September 2017

Robotics Curriculum Enhancement

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An Interactive Qualifying Project Report
submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

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October 13, 2016

Abstract

Both students and professors of robotics engineering require educational media that supplements existing RBE1001 and RBE2001 content. The purpose of this project was to study methods for student outcome improvement, design a solution in the form of educational media, and monitor the efficacy of the product. After determining a set of needs from student and course staff feedback, videos were developed using Final Cut Pro and Motion to supplement the curriculum of the previously mentioned courses.

Acknowledgements

The authors of this paper would like to acknowledge the great deal of time and guidance that numerous instructors and students in the robotics engineering program at WPI contributed to this project. Specific thanks extend to advisors Kenneth Stafford and Bradley Miller for their important role in shaping the final result of this project. We would also like to thank Craig Putnam, Nicholas Bertozzi, and Joseph St. Germain for their participation in the video series produced for this project. Lastly, we express gratitude for the number of student course staff who provided valuable input for this project.

Executive Summary

This report comprises a proposal for an Interactive Qualifying Project to produce videos for use in the Robotics Engineering program at Worcester Polytechnic Institute. The purpose of this document is to explain the motivations and goals of this project, which is to be completed primarily (⅔ units) in the E1 term of Summer 2016. An additional ⅙ unit will be completed in each D16 and A16 for research and feedback, respectively. This report describes the final result of the research component of this IQP, and provides a detailed account of the research that was used to ultimately shape the objectives of this project.

Authorship

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Abstract	Kacper
Acknowledgements	Joseph
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Introduction

This project explores ways to improve student educational outcomes through the use of videos within the context of the Robotics Engineering program at WPI. The Robotics Engineering program is a relatively new and fast-growing addition to the academic landscape at WPI, which was the first institution to offer this discipline as a major field of study.

The field of robotics is notable for its highly interdisciplinary nature, combining aspects from the more established disciplines of mechanical engineering, electrical engineering, and computer science. At WPI, undergraduate coursework in robotics engineering consists of a mixture of classes in all three of these disciplines, as well as a variety of robotics-specific courses that synthesize concepts from these different fields as they apply to robotics engineering.

In addition to the above characteristics, robotics' status as a nascent, emerging field complicates how the subject must be taught. For instance, there is a noted lack of textbooks and other authoritative resources on the subject due to the rapidly evolving nature of the subject. As a result, students and professors are inclined to use more heavily other sources of information, which forms the basic impetus for this IQP. The aim is that by creating videos that cover topics central to the robotics engineering curriculum, this project will effectively create an outside resource that students can use as a study aid.

Using this goal as a guiding principle, there are two central questions that this project seeks to assess and answer. The first is to investigate what particular topics or classes within the robotics curriculum could most benefit from additional resources. As the coursework necessarily draws from disparate fields, there are certainly differences in how well students understand certain topics according to their individual strengths and interests. A stated objective of the program is to bring all students up to some baseline proficiency in all three of the aforementioned core disciplines, so the additional resources provided by this project could be useful in achieving this goal.

The other core issue that this project seeks to address is to gain some understanding of how students learn best from videos and other educational resources, so that the content produced as a result of this IQP is of sufficient quality to be used by students and faculty in Robotics Engineering courses. Naturally, how content is presented has a significant impact on how it is received by its intended audience. It is therefore in the best interest of this project to research not only what content to cover, but also to establish early on how it should be presented to achieve the best results.

There have been multiple IQP and MQP projects in recent years that have attempted to remedy some of the same issues facing the Robotics Engineering program, with varied results. Externally, there is a large body of research on how to teach through videos as well as other forms of media. Thus, it will be important to synthesize information from all available sources in order to make informed decisions about the direction of this project. By reviewing the pre-existing body of information relevant to the above stated goals, this project will be able to make meaningful improvements over past work and ultimately be a useful resource to both student and faculty demographics.

In spite of a relative wealth of useful information that exists as background data, there are still significant opportunities to conduct new research specific to the aims of this project.

While there are past projects that have certainly had some similar goals to this undertaking, the hope for this IQP is to discover novel ways to improve the educational experience of Robotics Engineering students at WPI. To this end, surveys will be conducted of current students in the program to obtain data that can then be used to form conclusions about what subjects to cover and how to cover them. Additionally, close interaction with the faculty of the Robotics Engineering program will be instrumental in shaping the final structure of this project.

The end result of this project—in the form of educational videos—will hopefully be a meaningful addition to the robotics engineering curriculum. These videos have the potential to be used in a myriad of ways both in and out of the classroom, and they give instructors an additional new tool to improve student understanding. Their utility may be such that future students and instructors choose to expand upon the results of this undertaking by creating additional material, just as this project expands on resources that came before it. Regardless of their ultimate role, it is the hope of the student authors of this project that the videos produced in this endeavor benefit both students and instructors, and in doing so fulfill the goals outlined above.

Background

As stated above, the core goal of this project is to meaningfully expand the resources available to students in the Robotics Engineering program at WPI through the creation of videos. In order to assess how to best accomplish this objective, it is necessary to first investigate the impact of educational videos in the classroom, including their efficacy and the myriad of ways in which they can be used. It is equally useful to review the attempts made by previous IQPs in order to understand how to best proceed with this project.

Videos as Educational Media

A major facet of this project is the idea of using videos as a teaching medium as opposed to other, more traditional means such as textbooks. Before such a task can be undertaken, it is necessary to review the body of evidence regarding the efficacy of videos as an educational resource.

To this end, there is evidence to suggest that students learn well from videos (Greenberg & Zanetis, 2012), with some sources suggesting that video lectures may even be better than in-person lectures with respect to student outcomes (Bishop & Verleger, 2013). While this by itself suggests that videos can be effective as a whole, it does little to illuminate what the characteristics of an effective video are.

The answer to this question is more nuanced, but a branch of cognitive psychology known as cognitive load theory gives significant insight into how to create effective teaching materials. The term “cognitive load” refers to the amount of mental effort required when learning something new. At its core, cognitive load theory divides the working memory into three categories—the “intrinsic” load, the “germane” load, and the “extraneous” load. The intrinsic load refers to the relative difficulty of a certain concept. The germane load refers to the amount of mental effort required to make the connections and reach the understandings necessary to fully understand a given lesson. A central idea of cognitive load theory is that the goal of the instructor is to reduce these loads in their lessons as much as possible— this makes the lessons easier to understand for students, but not necessarily easier.

A related conclusion is that instructional materials (such as videos) can be designed in such a way to make less mentally taxing for the viewer, and thus more effective. This is of obvious importance to this project's goal of improving the quality of student learning within the robotics program. A number of ideas have been put forth about how exactly to improve instructional materials, including matching animations to explanations, eliminating superfluous information, and breaking the material down into distinct segments (Brame, 2015). This seems to support the animation-driven videos proposed in this project. When properly designed, such animations add another element of clarity to explanations. A subject such as robotics may be particularly well suited to this approach as there are many topics in robotics engineering that can be difficult to explain with only words. There is also evidence that suggests the optimal length for an educational video is around 10 minutes (Schaffhauser, 2015). Making videos any longer than this may exceed the attention span of viewers as the video goes on, yielding diminishing returns as a video gets longer. This is an area where simple video-captures of entire lectures are ineffective. By breaking content down into easily digestible segments, the learning capacity of students can likely be improved. When paired with animations and high production value, these suggestions form a solid framework for video-based educational content on any subject.

Another major advantage that videos have over traditional lectures is their versatility. An instructor may choose to use videos in a number of different ways. They might use videos with animations in lectures to reinforce previously taught concepts. Alternatively, some of the videos could be used as a review, or to teach requisite background information for an in-class lecture. This would eliminate the need for professors to have to use lecture time to teach or review these concepts, and allow them to focus on more important topics. They may even choose to reinforce those videos with quizzes or other forms of feedback. An instructor may choose to use instructional videos of outside of class as homework or just as a simple learning supplement, The ability of videos to be viewed from more or less anywhere has important implications for their possible use in inverted classrooms—a learning system that is likewise well-suited to the goals of this IQP.

The Inverted Classroom

The inverted classroom-- also referred to as the “flipped” classroom-- is a pedagogical technique where students are expected to cover lecture material on their own time (for instance, by watching a video or reading a chapter in a textbook) (Marlowe, 2012). By using time that would otherwise be used for homework to review lecture material, class time can instead be used to reinforce these new concepts with class discussions, practice exercises, and example problems. This reversal of traditional lecture and homework roles is the root of the term “inverted classroom”, and the model itself has seen dramatically increased use over the last few years (Schoolwires, Inc., 2012).

Much of this growth can no doubt be attributed to the Internet, which is the primary means of distribution for flipped learning content. In most cases, the content is generally produced as video clips that cover lecture content that the students can then watch on their own time. With the prevalence of video hosting sites such as YouTube, it is very easy to get these learning materials into the hands of students. A key advantage asserted by proponents of the flipped classroom is that presenting lecture content in this manner allows students view at their own pace (educause.edu). If, for instance, a student misses something the lecturer says or simply wishes to hear it a second time, they can easily skip back in the video to see it again. Another advantage from the teacher's point of view is that "doing homework in class gives teachers better insight into student difficulties and learning styles" (Herreid & Schiller, 2009). This allows lecture time to be spent more productively by targeting specific areas where students may have issues.

The inverted classroom model can be implemented to varying extents depending on the preferences and needs of the instructor. For example, while some may choose to only have lecture videos for students to view outside of class, other instructors may prefer to reinforce the ideas with comprehension quizzes or other activities.

