course students receive four hours of instruction each week. Given that the EM course did not offer a lab the video intervention was used as the fourth hour of instruction instead of a recitation section. In other words it supplemented rather than took take time away from the three weekly class meetings.

The class was taught in a flipped classroom format rather than by lecture using a format previously demonstrated by the author [8]. Students were assigned pre-class readings and short explanatory videos to watch and took a short online quiz that focused on the "understand" and "apply" levels of Bloom's Taxonomy [1]. Students could attempt the quiz multiple times. Students also were given the outline of the problem(s) they would solve in class. The outline framed the problem(s) but did not provide any data or details. The students turned a brief outline of the process they would use to solve the problem(s) so they would be prepared in the classroom. In a typical class period teams of 3-4 students worked on problems with mini-lectures or assistance from the instructor when needed. The overall weighting of these components in determining course grades was: 20% online quizzes, 15% solution outlines, 35% exams, 25% video projects, and 5% for written reflections.

As mentioned previously the required fourth hour of the course was creation of short videos. The video project was offered twice, once in 2013 and once in 2014. The 2013 iteration was an initial trial which informed the 2014 iteration reported here. Lessons learned from the initial iteration are discussed throughout. In 2013 students produced two videos compared with three videos in 2014. In the first year students were asked to self-select a basic concept in electromagnetics for their video. This turned out to be too unstructured since midway through the course students had difficulty distinguishing concepts. In the second year a list of equations from the text that represented a concept were provided[1] and students had to make a video about the concept represented by the equation. In the second iteration the three different videos corresponded roughly to the material that had been recently introduced in the course. The first video was on transmission lines, the second on electro- or magneto-statics, while the third video covered Maxwell's equations and waves. Instruction were given to students to focus on the concepts and the rubric used to score the videos (also provided to students) emphasized the focus on concepts. To ensure that students utilized multiple representations, they were required to represent the formula in *at least* four of these ways: a formula or set of equations, a written definition or description, an algorithmic construct like a flow chart or pseudocode that explains how the formula operates, a diagram (e.g. a schematic diagram), a graph or animation, or a physical device(s) or phenomena that uses the formula. The rubric emphasized that the score would strongly depend upon the quality and variety of representations used.

In the first iteration videos were no more than five minutes in length which turned out to be too long given the time and effort that goes into producing quality videos. In the second iteration videos were restricted to one to two minutes. Students were told the video should help the target audience of other undergraduates understand what the formula means by seeing it represented multiple ways. For both iterations of the course students were given explicit training in how to create videos which covered both technical aspects—green screen use, stop motion methods,

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[1] The formulas chosen to represent concepts (drawn from the 6th edition of Ulaby) are:
Video #1: 2.39, 2.46, 2.53, 2.73, 2.84 and 2.93, 2.97, 2.104
Video #2: 4.13, 4.19 and 4.21, 4.26, 4.29, 4.43, 4.51, 4.60, 4.63, 4.71, 4.79, 4.109, 4.121, 5.10, 5.22 and 5.24, 5.47
Video #3: 7.15, 7.32, 7.54, 7.66, 7.75, 7.77, 7.100, 8.12, 8.28 a or b, 8.32, 8.58

VideoScribe animation software, and Final Cut Pro X video editing software—as well as how to lay out a coherent plot, create a storyboard, and gain a basic understanding of how to write for the screen using multimodal elements such as still images, video, audio, transitions, and effective use of editing. It was highly important that students learn multimodal communication and media literacy; how they are impacted by media messages and how in turn impact other by becoming producers of their own media messages. In the first iteration there was more focus on frontloading technical training which led to overall poor video conceptualization. In the second iteration technical training was spread throughout the semester so that new techniques were available for each of the three videos. More emphasis was placed in teaching students how to storyboard videos and frame their arguments with multimodal elements in the second iteration. This training is necessary because video is a different medium than typically used in engineering communication (i.e. technical reports or diagrams) and the medium is temporally linear with less ability to provide supplementary information. Thus the choice of content and how it is presented are key to clear communication. Furthermore multimodal communication is becoming more important in the engineering workforce as customers and others increasingly use videos to access needed information.

Video projects were supported by two faculty. The course instructor was responsible for advising students and evaluating technical content while an Instructional Technologist in the university's library and information technology division taught the weekly one hour course on video production and evaluated the videos on production value. Student used a dedicated video lab for video editing and had access to the sound booth for voiceovers as well video production equipment. In creating their videos students followed accepted video development practices. In the first year video production was done as a single assignment. This, however, led to very inconsistent video production quality. In the second iteration each video was done in three sequential steps win instructor feedback on the first two steps:

1) A complete storyboard for the video was due two weeks before the video due date. 25% of grade.
2) Draft full length, narrated video due one week before the due date. 25% of grade.
3) Final video ready for public presentation. 50% of grade.

In addition the draft video was shown to peers who also provided feedback.