In order to assess the viability of this model, it is also necessary to look at the body of data regarding the efficacy of inverted learning. To this end, there is a significant body of evidence suggesting that an inverted classroom is an effective way to enhance student learning (Kurtz, Tsimerman, & Steiner-Lavi, 2014) . As mentioned before, a commonly cited advantage to this style of teaching is that it allows students to re-watch the material as often as they please. In addition to improved student outcomes, there is evidence that an inverted classroom model is well received by students and instructors alike, with one study showing 97% of instructors who had implemented such a system in their own classroom would recommend it to a colleague (Strayer, 2015). This suggests that subjectively, the participants of the inverted classroom feel that the system improves their learning—a sentiment that is supported by the data. While this approach is most common in secondary education classrooms, there is reason to believe that the flipped classroom would be equally effective in an undergraduate engineering setting (Mason, Shuman, & Cook, 2013). It is important to note, however, that many of the same sources that seem to generally support inverted learning also acknowledge its drawbacks. For instance, one common issue that this project directly addresses is the large initial investment of time necessary to produce the inverted lecture content.

The concept of the inverted classroom is clearly aligned with the goals and result of this IQP—to improve student educational outcomes within the context of the WPI robotics engineering program. Since there appears to be evidence that this sort of learning style can indeed improve student outcomes in university-level engineering curricula, it seems reasonable to invest effort into producing content that supports that goal. The content produced as a result of this IQP could easily be used in an inverted learning setting by serving as a substantial resource for robotics-related topics tailored to the curriculum for each class. One advantage of producing videos as opposed to other teaching media is that they are naturally conducive to this sort of inverted teaching format, so professors will be able to use them this way if it suits their needs. It seems that this approach is particularly well suited to addressing certain challenges in teaching robotics engineering; namely, the difficulty of bringing all students up to some baseline proficiency in the three constituent engineering disciplines of mechanical engineering, electrical engineering, and computer science. Since more class time could be devoted to evaluating specific areas of difficulty for students (one of the aforementioned benefits of an inverted classroom), professors could more effectively target the areas where students struggle. It is also worth noting that inverted learning content of the type produced for this IQP would allow students to learn at their own pace, which also contributes to improved student learning as mentioned previously. A major goal of the program is to bring all students up to some baseline proficiency, and allowing each student to learn in their own way would certainly help to bring up the scores of students who might struggle in a traditional setting.

Massive Open Online Courses

Massive open online courses, or MOOCs, are a new educational trend that is closely linked to the concept of an inverted classroom. The basic idea of a MOOC is that all of the traditional components of a university course—such as lectures, exams, and problem sets—are distributed over the Internet to a potentially unlimited audience. Anyone who is interested can then access the materials and proceed through the course as a student enrolled in the university would. Though these MOOCs are typically designed and published by accredited universities, students in the course are not usually graded or evaluated in any way and thus no university credit is granted for finishing the course. The actual lecture content for these courses is ordinarily distributed in the form of video lectures—much in the same way content is accessed in an inverted classroom.

This concept of a MOOC has bearing on this IQP in several ways. Even though the intent of this project is not to develop a MOOC for robotics classes at WPI, the video content produced from this project could certainly be used this way in the future. A more likely scenario is that the videos from this IQP could be shared on a public platform such as a video-hosting site and could therefore be accessed even by students who do not attend WPI. While this is obviously not the same as a full MOOC, it could be useful to students elsewhere who are attempting to learn about robotics-related topics. Even if these students are not the intended audience of this IQP, having WPI-sponsored content widely available could be beneficial for the brand of the university.

Past MQPs and IQPs

Multiple IQPs and MQPs in the past have attempted to remedy a perceived lack of content available for extracurricular study within the Robotics Engineering program. These past attempts—which attempted to address many of the same goals as this IQP—are an instrumental source in directing the focus and scope of this project. One prominent example was an attempt to research and ultimately create an educational robotics e-book (Jassmond, 2013). This project also aimed to improve the quality of education within the robotics engineering program, with particular attention paid to the lack of existing resources for robotics education. The idea was that this resource gap could be remedied by creating an electronic textbook tailored specifically to the material in the introductory-level RBE1001 class. Furthermore, it was believed that an electronic textbook would impart some additional benefits—such as cost and portability—over traditional textbooks.

This project partially failed to meet its stated goals for a few reasons. One was the simple fact that the end product was incomplete and considered by instructors to be of insufficient rigor for the course. Students were likewise skeptical of the e-book's utility, feeling it to be of only tangential help on the course's main topics. This suggests that care must be taken to ensure high levels of quality in the material produced for this IQP.

Another problem faced by this project was a lack of concrete data to draw conclusions from. Though surveys and focus groups were conducted, the author admits that a small sample size, time constraints, and limited data sources combine to limit the importance of the collected data (Jassmond, 2013). This is problematic, as it makes it difficult to objectively assess whether the stated goals of the project were met.

A 2013 IQP project with similar aspirations of creating an RBE1001-specific electronic textbook was met with many of the same challenges (Gagnon, Johnson, Weeks, & Bowen-Biggs, 2015). This group reported low rates of e-book use, once again stemming from an incomplete final product and a perceived lack of rigor or accuracy among the content that was produced. They likewise attribute this in part due to a lack of clear and conclusive data upon which to base decisions. The outcome of these previous projects shows that particular attention must also be paid to thorough data-gathering in order to meet the goals set forth for this project.

It also suggests that electronic textbooks may not be a feasible means of improving the robotics engineering curriculum. A major pitfall experienced by these previous projects is that the content in the finished product was perceived as not being sufficiently rigorous or complete for use in actual courses. By enlisting the instructors who teach the robotics courses to guide the content and narrate the videos for this IQP, the possibility of this outcome is mitigated to some extent. Since the professors will be able to use their own explanations in the videos, there is little risk of a concept being misinterpreted by a student author who is understandably less well-versed in the subject. Additionally, these same professors have intimate knowledge of the robotics courses, and should therefore be able to determine what content goes into a given video, and how to present that content for the purposes of WPI robotics engineering classes.

Preliminary Surveys

Before the main objectives of this IQP could be articulated, it was first necessary to conduct research to gauge the needs of the robotics program. While the research detailed in previous sections is helpful in illustrating the possible ways the result of this IQP could be used, it is imperative to tailor these methods to the specific environment of the WPI robotics engineering program. This is only compounded by the fact that in the previous IQPs described above; complete and accurate data collection (or lack thereof) was of critical importance to the end result. For these reasons, it was first necessary to investigate the elements of proper survey design and information gathering techniques to avoid some of the pitfalls encountered by other projects.

Before an attempt could be made to collect data, investigation was conducted into surveying and data collection methods to ensure accuracy and completeness. One critical aspect of survey development is to ensure that the right questions are being asked (Ross, 2002). This starts with succinctly articulating the goals of the survey, and then asking questions that yield answers that directly address the issue. Asking questions that are only tangentially related to the issue do not yield meaningful data.

A related point is that it is important to design the questions themselves correctly; that is, so that there is no ambiguity about what is being asked. Similarly, no technical jargon or leading questions should be used (Harrison, 2007). This only serves to confuse participants or goad them into giving predetermined answers, defeating the entire point of a survey. From a data collection standpoint, closed-ended questions are preferable to open-ended ones, as closed-ended questions are less prone to misinterpretation and are easier to analyze compared to the more qualitative open-ended questions (Harrison, 2007). However, open-ended questions can be better for gauging a participant's opinion more concisely and accommodating unexpected answers (Thayer-Hart, Dykema, Elver, Schaeffer, & Stevenson, 2010).

Another consideration is the actual method of surveying. The accuracy of a given survey is related to both the randomness of the surveyed population and the number of people surveyed (Ross, 2002). The randomness refers to how representative a sample population is of an entire population. For example, if one was attempting to determine the opinions of robotics students on a particular issue but only surveyed female participants, then the resulting data would not necessarily be representative of the entire robotics student body. Instead, the data would likely be biased towards the opinions of the overrepresented group. For this reason, it is also important to survey a large enough number of people to ensure a representative sample. If only two students are surveyed out of a total of 1000, then the data collected is certainly not representative of the opinions of the entire student body. It is therefore of utmost importance to ensure a representative sample for the surveys used in this IQP.

Though surveys can provide a wealth of qualitative data surrounding a given issue, it is sometimes also necessary to get a more qualitative assessment of the problem being addressed. In the case of this IQP, it was decided that interviews with professors and other course staff might provide useful information for this project. While these interviews yield information that is undoubtedly more difficult to analyze in a procedural way, it is extremely useful in comprehending some of the issues this project seeks to address. Since this project is intended to address the needs of both professors and students, these interviews are also useful to gather information about the instructor target group compared to surveying, which is intended for students.

To assess the effects of this IQP, it was also deemed important to collect data both before and after producing content. This will hopefully show some of the ways in which the robotics community benefits from this project. The methodology and results of these data collection attempts can be seen in later sections of this paper.

Methodology

The ultimate goal of this project is to produce a set of educational videos for the WPI robotics engineering program that will have tangible benefits for both students and professors. In doing so, there are a few main questions that must be addressed. Namely:

- What areas of the robotics curriculum could benefit the most from a series of educational videos?
- In what ways do videos present advantages over traditional teaching methods? How can we make the most of this medium?

Completing a review of the existing literature and research surrounding these topics is instrumental to understanding the context behind this project. However, it is likewise necessary to conduct independent research into the specific issues faced by the robotics engineering program at WPI in order to answer these questions fully. By starting the investigation here, we can uncover information that will in turn be useful in guiding the development of high-quality videos.

Preliminary Research

In the term leading up to the main production phase of this project, extensive information gathering was conducted to understand the particular needs of the WPI robotics engineering program. As with any discipline, there are certain areas of the robotics curriculum that are more difficult for students to master. One primary goal of this stage of the project was to ascertain what exactly these problem areas were. The other goal was to devise the most effective way to present these concepts in the form of videos. These challenges, reflected in the questions posed above, formed the basis of our initial research.