Evaluating Videos

Student videos were evaluated on both technical content and video production value using a rubric. Both instructors contributed to the rubric. In the first year there was less emphasis on video production values which led to some videos that had such poor quality they were difficult to rate. Production values were more strongly emphasized in video evaluation in the second iteration. Students were given the rubric, Table 1, at the start of each video project.

Besides the instructor ratings videos were also peer rated using a much simpler scale and students were also asked to rank-order the videos from best to worst. The rating scale for peer review was based on a 1-3 scale and was used to gauge how appropriate the video was for the target audience:

1 = I would probably not watch the video again or recommend the video to friends.
2 = I would watch it a second time, and some of my friends might find the video interesting or informative.
3 = I would watch the video many times and think most people would really find it interesting or informative.

Results of Video Intervention

As described previously the rationale underlying having students create videos for the requisite fourth hour was to help them self-explain concepts and become familiar with multiple representations. By its nature this intervention was not designed to have students better understand all concepts related to the introductory electromagnetics course but rather to dive deeply into a few concepts. It was also hoped that that students would benefit by seeing explanations of concepts developed by peers.

Several measures of student performance were analyzed with respect to the rubric scores on the videos. These were performed for both the 2013 and 2014 iterations of the course. Many factors between the two offerings of the course were similar including the content, class sizes, assignments given, relative grade weighting, and the exam structure and format. The instructor had several years' experience teaching electromagnetics at a different institution. Although much of the course was the same the students were different between the two courses and the video assignments were structured differently as discussed previously. It should be noted that given the relatively small number of students in both semesters and the fact that student worked in teams it not possible to make definitive statements about the effectiveness of the intervention from quantitative measures. However below some trends are observed that, while not definitive, point to areas that are worth further investigation.

To see if the video project was related to how well students learned electromagnetic concepts, rubric scores on the video were correlated with scores on conceptual and short answer problems on the final examination as well as other measures of student understanding. In the 2013 iteration the correlations between rubric scores for videos and conceptual multiple choice and short answer problems on the final exam were generally zero or slightly negative, but not at a statistically significant level. In other words students who received higher exam scores may have done the same or slightly more poorly on videos. When the format of the videos was changed in 2014 rubric ratings the explanation student videos made of their formula remained uncorrelated with concept inventory scores and the ability to do short analysis problems. There were, however, small positive correlations between scores on concept inventory type questions and how well students used multiple representations in their videos, but not at a significant level ($r = 0.32$, $p < 0.4$). In summary given the small sample sizes it is not possible to say there is a relationship between more traditional measures of performance in a classroom setting and student ability to express a concept through a video.

To determine if student perceptions of peer videos were related to the instructor perceptions, the rubric *rating* scores of the instructors were compared with how students ranked their peers' videos. In 2013 before changes were made to the way videos were structured there were no statistically significant correlations for either of the two video projects. The only rubric rating factor that was slightly correlated with student rankings was how the video connected with the target audience with $r \cong 0.5$ and $p < 0.2$. In 2014 with videos representing equations through multiple representations there were strong positive correlations between student *rankings* and instructor rubric *ratings* on both the inclusion of representations ($r > 0.8$, $p < 0.05$) and on the quality of explanation of the concept ($r > 0.8$, $p < 0.05$). The ratings of connecting with the audience and the narrative quality were also had moderate to strong positive correlations, but not always at a level that was significant ($r > 0.6$, $p < 0.2$). The instructor rating and peer ranking of video quality was not significantly correlated. It is worth noting, however, that there were relatively strong correlations between scores on all rubric categories. In other words videos that provided a strong narrative and well-structured representations also generally had strong production values.

Overall the clearer guidelines on video content and focus on multiple representations did seem to better align student and instructor perceptions of the video. The generally positive correlations indicate that student and instructors tended to agree on what features made one video "better" than another and the conception of "better" that was most in agreement was that of providing multiple representations and clarity of explanations of the formula represented in the video. It should be cautioned, however, that the small sample size and lack of a controls between the two groups make these conclusions highly tentative.

Looking at across all three video projects in the 2014 iteration the rubric scores were relatively consistent between projects. A more in-depth, qualitative look at student videos indicated, however, aspects of the videos that changed over the duration of the course in response to instructor feedback. For the first set of videos over half introduced some form of misconception through the use of multiple representations. For example one student's explanation of quarter wave matching had different amplitudes of waves from each interface going back towards the generator. A large number of videos also failed to include any form of physical representation. These issues were greatly reduced in the second and third videos. Also throughout the videos students tended to integrate fewer video techniques—e.g. green screen, stop motion—into their videos are relied more on techniques that were proven effective. The rationale for this was mainly due to the large time investment for minimal increase in quality or clarity. Overall the quality of videos improved significantly during the course. Issues that remained problematic throughout all three iterations of the videos were students going through mathematical derivations quickly and the use of non-professional imagery. Note that on the first videos students created they often focused on a particular technique they were interested in such as stop motion or green screens. This novelty tended to wear off for later videos, however, perhaps because of the difficulties and time inherent in using such techniques well.