Among the first challenges in this process was deciding how to actually collect information. Given that this project is intended to benefit students and faculty, any data collection process needed to gauge the opinions of both these constituent groups. Surveying was regarded as a particularly effective way to gather quantifiable data from many different people. However, surveying and questionnaires are of limited use in situations where the sample pool of respondents is quite small. Since there are relatively few instructors (at least relative to the number of students in robotics classes), it was more effective to gather opinions from these course staff members in formal interviews. These interviews yield feedback that is more qualitative in nature, but still useful in shaping the direction and scope of this project. The considerably larger pool of students in robotics classes was better suited to surveying via questionnaire, given the impracticality of interviewing each student one-on-one. Given these factors, dividing the methodology between students and instructors in this way was deemed to have the highest potential for gathering useful data.

After developing this framework of interviewing and surveying, we were then left to decide which questions to pose to students and instructors. Our research into survey methods and past projects (see Background) indicated the importance of asking questions that directly address the issue being investigated. With this in mind, we sought to craft a line of questioning that only gave us information that contributed to our decision-making and avoided inquiries with only tangential importance. In order to improve the definitiveness of the collected data, we likewise decided to eliminate open-ended questions wherever possible. As previous research suggested, closed ended questions are less prone to confusion by participants, and also yield answers that are easier to quantify.

The complete survey that was drafted in response to these considerations can be found in Appendix A**.** Though the exact line of questioning will be omitted from this paper, it can be observed that all questions are thematically tied to the previously stated goals. For instance, a few of the questions ask respondents to select the most difficult topics from a handful of different robotics classes. An online surveying tool was used such that respondents were first asked which robotics classes they have already taken (or are currently taking), and then only questions about these classes were displayed while omitting questions about classes they have not yet taken. This helps to avoid false answers in the data. Though these questions were highly important in deciding what topics to cover in the videos, a detailed discussion of the data is left to the Results section of this paper.

Other questions inquired about students' opinions on educational videos, especially relative to other forms of teaching. For example, some of these questions asked students' opinions on optimal video length, or how educational videos compare to traditional lectures. While our previous research already gave some insight into these questions, we decided it was important to distinguish these findings for ourselves, especially within the specific environment of the robotics program at WPI.

The end of the survey mostly focuses on demographics-related questions. Respondents were asked their class year and major, for example. Robotics classes often include a broader array of students that just robotics engineering majors, so these sorts of questions were instrumental to better understanding the audience. It is important to note that while the primary target of this project is students and professors, there are other groups of secondary consideration. Our initial research suggested the possibility of the final videos being used by students outside of WPI either as standalone references or as part of a MOOC-like system. One audience that was discussed in particular was students participating in high-school robotics competitions such as First Robotics Challenge. Ultimately, we decided to mainly target students at WPI while still considering the possible benefit to these secondary audiences in selecting our video topics. In accordance with this decision, a few questions ask respondents if they have experience with any of these outside robotics organizations and if so, what topics might be useful for that audience. As before, a more detailed analysis of the responses can be found in the Results section.

We submitted our final survey to the WPI Institutional Review Board (IRB) for approval before any students were questioned. This body regulates surveys to protect the personal information of students, and all surveys must be submitted for review and cleared before they can be conducted. The survey developed for this project was approved, and we took care in our questioning to assure students of their anonymity and prevent any identifying information from being collected.

With the questions finalized and approval received, the surveys were presented to students in the robotics lab during their weekly lab period. The labs were filled out online on a number of computers set up for the purpose of this survey. Students were incentivized to fill out the survey with a prize of one pastry for their participation. This process was used for the lab sections in both the freshman and sophomore-level robotics classes that were being offered during that term. Concurrently, IQP team members were visiting the robotics lab intermittently and asking other robotics students to fill out the survey if they hadn't done so already.

Many aspects of the survey collection process were influenced by our earlier research into proper surveying methods. Namely, irrelevant and confusing questions were avoided, and we tried to make our survey population as random as possible so as not to introduce biases into our results. Still, biases may persist. For example, under the methodology used for this survey, it is possible that the data may be biased towards students who were comfortable taking the survey. Another consideration was to gather enough responses to have a representative sample. Ideally, all members of the target population would be surveyed, but this is generally impractical. In lieu of this ideal, we attempted to gather as many responses as possible from the population of students who have taken robotics classes at WPI. Using the collection process detailed above, these efforts resulted in **(how many?)** responses, which is a considerable sample size of the roughly **(how many?)** students in the robotics engineering program.

During the same general time period that these surveys were distributed, educators in the robotics engineering classes were interviewed for their opinions and recommendations for this project. Professors [1][10][11][14], student course staff [4][9], and a robotics lab technician [13] were interviewed individually. The line of questioning for these interviews was less formalized than in the survey, but the same themes and general ideas remained consistent. In a general sense, participants were asked about which areas of the robotics engineering courses could benefit the most from supplemental material and how this project can best benefit the robotics community at WPI and elsewhere.

Because professors are intended as a primary beneficiary of this project, four of the professors teaching courses within the Robotics Engineering program were asked their opinions on these matters. Owing to the shortcomings of previous projects, each indicated that all resources developed as part of this project must be sufficiently rigorous in order to have practical applications in the robotics classes. Also, unique areas for improvement were mentioned reflecting the professor's background. For instance, professors whose background was in electrical engineering understandably gave answers that put more emphasis on electrical engineering concepts in the robotics engineering classes. However, some common themes established throughout these interviews were a desire for focus on some of the more fundamental concepts in robotics engineering, early preparation for the junior-level RBE3001 and RBE3002 courses, and a desire for more practical applications of some concepts taught in robotics engineering courses. Some professors indicated that quizzes and homework assignments might be beneficial for reversed-classroom settings [1][11]. Moreover, a need for corresponding homework assignment or additional exposure to the video content was suggested. This was suggested to raise the general baseline of student knowledge, allowing the professor to go deeper into lectures or provide additional examples. [10] By introducing concepts in videos, lectures become clearer because students enter the class already having a general understanding of the topics covered. This has special implications in RBE1001 because this course provides an introductory level exposure to a large number of topics. [15]

As mentioned, students who serve as assistants in these courses were also consulted. Their perspectives yielded valuable insight as they interact closely with the students in the robotics courses, and thus have a particularly intimate understanding of the areas that students have difficulty with. One of these student assistants had previously done work in a similar vein to this project, creating educational videos intended for use in the robotics courses. This individual was asked for his advice on video production and how to maximize the effectiveness of the produced content. Indeed, the videos produced in this earlier effort were an excellent resource of inspiration in creating videos for this project. Accordingly, the student surveys included questions asking whether participants had seen any of these previous videos and what they thought about their quality and usefulness.

At the conclusion of this data collection effort, we were left to decide how many videos to create, and what these videos were to cover. One main issue that we considered in making this decision was the relative benefits of focusing on one particular class, versus spreading out the video content to cover concepts from a variety of robotics classes. Spreading out the video content to cover multiple courses, would allow us to select a greater variety of requested topics. Conversely, focusing on one specific course would allow us to make a greater impact on that particular class. After conferring with our advisors, we decided to focus on the introductory-level RBE1001 course, reasoning that this course stood to benefit the most from this project and was thus deserving of the bulk of our efforts. However, we decided to choose concepts that recurred throughout the robotics course sequence and were highly requested by students. Operational amplifiers, for example, are covered in a few different robotics courses in a variety of different applications. In each course they are covered in, students also reported that operational amplifiers were a difficult concept worthy of extra attention. Thus, we decided to make at least some series of videos on topics like this that would progress from the introductory-level course to intermediate-level concepts.

After deciding to focus on the introductory robotics course, we also elected to create videos on both the theoretical and practical aspects of the curriculum. Some videos would be narrated by professors and focus on lecture-based concepts, while others would be narrated by project members and lab staff with a focus on lab-related topics, which is an important element of the RBE1001 course. After weighing these ideas against other considerations, such as the time and resources allotted to complete this project, the following list of videos was decided upon for this project:

- Operational Amplifiers (3 videos)
- Force Analysis (3 videos)
- Linkages and Mechanisms (3 videos)
- Introductions to 4 RBE1001 laboratory assignments (4 videos)
- Overviews of:
    - Using a laser cutter (1 video)
    - Using bench top lab equipment (2 videos)

The above list represents the videos deemed to be of most importance to this project. If time and resources remained, additional videos might be produced on other highly requested topics, such as phasors. Of the videos enumerated above, the first three series (on operational amplifiers, force analysis, and linkages) would be narrated by professors who teach the course. This setup helped to ensure that the quality of the material and accompanying explanations were sufficiently rigorous, which was an issue in previous student-produced projects. Other videos, such as the ones on the use of lab equipment, could be narrated by the students completing this project given their relative simplicity. The lab introductions were intended to be narrated by the robotics lab manager, in order to prevent him from having to explain the assignment repeatedly during the lab period. By having the students watch the introductions on their own time before lab, they could have more time to actually complete the assignment and ask other questions of the lab staff.

Production

With topic selection complete, the focus of this project transitioned into producing the actual videos. The production process was composed of three essential elements: scripting, filming, and animating. Each of these tasks was of critical importance to creating a high-quality end result.

Before any video scripts could be written, we sought professors to narrate the planned series of videos. Three different professors were arranged to narrate the three series that required professional narration. All three of these professors were faculty of the robotics engineering program at WPI who taught the RBE1001 and intermediate-level RBE2001 courses, since they were understandably the instructors with the most intimate knowledge of the curriculum.

After securing commitments from these professors, we were left to decide the best way of selecting topics and generating scripts for the videos. While the content of the videos was ultimately our decision, we also sought to give the professors enough freedom to make sure the scripts presented the concepts covered in the right way. For each series produced, the process generally began with a general conversation between the narrating professor and the students involved in this project. This initial meeting largely focused on what topics to cover in the series and how to divide these topics up such that they fit into roughly 10-minute videos, which was judged to be the most effective length based on our previous research.

Once the breakdown of topics had been agreed upon, we drafted a storyboard for each video that detailed how each installment would progress scene-by-scene. These outlines included our ideas for what animations would be on the screen during each scene, along with an accompanying summary of what the narrating professor would discuss. However, we stopped short of trying to draft a script for professors to follow verbatim, opting instead to allow professors to use their own words and explanations. This process allowed us to control the direction of the project while still allowing professors to ensure the content was up to the standards of the course the videos were intended for.

These initial storyboards were typically revised multiple times in subsequent meetings with professors before they reached their final state. Some professors opted to take the storyboards and write out a full script for their scenes, while others preferred a less scripted approach.

Filming began shortly after the revision process was completed. Our previous research had indicated the importance of high production value in educational videos, so care was taken to ensure the quality of the film we captured. All of the videos were shot on DSLR cameras with an external microphone to deliver high-fidelity video and audio. Other considerations included using the same camera placement between filming sessions and recording multiple takes to allow for more flexible editing. We likewise tried to adhere to basic principles of cinematography such as avoiding direct light sources in the frame, and improving the composition of the shot by asking the professor to clear their desk before filming.

Animation usually started concurrently with filming, as we became able to match visuals to the words of the narrator. The animations were included because they were an effective way of explaining engineering topics that are sometimes difficult to describe with words only. Previous research had suggested that pairing words with effective visuals might be a powerful way to improve student learning. Likewise, the frequent on screen movement created visual change that helped to keep the viewer's attention. These animations were thought through carefully and coordinated between videos to maintain stylistic consistency, and were the most time consuming portion of the project by a large margin.

The videos dedicated to lab-based practical concepts generally required less intensive animation than the lecture-based ones. The four introductions for the RBE1001 lab assignments were narrated by the lab instructor, with the production process largely mirroring the process used with professors. However, since the videos were intended to replace the speeches delivered at the outset of each lab, they required less scripting owing to the lab instructor's familiarity with the focus of the video. Given their straightforward nature, they were practically devoid of animation.

The only videos that were narrated by students were those that focused on the use of laboratory equipment. Owing to their less technical nature, we decided that it would be appropriate to script and narrate these videos independently. However, we still discussed our script with the robotics lab manager, and in the case of the laser cutter video, with the director of the manufacturing laboratory at WPI. This helped to ensure that the information communicated in these videos was correct and helpful to students.

Product Evaluation

After the developers reviewed the content, data about the utility of the product was obtained. Student feedback was determined to be a useful data point yielding information about overall quality and efficacy of the videos. This is because students are a subset of beneficiaries and will ultimately utilize the content developed each term. Additionally, the perspective of the viewer is essential to developing a quality video for application, so an evaluation of both clarity in communication and quality of production could be obtained through polling.

A survey asking students for feedback about the videos was developed. Students who had enrolled in RBE1001 and RBE2001 classes comprised the sampling population. Short answer questions were used because they offer unrestricted responses and feedback. Brevity was emphasized to increase the quality of the responses; long surveys were suggestive of decreased participation. Groups of five to ten robotics students were shown a video and asked to answer the questions given 15 minutes. Their responses were anonymous and limited to a paragraph in length.

Results

The course taken by this project yielded some meaningful answers to the questions that we initially set out to investigate. Our initial round of data collection made clear the opinions of students and professors in WPI's robotics engineering program. By synthesizing this data with what was already learned through previous research, we were able to create videos that addressed the needs of the program. This chapter details the outcomes of these efforts, as well as our attempts to validate them with additional surveys and interviews after the videos' completion.

Outcomes of Preliminary Student Surveys

As detailed in previous sections, the video making process was preceded by an attempt to gather information from students and professors to ascertain the answers to two main questions:

- What subjects in the robotics engineering curriculum could benefit the most from additional content?
- What makes an effective educational video? In other words, how can we make the most of this medium?

Our efforts to answer these questions took two forms—surveying students in robotics engineering classes, and interviewing professors who teach those classes. The survey included questions directly related to the above two inquiries, and was intended to yield quantitative data that could be useful in deciding what videos to make and how to make them. The survey and accompanying results can be found in their entirety in Appendices A and B.

For example, numerous questions that were posed to students asked what topics were particularly challenging in each of the RBE1001, RBE2001, and RBE2002 courses. The list of topics presented in the survey was taken from the respective syllabus for each class. The structure of our survey was such that the question would only be displayed if, in a previous question, students reported being enrolled in the class or having taken it in the past. It is also worthwhile to note that the listed topics represent a diverse array of subjects, drawing from the disciplines of mechanical engineering, electrical engineering, and software engineering. This is reflective of the interdisciplinary nature of the robotics engineering curriculum, and indeed the field as a whole.

For the RBE1001 course, some of the topics that students reported having the most difficulty on were operational amplifiers, force analysis, embedded architecture, circuit design, and general programming topics. For each of these answers, at least 25% of respondents reported finding the topic difficult. In the case of this course, the most frequently cited difficult topics don't seem to bias heavily towards any one of the aforementioned constituent disciplines that comprise robotics engineering. Nonetheless, these subjects were selected as candidates for additional video content.

In the intermediate-level RBE2001 course, respondents frequently reported difficulty with operational amplifiers, linkage position synthesis, energy storing circuits, PID control, Bluetooth protocols, and the combined topic of diodes, rectifiers, and 555 timers. The responses to this question show some interesting trends. Bluetooth protocol was the most selected answer by a fair margin, with 50% of respondents reporting difficulty with this topic. The second most selected area of trouble was with diodes, rectifiers, and 555 timers, with 42% of respondents reporting difficulty. However, we believe this result can be partially explained by the fact that this topic is typically covered near the end of the course, and in many terms insufficient time is left to cover it in sufficient detail. While this doesn't disqualify it as an answer, it certainly suggests that students may be reporting difficulty simply because the topic wasn't covered when they took the class and are thus unfamiliar with it.

Also interesting is the fact that 36% of respondents indicated difficulty with operational amplifiers, making it the third most reported answer. Given that operational amplifiers were also frequently reported as a difficult topic in the RBE1001 course, this may seem counterintuitive. An outside observer might infer that after covering a topic twice in two separate courses, then students should have little difficulty with it. This problem can be resolved with the observation that operational amplifiers have a myriad of uses, and they are presented in a variety of different applications throughout different robotics engineering courses. Thus, what they are used for in one course may not necessarily be what they are used for in the next. However, there is of course some relation between what is taught in different courses given that the theory that underlies the function of operational amplifiers is the basis for all their different applications. The fact that students consistently report trouble with this topic indicates that it might be valuable to produce video content for it.

The final class that this question was asked for was the other intermediate-level robotics class, RBE2002. For this course, the related topics of phasors and analog signal filtering were the most reported topics by a large margin, with 62% and 46% of students reporting difficulty, respectively. Also covered in this course are new applications of operational amplifiers, which appeared once again as the third most reported topic, with 31% of students indicating difficulty. This reinforced the observation that the study of operational amplifiers continues to be a difficult area for students. The high level of responses for phasors and analog signal filtering seems to indicate that this is by far the most difficult aspect of the course for students, so it might also be worthwhile to produce videos on these subjects.

Other questions in the survey examined the opinions of students on videos as an educational medium. Several questions queried students about past videos produced for the robotics program. Respondents were first asked whether they had seen any of these videos, and if they answered affirmatively, then several other questions were displayed. Of the 57 surveyed, 33 reported having seen at least one of these past videos.

One question asked of those who had seen the previous videos was how they would rate their overall pacing. The distribution of student responses to this question can be seen below in Figure 4.1.

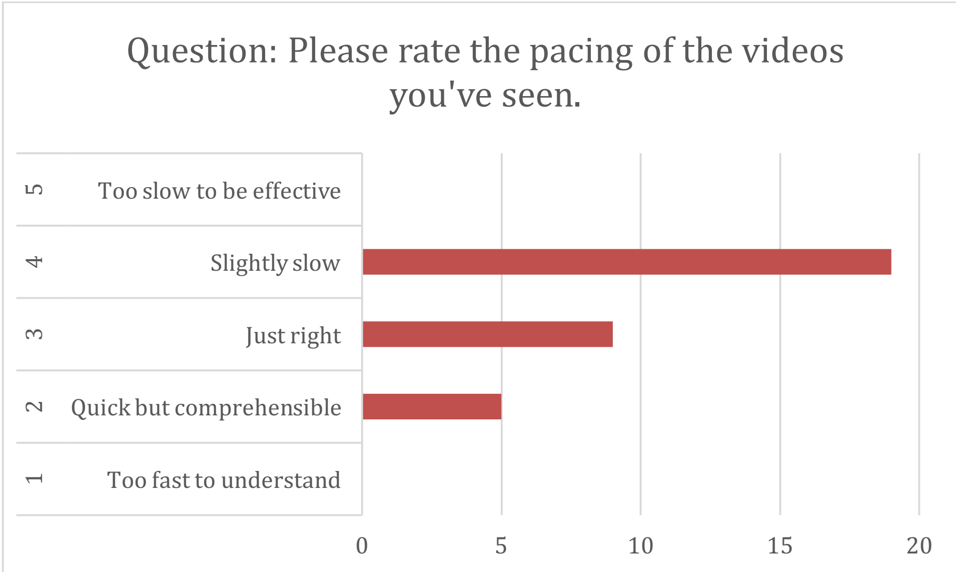

Figure 4.1: Distribution of student responses to survey question 5

The responses to this question indicate that a large number of students felt that previous videos were somewhat slow in their pacing, with an average response of 3.42 on a five point scale with 1 being extremely quick and 5 being extremely slow. It is notable, however, that no respondents reported feeling that the videos were extremely slow or extremely fast in a way that would render them unusable. This suggests that the pacing of previous videos might have been slightly slow, but was at least close to ideal. Thus, videos made in this project are probably best served by moving at a slightly faster pace without significantly altering the tempo.