Conclusions & Future Directions

Student-created videos were implemented in a junior electromagnetics class to improve conceptual understanding. The initial use of videos suggested several ways to improve the experience for students including: shortening videos to no more three minutes duration, using equations from the textbook to introduce concepts rather than have students self-select concepts, be more specific about the use of multiple representations, spreading technical training on video production techniques throughout the semester, and utilizing scaffolding such as story boards to generate more coherent narratives.

The instructors initially intended for students to pursue videos individually but there was a strong preference for working in groups. The first iteration had mostly groups of two with at least one group of three. Team composition sometimes shifted between video projects. During the second iteration the largest allowed team size was two students, but individual videos were also allowed the instructors observed that teams of two were more effective because they were able to brainstorm with a peer.

In their videos students generally engaged deeply with the equation they chose and provided coherent explanations of the underlying concept framed as multiple representations. Physical example and representations seemed to be more difficult for students to incorporate into their videos. The students' ability to communicate electromagnetic concepts through videos improved over the course of the semester for both iterations of the course. Hence the importance of scaffolding and peer reviewing these assignments. Peer reviewing allowed students to help their peers reflect on and articulate their messages through multimodal storytelling. In turn, each student learned how to offer valuable peer feedback outlining and identifying pros and cons in technical conception as well as misconceptions of content.

Investigations of the relationship of rubric-based video scores to other measures of student learning were less compelling given the relatively small sample sizes and variance in rubric scores. The 2014 iteration gave some indication that there was a relation between communicating concepts and scores on conceptual exams, although this was not conclusive. Students and instructors generally rated and ranked vides similarly. Students highly rated videos the instructors judged to be strong in using multiple representations and clear conceptual understanding.

Overall the experience highlighted the importance of structure, peer reviewing, and scaffolding when having students create videos to represent concepts. Such scaffolding is not only important for technical content but also for production techniques and narrative creation (e.g. story boards). One area that more scaffolding is needed is in how to create multiple representations. Students struggled early on to find appropriate representations, particularly physical or concrete representations. Another area more scaffolding would be useful is in how to avoid misconceptions. Several student videos evidenced misconceptions in the final product which could have been avoided had a way to identify misconceptions in the storyboard phase been available.

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Table 1: Representational Video Rubric

	Exceeds Expectations		Meets Expectations		Below Expectations
Explanatory Power	o The presentation connects ideas together. o Video explains the formula accurately and succinctly.	Somewhere between exceeds and meets expectations	o The presentation and choice of the concept is correct but does not succeed in connecting ideas together. o Video explains the formula, but could have been more clear.	Somewhere between meets and below expectations	o The presentation and formula fails to connect ideas together, seems focused on recitation of facts, or is not relevant. o Little explanatory power.
Uses Multiple Valid Representations	o Uses more than four different representations. o The representations clearly explain the concept underlying the formula. o The representations are valid or potential misconceptions identified.		o Uses four representations. o The representations partially explain the concept underlying the formula. o The representations are mostly valid.		o Uses less than two different representations of the concept. Analogies are confusing and/or false.
Supports Learning for a Specific Target Audience	o The content is effectively targeted to undergraduate engineering students. Ideas the audience may not be familiar with are explained well and completely.		o The content of the video is appropriate for non-engineering students. The presentation generally reaches the target audience with a few lapses. Ideas the audience may not be familiar with are explained, but not always clearly.		o The content of the video is not appropriate for engineering students. Content has offensive elements. Ideas the audience may not be familiar with are not explained.
Tells an Interesting and Coherent Story	o Storyboard helped aid identification of resources o Little to no holes were found within the story. o Narration clearly has a well written argument with a strong thesis, introduction, body, and conclusion. o The pace (rhythm and voice punctuation) fits the story line and helps the audience really "get into" the story.		o Storyboard somewhat grasped the connection between images and audio. o Some holes were found within the story. o Narration captures some elements of an essay. o Occasionally speaks too fast or too slowly for the story line. o The pacing (rhythm and voice punctuation) is relatively engaging for the audience.		o Storyboard was not well thought out and did not visually represent connection between images, music, transitions, titles, effects, and/or narration. o Many holes in story were found. o Narration needs work and does not embody the elements of an essay. o No attempt to match the pace of the storytelling to the story line or the audience.
Technical Quality of Audio & Video	o Images create an appropriate atmosphere or tone and appropriately reflect and match narration. o Effects and transitions were used appropriately and consistently and aided in the development of story. o Audio of high quality and aligns with video.		o Images create an atmosphere or tone that matches some parts/narration of the story. o Effects and transitions were somewhat inconsistent or overused yet did not disrupt the overall message of the story. o Audio aligns with video but not of professional quality.		o Little or no attempt to use images to create an appropriate atmosphere or tone. o Effects and transitions were not used appropriately and were inconsistent or distracting. o Audio did not match video or was of such poor quality it detracted from viewing experience.
Appropriate and Engaging (Audience Rating)	o Rated highly by audience comments and feedback. Few negative reviews.		o Mixed reviews of the video.		o Feedback is predominately negative.