Respondents who had seen the previous videos were also asked how they used those videos. A breakdown of the multiple responses to this question is shown in Figure 4.2.

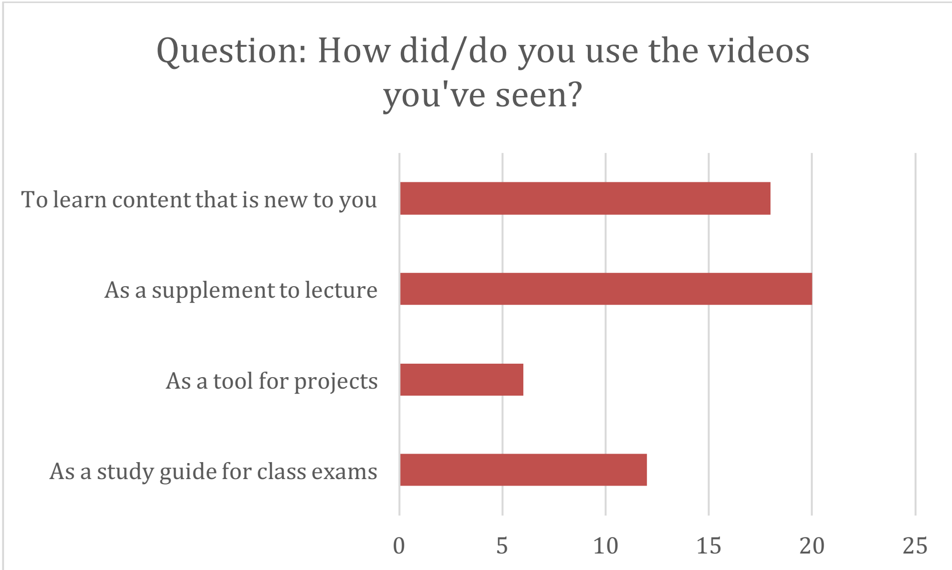

Figure 4.2: Breakdown of student responses to survey question 6.

The answers to this question are fairly evenly distributed, indicating that students encountered these educational videos in a variety of applications. They most often reported using them as a supplement to the professor's lecture, or to learn content that was altogether new. Since it seems likely that any future videos will likely be used for these purposes, it makes sense to develop the new content with these uses in mind.

Other questions were not dependent on whether respondents had seen previous videos, and were instead focused on educational videos more generally. For instance, one question asked students how effective they felt videos were compared to other forms of teaching. The responses to this question are shown below, in Figure 4.3.

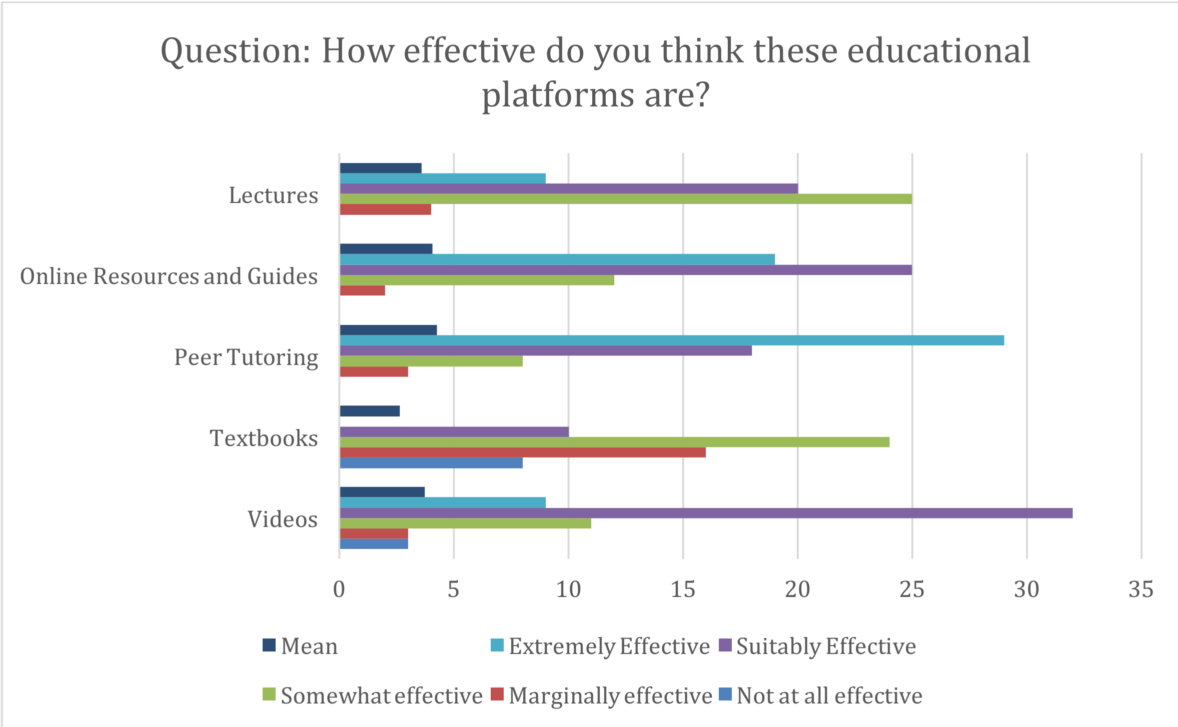

Figure 4.3: Breakdown of student responses to survey question 1.

The responses to this question yield some surprising results. Judging by the mean score for each platform (on a five-point scale, with 5 corresponding to extreme effectiveness and 1 to minimal effectiveness), it appears that students feel peer tutoring to be the most effective educational method, with a mean score of 4.26. Videos were reported as the third most effective method, behind online guides and resources. While it is true that videos only ranked third in this comparison, this information may still bode well for this project. It is worth noting that videos outscored both textbooks and traditional lectures, which comprise the most common forms of teaching in most classrooms. This suggests that producing videos will likely have more impact than producing an e-textbook, as previous projects have attempted. Depending on the final hosting location of this project, it may also very well qualify as an online resource and guide itself, both for students at WPI and those elsewhere. The highest-scoring option—peer tutoring—was not a practical option for this IQP, and though its effectiveness cannot be denied, this project primarily sought to find other, more permanent, educational strategies.

In an attempt to corroborate what was learned during the literature review, students were also asked what they felt the optimal length of an educational video was. The results, shown in Figure 4.4, show that students overwhelmingly reported 5-10 minutes as being ideal. This corresponds closely to the oft-mentioned 10 minute figure cited in the literature.

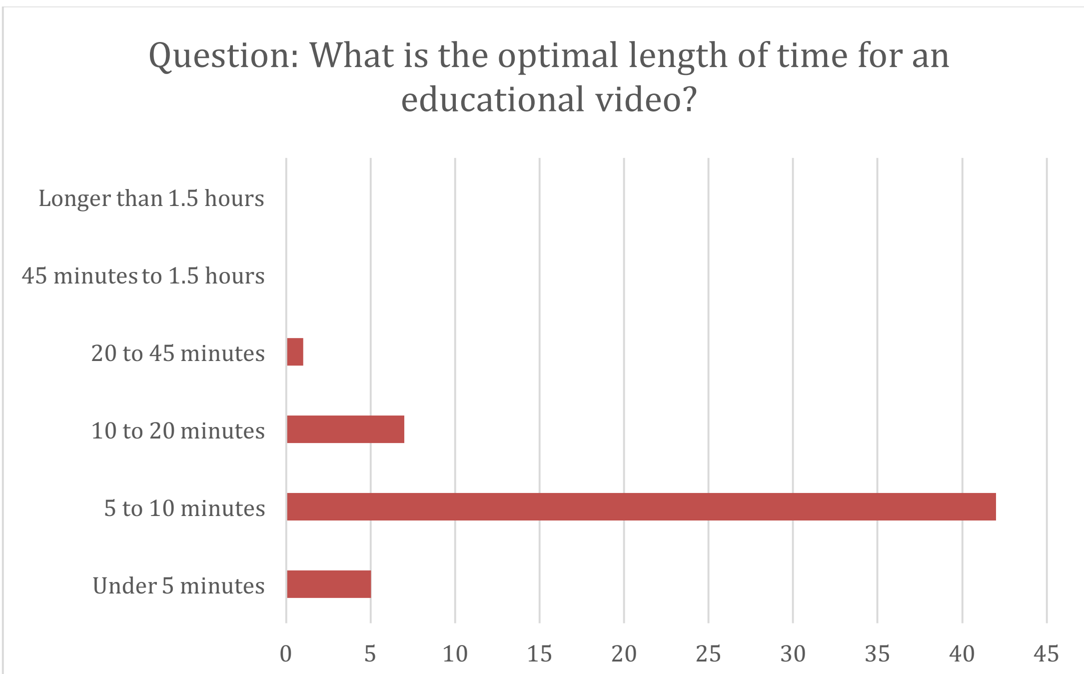

Figure 4.4: Breakdown of student responses to survey question 2.

A final video-related question compared various forms of educational videos. Students were asked to rate, on the same five-point scale with 5 corresponding to most effective and 1 to least effective, the relative educational merit of the following three types of videos: those that consisted only of a narration by an on-screen speaker, those which included slideshow-style notes with voiceover, and those which included some animation or application of the topic being discussed. The responses to this question, which are visualized in Figure 4.5, indicate that students strongly prefer videos that include some sort of animation or practical application. Videos with animation received a mean score of 4.33, compared with below 3 for both of the other two options. This suggests that including animations in the videos produced for this project might be a valid means of increasing their educational worth.

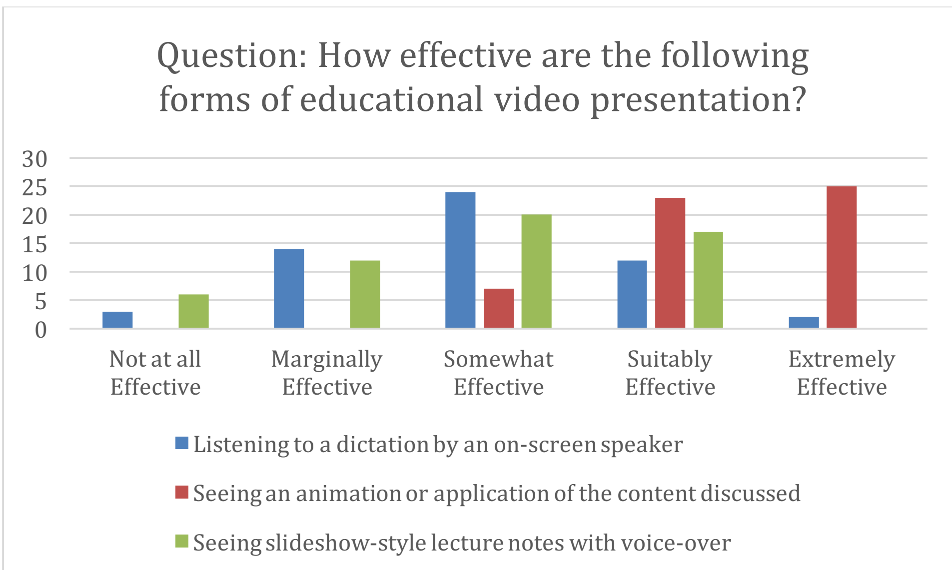

Figure 4.5: Breakdown of student responses to survey question 7.

Outcomes of Preliminary Staff Interviews

Concurrent with the surveying of students in the robotics engineering courses, professors and other course staff within the program were also sought out for information that could be used in this project. These inquiries generally took the form of in-person interviews, where the general line of questioning sought to address many of the same issues as the student survey, albeit in a more qualitative way.

On many points the opinions of professors agreed with both previous research and the data gathered from students. One example of this is on the issue of video length, where most felt that around 10 minutes was an ideal length. On other issues, however, there was some disagreement. On the issue of topic selection, for instance, one professor (Stafford, Professor, 2016) indicated that some of the topics that surveyed students indicated as not difficult were in fact still areas of trouble for many. In the RBE1001 course, student responses indicated that force analysis was a difficult topic for many, though not quite as difficult as some others. This professor, who taught the course, indicated that students struggled with this more than the data might suggest, as evidenced by their performance on quizzes in class. This same professor also indicated that linkages might be another area worthy of additional attention, even though students did not report this topic as being particularly difficult.

A general recurring theme in these interviews with course staff was an acknowledgement that computer science-related topics were perhaps less suited to the sort of animation-heavy videos proposed in this project. The other two constituent branches of robotics, mechanical engineering and electrical engineering, cover topics that are decidedly better suited to describing via animation. While many students report some computer science-related topics to be difficult and needing of additional educational content, the discipline as a whole is often difficult to relate in an overtly visual way.

Video Selection and Production

The task of selecting which videos to produce was approached with the cumulative knowledge gained through previous research, interviews and surveys with professors and students, and our own assessment of the problems being addressed. The original list of selected videos is enumerated in its entirety in the methodology section of this paper.

One key consideration in making this decision was determining how to weigh the competing opinions of students and professors as indicated by the collected data. In general, an attempt was made to first select topics where all parties seemed to be in agreement, such as on the topic of operational amplifiers. Given that this was a topic that was consistently indicated to be problematic by students, and likewise by professors, it was quickly decided that a series of videos should be dedicated to it. Some subjects that were highly requested by students—such as PID control—were excluded from this project because there are already WPI-produced videos on the topic.

In general, the videos produced for this project were grouped into series rather than being stand-alone products. This allows the content to go into sufficient depth for a university-level course that may not be possible within the confines of a single ten-minute video. It allows for additional elaboration on a subject without resulting in significantly longer videos, so students can watch one video at a time. Many of these series extend beyond the scope of a single class, so producing series allows for natural breaks to delineate content that may be appropriate for one class over another.

On a related point, a decision was also made to focus on the RBE1001 class over the intermediate-level RBE2001 and RBE2002 courses. This judgment, which was mentioned earlier in the methodology, was largely an attempt to heighten the impact of this project.

The rationale was that by focusing on a single class to the exclusion of others, the benefit to the targeted class would be more tangible.

This decision had a significant impact on the final selection of videos. As mentioned, an attempt was made to choose topics that are covered in RBE1001, but are also covered in the intermediate-level courses. This way, a series of videos could be produced where the first videos would be appropriate for new robotics students, and when they reached the next courses, the same subjects would be covered in greater detail and the previous videos would still be available as a review. The series of videos on both linkages and operational amplifiers are examples of this approach. The series on force analysis is exclusively targeted at the RBE1001 class, and is a response to instructor concerns about student understanding of the material. While it is not covered in any greater detail in the intermediate-level courses, force analysis is certainly an important topic for these classes and thus the videos will likely be useful to students in these courses as well.

Once the decision to focus on the RBE1001 course was made, it also became necessary to determine a balance between the practical and theoretical elements of the course. RBE1001 has a significant laboratory element where students exercise the concepts learned in lecture and build robots of their own. Given the significance of this aspect to the overall composition of the course, it was natural to devote at least some of the videos produced in this project to laboratory topics. The robotics lab manager—who runs the laboratory elements of the RBE1001 courses—recommended pre-recording his introductions to the course as a series of videos. The idea of this effort is that it would save him from having to cut into laboratory time at the outset of each lab period by repeatedly explaining that week’s assignment. By watching videos ahead of time, students could come to lab already having an idea what to do. That way, their time in the laboratory could be spent more productively and the laboratory staff would have more time to help students with the difficult parts of the assignments rather than spending time explaining it. Another series of videos was produced to supplement these laboratory intros. These videos explained the proper use of laboratory equipment such as oscilloscopes, function generators, power supplies, digital multimeters, and laser cutters. Tools that are often used together (such as oscilloscopes and function generators) were grouped into a single video, resulting in three total videos on these topics. The intent was to help students become familiar with tools that might otherwise be difficult to use. Together with the laboratory intros, these videos have the potential to save an hour of laboratory time for each student. This estimation is based off the combined total length of the seven videos, and does not account for the additional effort saved by other factors, so the actual benefit is likely greater.

This process of choosing topics resulted in the final list of 17 videos listed in the methodology chapter. This determination was made by weighing the topics desired by students and professors against how much time and resources could be dedicated to this project. However, in some cases, this total required adjustment as goals shifted. One prominent example of this was the series of videos on operational amplifiers, which ended up being adjusted from three videos to seven. This was done in order to fit all the content from the RBE1001 course to RBE2002, which quickly became too much to fit into three 10 minute videos. The other series that required adjustment was the series on linkages, which was extended from three to four videos for the same reasons.

Post Production Survey Results

The data from student responses was used as a general interpretation of efficacy and product quality. Of the 17 student responses collected, 16 mentioned animation as a useful presentation technique and emphasized that adding more visual aids would improve the video. All samples noted that the quality of the video was adequate for this application, but two mentioned that this media is not accessible to those who are hearing impaired in its present state.

Additionally, half of the responses noted the use of increased viewing speeds. This presents a new need on the part of students; the videos must be clear and informative while maintaining brevity. Half of the samples mentioned that visual elements (including animations and white-board style equations) were useful. One sample suggested the use of a live whiteboard for active actors. Four responses noted that brevity was an advantage of the video and that this content did indeed supplement existing knowledge. All respondents suggested that the overall quality of the content and video was acceptable for use by robotics students.

Conclusions & Recommendations

The interpretation of our results reveals data about which subjects in the robotics curriculum benefit most from the content produced and incorporates elements of educational video production that were found to be effective for the sampled student body. Thus, content with utility was developed for the introductory level robotics courses. Through preliminary student and course staff surveys and interviews, topics that were naturally explained with visuals and applicable to introductory robotics courses were selected for production.

Further, these data revealed information about presentation styles including animation that were useful for explaining the selected topics. In this way, series of videos were developed to aid with the explanation of introductory electrical and mechanical topics. The preliminary survey results and comments from course staff revealed conceptual difficulties in the analyses of linkages, free body diagrams, and operational amplifiers.

These concepts were effectively explained through video because they require graphical analysis techniques and prerequisite knowledge of hardware. The survey data collected suggested that students struggled repetitively with these analysis concepts, and professors recommended these topics because of previous successes with video explanation and need for supplemental content used outside of lecture or in the flipped classroom setting. Data about the usage of video by students was inconclusive, but interviews with professors suggested applications in a flipped classroom setting, for project development, and as lecture supplements.

To meet the needs of student viewers, the content developed was concise and segmented. This allows students to be able to quickly refresh themselves about the knowledge of a topic at their own paces, and it allows professors to schedule videos in parallel with lectures as the content was taught. Thus, the videos for lecture content were kept in a range of 5 to 10 minutes, while the lab videos condensed the introductory explanation for each session to 15 minutes.

Interviews with professors and course staff were necessary to understand the needs of these beneficiaries. They revealed that students can often overestimate their knowledge of a subject, evidenced in poor project outcomes, and they struggle repeatedly with the same concepts throughout their undergraduate education. To address this, the series of videos were produced to be modular; they are stand-alone viewable to address specific issues but can be used sequentially when teaching a course or reviewing general material about a subject. This way, both beneficiary groups find an application for the product developed.

Lab introductory sessions also benefit from the content produced in this project. Interviews with lab staff indicated inconsistencies in pre-lab explanations between sections. It was also noted that these explanations often varied in length, resulting in between 30 and 45 minutes of lab time devoted to introduction and explanation. To address this, the lab video series was developed for the RBE1001 course. Each video is approximately 15 minutes in length. Over the course of the term, this video is played twice a week for each lab in the class. This results in approximately ten hours per week that were previously devoted to explanation of laboratory procedure available to lab staff and prevents inconsistencies in protocol. Additionally, these videos can be assigned for homework, resulting in increased working time during the lab sessions themselves.

The equipment videos produced served educational purpose for the producers of the content and service a niche beneficiary. Students attending WPI seeking proper tool procedure for electrical equipment such as the function generator and multimeter have quick access to reminders. Because these videos are simple and require few animations to explain, they were particularly useful for building a skillset with video editing and animation production software. The production of these videos set the pace of the later work in this project and allowed for early stylistic revisions to be made to techniques for video production and animation development. It is recommended that future developers with limited production experiences follow a similar protocol.

The data reveal similarities in how students would use videos developed in this project as a resource and shows potential measures for improvement. Students who found this video to be a review enjoyed the brevity; students who are learning this for the first time in a flipped classroom setting may find more thorough explanations more appropriate. Additionally, students watching at increased speeds found the video clear and understandable. This suggests that the pace may be increased. Additionally, accessibility for all students will be necessary in revisions via subtitles.

Sixteen of seventeen responses suggested the use of more animations and visual aids. Because this is the most time intensive process of video production, additional time and resources would be necessary to implement these corrections. This also suggests that students, given exposure to video media, have a bias toward visual explanations. Furthermore, four responses noted that mechanical topics were naturally understood through visual explanation. This was speculated in interviews with course staff and from initial survey data. Three responses mentioned that an on-screen actor made the explanations less clear or detracted from the video. One response mentioned that distractions were present in the speaker's background, and several mentioned that onscreen explanations would be clearer if highlighted, suggesting that small stylistic changes benefit overall clarity.

Future development of this project will yield a more holistic coverage of robotics content in video and improved access to resources for teaching and learning. Improvements made to the quality of existing content will make some explanations more clear and are necessary for the laboratory video series. This is because the document in the video itself is only partially visible, and improvements in quality can be made with off-screen time for the speaker.

Expanding the video series to cover mechanical concepts in a deeper scope would be valuable to the existing project. This can include a video with complex examples requiring conceptual synthesis or the introduction of kinematic chains. This would be tailored to students in the RBE2002 series. Although they exist, videos devoted to mechanical analysis for projects, such as power transmissions and motor selection, can be expanded to include more complex content or feature an example.

To increase overall quality and measure of efficacy, more data sampling is necessary. This would require a survey or focus group evaluation of all videos. Additionally, testing on the efficacy of videos in the flipped classroom setting may be more conclusive of improvements in student outcomes. This can be accomplished through interviews with professors who use the content developed with assessment tools such as short quizzes or homework. Similarly, student performance measures can be obtained though data from viewers. However, results may be misleading or inconclusive without a large number of data points, so generalizations were not made exclusively based on these samples.

To improve production, rehearsal and script writing should be incorporated prior to the production of a video. Actors who rehearsed or wrote down their scripts were more effectively able to communicate the content, spoke naturally, and enhanced the results of animation through clear stipulations.

Animations, although labor intensive, were determined to be essential for effective communication. With this in mind, a majority of production resource should be devoted to enhancing the authors' presentation.

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Appendices

Appendix A: Pre Production Survey Responses

Default Question Block

How effective do you think these educational platforms are?

	Not at all effective	Marginally effective	Somewhat effective	Suitably Effective	Extremely Effective
Textbooks	○	○	○	○	○
Videos	○	○	○	○	○
Lectures	○	○	○	○	○
Peer Tutoring	○	○	○	○	○
Online Resources and Guides	○	○	○	○	○

What is the optimal length of time for an educational video?

- ○ Under 5 minutes
- ○ 5 to 10 minutes
- ○ 10 to 20 minutes
- ○ 20 to 45 minutes
- ○ 45 minutes to 1.5 hours
- ○ Longer than 1.5 hours

Which of these courses have you completed? Select all that apply.

RBE1001	RBE2001	RBE2002	RBE3001	RBE3002	RBE course not listed
☐	☐	☐	☐	☐	☐

Have you seen any educational videos produced by the RBE program?

- ○ Yes
- ○ No

Please rate the pacing of the videos you've seen.

- ○ Too fast to understand
- ○ Quick but comprehensible
- ○ Just right
- ○ Slightly slow
- ○ Too slow to be effective

How did/do you use the videos available? Select all that apply.

- ☐ As a study guide for class exams
- ☐ As a tool for projects
- ☐ As a supplement to lecture
- ☐ To learn content that is new to you

How effective are the following styles of educational video presentation?

	Not at all Effective	Marginally Effective	Somewhat Effective	Suitably Effective	Extremely Effective
Listening to a dictation by an on-screen speaker	○	○	○	○	○
Seeing an animation or application of the content discussed	○	○	○	○	○
Seeing slideshow-style lecture notes with voice-over	○	○	○	○	○

What concepts were particularly challenging in RBE1001? These are listed below. Select all that apply.

- ☐ Programming Topics (structs, arrays, datatypes, state machines, etc)
- ☐ Force Analysis and Free Body Diagrams
- ☐ Vehicle Mechanics and Performace
- ☐ Linkages
- ☐ Circuit Design
- ☐ Motors
- ☐ Power Transmissions
- ☐ Operational Amplifiers
- ☐ Controls
- ☐ Sensors
- ☐ Mechanisms
- ☐ Embedded Architecture
- ☐ Pneumatics
- ☐ Digital Signals
- ☐ Behavior Programming
- ☐ Entrepreneurship

What concepts were particularly challenging in RBE2001? These are listed below. Select all that apply.

- ☐ Kinematic Fundementals
- ☐ Linkage Position Analysis
- ☐ Energy Storing Circuits
- ☐ Operational Amplifiers
- ☐ DC Motors
- ☐ Arduino & C++ Programming
- ☐ Real-Time Control Programming

- ☐ Linkage Velocity Analysis
- ☐ Graphical Linkage Synthesis
- ☐ PID Control
- ☐ Interrupt Service Routine Programming
- ☐ H-Bridges
- ☐ Motor Control Circuits
- ☐ Flowcharting
- ☐ Thévenin & Norton Circuits
- ☐ Bluetooth and Packet Protocols (Data Transfer)
- ☐ C++ & Arduino Libraries
- ☐ System Power Requirements
- ☐ State Machine Programming
- ☐ Robot Steering Mechanisms
- ☐ Diodes, Rectifiers, & 555 Timers
- ☐ PWM Signal Generation

What concepts were particularly challenging in RBE2002? These are listed below. Select all that apply.

- ☐ Analog Signal Filtering
- ☐ Force Sensing
- ☐ Mechanical Impedance
- ☐ Operational Amplifiers
- ☐ Digital Signal Processing
- ☐ Digital Circuits
- ☐ Intertial Measurement Units
- ☐ Robot Dynamics
- ☐ Switch Debouncing
- ☐ Concurrent Programming
- ☐ Phasors
- ☐ Computer Architecture

- ☐ Multiprocessor Architectures
- ☐ Race Conditions in Programming
- ☐ Power Electronics

Do you have FRC or FTC experience as a student, mentor, or volunteer?

- ○ Yes
- ○ No

Which of these practical concepts would be most beneficial to the FRC and FTC communities?

- ☐ Programming Topics
- ☐ Mechanisms and Linkages
- ☐ Practical Circuits
- ☐ Sensing
- ☐ Motor Selection
- ☐ Pneumatics

Which of the following describes you?

- ○ First year student
- ○ Second year student
- ○ Third year student
- ○ Fourth year student
- ○ Studying longer than four years

What is your major?

- ☐ RBE
- ☐ ME
- ☐ CS
- ☐ BME
- ☐ IMGD
- ☐ AE

☐ ECE ☐ Other

Please specify your major.

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Appendix B: Pre Production Student Survey Data

Q8 How effective do you think these educational platforms are?

	Not at all effective	Marginally effective	Somewhat effective	Suitably Effective	Extremely Effective
Textbooks	❍	❍	❍	❍	❍
Videos	❍	❍	❍	❍	❍
Lectures	❍	❍	❍	❍	❍
Peer Tutoring	❍	❍	❍	❍	❍
Online Resources and Guides	❍	❍	❍	❍	❍

If Videos - Not at all effective Is Selected, Then Skip To Which of the following describes you?

Q9 What is the optimal length of time for an educational video?
- ❍ Under 5 minutes
- ❍ 5 to 10 minutes
- ❍ 10 to 20 minutes
- ❍ 20 to 45 minutes
- ❍ 45 minutes to 1.5 hours
- ❍ Longer than 1.5 hours

Q1 Which of these courses have you completed? Select all that apply.
- ❑ RBE1001
- ❑ RBE2001
- ❑ RBE2002
- ❑ RBE3001
- ❑ RBE3002
- ❑ RBE course not listed

Q2 Have you seen any educational videos produced by the RBE program?
- ❍ Yes
- ❍ No

Answer If Have you seen any educational videos produced by the RBE department? Yes Is Selected

Q3 Please rate the pacing of the videos you've seen.

- ❍ Too fast to understand
- ❍ Quick but comprehensible
- ❍ Just right
- ❍ Slightly slow
- ❍ Too slow to be effective

Answer If Have you seen any educational videos produced by the RBE program? Yes Is Selected

Q10 How did/do you use the videos available? Select all that apply.

- ❑ As a study guide for class exams
- ❑ As a tool for projects
- ❑ As a supplement to lecture
- ❑ To learn content that is new to you

Q15 How effective are the following styles of educational video presentation?

	Not at all Effective	Marginally Effective	Somewhat Effective	Suitably Effective	Extremely Effective
Listening to a dictation by an on-screen speaker	❍	❍	❍	❍	❍
Seeing an animation or application of the content discussed	❍	❍	❍	❍	❍
Seeing slideshow-style lecture notes with voice-over	❍	❍	❍	❍	❍

Answer If Which of these courses have you completed? RBE1001 Is Selected

Q4 What concepts were particularly challenging in RBE1001? These are listed below. Select all that apply.

- ❑ Programming Topics (structs, arrays, data types, state machines, etc.)
- ❑ Force Analysis and Free Body Diagrams
- ❑ Vehicle Mechanics and Performance
- ❑ Linkages
- ❑ Circuit Design
- ❑ Motors
- ❑ Power Transmissions
- ❑ Operational Amplifiers
- ❑ Controls
- ❑ Sensors
- ❑ Mechanisms
- ❑ Embedded Architecture
- ❑ Pneumatics
- ❑ Digital Signals
- ❑ Behavior Programming
- ❑ Entrepreneurship

Answer If Which of these courses have you completed? RBE2001 Is Selected

Q5 What concepts were particularly challenging in RBE2001? These are listed below. Select all that apply.

- ❑ Kinematic Fundamentals
- ❑ Linkage Position Analysis
- ❑ Energy Storing Circuits
- ❑ Operational Amplifiers
- ❑ DC Motors
- ❑ Arduino & C++ Programming
- ❑ Real-Time Control Programming
- ❑ Linkage Velocity Analysis
- ❑ Graphical Linkage Synthesis
- ❑ PID Control
- ❑ Interrupt Service Routine Programming
- ❑ H-Bridges
- ❑ Motor Control Circuits
- ❑ Flowcharting
- ❑ Thévenin & Norton Circuits
- ❑ Bluetooth and Packet Protocols (Data Transfer)
- ❑ C++ & Arduino Libraries
- ❑ System Power Requirements
- ❑ State Machine Programming
- ❑ Robot Steering Mechanisms
- ❑ Diodes, Rectifiers, & 555 Timers
- ❑ PWM Signal Generation

Q14 What concepts were particularly challenging in RBE2002? These are listed below. Select all that apply.

- ❑ Analog Signal Filtering
- ❑ Force Sensing
- ❑ Mechanical Impedance
- ❑ Operational Amplifiers
- ❑ Digital Signal Processing
- ❑ Digital Circuits
- ❑ Inertial Measurement Units
- ❑ Robot Dynamics
- ❑ Switch Debouncing
- ❑ Concurrent Programming
- ❑ Phasors
- ❑ Computer Architecture
- ❑ Multiprocessor Architectures
- ❑ Race Conditions in Programming
- ❑ Power Electronics

Q11 Do you have FRC or FTC experience as a student, mentor, or volunteer?

- ❍ Yes
- ❍ No

Answer If Do you have FRC or FTC experience as a student, mentor, or volunteer? Yes Is Selected

Q12 Which of these practical concepts would be most beneficial to the FRC and FTC communities?

- ❑ Programming Topics
- ❑ Mechanisms and Linkages
- ❑ Practical Circuits
- ❑ Sensing
- ❑ Motor Selection
- ❑ Pneumatics

Q13 Which of the following describes you?

- ❍ First year student
- ❍ Second year student
- ❍ Third year student
- ❍ Fourth year student
- ❍ Studying longer than four years

Q6 What is your major?

- ❑ RBE
- ❑ ME
- ❑ CS
- ❑ ECE
- ❑ BME
- ❑ IMGD
- ❑ AE
- ❑ Other

Answer If What is your major? Other Is Selected

Q7 Please specify your major.

Appendix C: Post Production Survey Data

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The visualizations of the robots and other physical entities is super helpful and aid greatly in [illegible] physical systems.

What part of the video stood out the most? Why?

Not any part in particular. Possibly when the robot used for force analysis is shown on screen. However it would help for engagement if the robot were animated to some degree.

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

It might help to emphasize "point B" and other details through a simple enlargement to [illegible] [illegible] animation, whenever a single variable of something in an equation is expressed.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

Well done. The audio is a little [illegible] as if he was in an open auditorium [illegible] [illegible] [illegible] fine.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

I think it was all very viable but it were approached from a pseudo-practical viewpoint which some things could have been shown better with examples but overall good

What part of the video stood out the most? Why?

The fun digrams/examples

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

It was all very clear, just start from a slightly more basic view, less purely technical terms

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

The processing good. A lot going on in the background though.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The diagrams provided and examples using those diagrams were very valuable.

What part of the video stood out the most? Why?

The wrench example and the RHR were two things easily visualizable.

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

The friction explanation could really have used an animation/graphic. Seeing them [illegible] useful, (hearing the voice over an image is)

I think definitely having more graphics/pictures, especially for very technical concepts, it would be a lot easier.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

Pretty good.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

For me, I already had learned the material, but it was a good refresher of details I had forgotten.
For someone who had not learned the material, all of the video was educationally valuable. It was a good, succinct explanation of a complex subject. It is also useful because people can go back and recheck.

What part of the video stood out the most? Why?

The succinctness. It was short and useful, so it is not hard to go back and recheck concepts you do not understand

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

Perhaps a better explaination of the right hand rules.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

The video and audio were simple, which is good, because it does not distract from the content

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The explanation of the conditions of equilibrium was good because it is a very important part of the lesson. But it should narrow the equations it discusses down to $\Sigma F_x = 0$ $\Sigma F_y = 0$ and $\Sigma M_k = 0$ because these matter the most to their current assignments.

What part of the video stood out the most? Why?

The explanation about us having relatively no acceleration even though we are currently moving through space. There were a lot of visual elements that keep you engaged.

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

I thought the frictional force explanation needed some more visual elements.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

The quality of the video was fine. Professor Stafford was clear and easy to understand. The visual elements were also clear.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The video is helpful for those who have not done statics, especially the visual stuff

What part of the video stood out the most? Why?

The visual diagrams and equations because they differed from the main video sequence

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

The explanations were pretty clear. I had no issues understanding the topics

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

The video was good the audio sounded a bit echo-y

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

the explanation of moments was useful, as was noting that right hand rule is just a convention not a rule.

What part of the video stood out the most? Why?

The diagrams were a good break from [illegible] just talking.

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

The description of what the 6 equation would be was very brief

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

quality was excellent, even on 1.5 speed

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

These videos are great for students that miss class. For someone who has taken statics, they are not.

What part of the video stood out the most? Why?

Speed of [illegible]

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

It is clear, although it helps that I am familiar with the material.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

~~Perhaps~~ Even at 2x speed! Everything was clear.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The video seemed fairly valuable in general.

What part of the video stood out the most? Why?

The description of the right hand rule was a fairly good explanation itself.

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

An explanation of what each finger for the right hand rule would be nice, τ = r × F, or represented as C = a × b

Thumb, Index, Middle

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

There was one transition where it started with Parker stopped talking and started up again as him talking. It didn't look great as a transition and maybe an image or something would helped it.

Some other additional visuals [illegible] pictures [illegible].

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

-When he stresed that static equilibrium can mean constant velocity & no acceleration
-his explanation of torque was very thorough which helps make sure everyone has a good understanding/ review of torque
-showing the derivation that forces are zero when accel. = 0 gives a good fundamental understanding

What part of the video stood out the most? Why?

The graphics of the earth, sun, and galaxy to show relative motion stood out because they were eyepopping

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

his explanation of friction with his chair felt like it took too long to explain and he could have used a better example however introducing friction as a force contributing to static equilibrium could help with the ramp lab in 1001

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

the quality did not need any work

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

I thought the video as a whole would be very educationally valuable for anyone who had not encountered statics problems before but had already taken physics

What part of the video stood out the most? Why?

The animations of the wrench did and similar animations could probably aid in other explanations

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

All the explanations were clear but some assumptions were made about understandings the viewer has. For example, the video could apply to a broader audience by going into a bit more depth on torque

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

The video quality is good enough for this application. The audio quality could be better, but I would only expect someone who is very hard of hearing to have trouble understanding the audio

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The visualization of coordinate systems and a 6 2-force member

What part of the video stood out the most? Why?

How fast the professor is talking

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

The interactive diagrams were helpful for identifying how to break out components into FBD's

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

Add a slide @ end that summarizes key points

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

the diagrams and equasions are valuble, they help explain things

What part of the video stood out the most? Why?

the office, it was distractingly cluttered

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

show diagrams instead of guy talking no point in watching him talk over a diagram

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

drop ~200Hz (too boxy)

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

In this topic, Engineering and Physics conventions begin to differ. It might be good to underline them, especially the ones involving FBDs

What part of the video stood out the most? Why?

Visuals provide great basis for understanding, and provide good bookmarks for video navigation.
It is also easier to follow with com. animations and visuals

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

I think formulas and some of the drawings should be provided on a white board. It looks more interactive in terms of narrative and there is a summary of the video on the go.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

1080p and good audio quality. There is some white noise and crackling at high volume. but I don't think there is a need for improvement.

An accross-the-desk view or in front of white-board setting would be better.

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

① Light bond with
② Formulas
③ friction

What part of the video stood out the most? Why?

the wrench, the problem of the Torque (distance)(force)

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

All the explanations are pretty clear. It will be a good idea to do a 3-D problem instead of only one 2-D problem

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

I think the quality of the video and sound are pretty good enough to understand the subject and appreciate the academic value

Robotics Curriculum Development IQP Survey

What parts, if any, of the video do you think were educationally valuable? Why or why not?

The logic behind the equilibrium equations help clarity my ambiguity

What part of the video stood out the most? Why?

Ken Stafford's explainations were more clear than visual and his energy is appreciated

Were any explanations particularly clear or unclear? What improvements can be made to how the content is described?

The friction explanation was very good! More visuals would be good.

How would you describe the quality of the video and audio? Can any improvements be made in the video-making process?

Again, visuals would help a lot more.