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Academic Needs Assessment to Inform Course and Program Design: A Hybrid Vehicle Engineering Program as a Case Study

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1. Introduction

Establishing the overarching learning objectives for an engineering program can be daunting. There are a suite of studies that have performed surveys to derive course learning objectives, but this aspect of the course design and assessment process is perhaps underappreciated in the education literature, and is more certainly uncommon in the automotive engineering education literature [2-7]. Creating these objectives is also challenging as various educational philosophies, interests, and perspectives are frequently present. For example, some believe that academia's main purpose is higher learning, while others posit that job placement is the major focus. Such differences can lead to a variety of distinct learning objectives, which in turn lead to very different academic curricula. Therefore, it is essential to first consider such purposes and then carefully tune the program objectives to said purposes, and to have guidance with writing the objectives themselves.

When designing an engineering program that is focused on job and career placement, learning objectives should be focused on outcomes that lead to employment. Therefore, a logical step is to conduct an industry-informed, academic needs assessment to guide the creation of learning objectives and certain general aspects of the program, such that the program truly fills the gap between students' abilities and interests and employers' needs. This type of program is very important today as employers have trouble finding qualified employees and students graduate with large student loan debt, and hence need to find employment quickly to ensure financial security. The industry-informed needs assessment that is presented here is designed to bring these two entities together, but can also be used to assess any gap that higher education needs to fill.

This paper presents the use of a needs assessment process to conduct an industry-informed, academic needs assessment, exemplified in the creation of a hybrid-electric vehicle engineering (HEVE) program for undergraduates and graduate students at Colorado State University (CSU). The program that was created is used as a case study to illustrate how the process and results of the needs assessment guide creation of the learning objectives and program details, so that readers can readily utilize this process for their own needs.

2. Methods

The needs assessment process applied was designed by the National Oceanic and Atmospheric Administration (NOAA) [1]. This methods is applied and documented (in a more narrative format) here with only minor modifications required to apply the process to engineering curriculum objectives development needs assessment.

The foremost goals of the needs assessment were to create program and course learning objectives, as well as guidelines for a program completion certificate, with the objective of the program being job placement in the hybrid-electric vehicle engineering industry. The relatively narrow focus of the program objectives was necessary considering the requirements of the request for proposals and funding agency. This program was funded from 2010-2014 through the US Department of Energy Vehicle Technologies Office under American Recovery and Reinvestment Act (ARRA) authority and guidelines. The emphasis in all ARRA projects was on workforce development, job placement and economic stimulus, and the strategic objective of the HEVE program was to be aligned with these national objectives.

The planning team consisted of the authors as this small team possessed the expertise, resources and authority to perform the needs assessment and to implement the recommendations that resulted. Dr. Stanton worked for Delphi Automotive after earning his B.S degree in Electrical Engineering at Clarkson University. He earned his Ph.D. in Engineering Education at Virginia Tech, and was employed at Colorado State University as a Research Scientist under the HEVE program. Dr. Thomas Bradley was Assistant Professor in Mechanical Engineering at CSU with industrial and academic experience in HEV engineering and analysis. Bradley was PI for CSU's portion of the HEVE program and had authority to implement necessary course development. Drs. Bradley and Stanton taught the HEVE-designated courses at CSU and were jointly responsible for design of the coursework and learning objectives.

At the time of the program instigation, Colorado State University was the site of a respected and nationally-ranked College of Engineering, and had recently hired new faculty in the field of automotive engineering, but (without a Colorado-centric automotive industry) was without an up-to-date understanding of the recent changes in the industry.

In the authors' assessment, CSU and HEVE program had the capability to develop coursework to support a wide variety of program scopes, and knowledge requirements. We could educate students to achieve general automotive engineering expertise, and/or more specific hybrid vehicle expertise, and/or more specific electrical power systems expertise, and/or design and control expertise. Each of these topics had constituencies within the student, faculty, and administration population. The information that we planned to collect from the industry surveys and interviews would be

1. a ranking of the topics that should be emphasized in HEVE coursework (over and above a typical BS degree in Engineering). The objective of obtaining this information was to develop our understanding of which courses were to be developed as part of the HEVE program.
2. a ranking of the skills that should be the learning outcomes from the HEVE program. The objective of obtaining this information was to develop our understanding of what learning objectives should be emphasized in developing course-level learning objectives for the HEVE courses.
3. a ranking of the specializations that might make up hybrid electric vehicle engineering (HEVE), with the objective of designing certificates that would provide content in these specializations.
4. an understanding of the workforce development challenges faced by industry, so that they might be addressed by the HEVE program.

The program principal investigators determined that a survey-based, and interview-based industry needs assessment would be appropriate to collect this information. The subject population for the industry needs assessment was chosen to be individuals within the automotive industry (broadly defined) who met the criteria of having hiring authority over engineering positions, being located in the US, and managing hybrid, electric vehicle or fuel cell vehicle programs. A list of companies that would be the target of our investigations included original equipment manufacturers, federal research laboratories, automotive suppliers, automotive consultancies, state and federal regulatory agencies, private research laboratories, and companies from the "entrepreneurial" automotive industry. Letters, emails and telephone calls were used to contact persons within these companies who would be able to recommend research subjects meeting the above criteria.

The survey instrument consisted of a three question survey that was distributed to the subjects by email, and a follow-up telephone interview. The research subjects were first prompted for their name, position, and relevant information regarding their experience and background. The three survey questions (corresponding to the first three information collection points above) and their rating scale are provided in the appendix. The research subjects are asked to categorize according to relative importance (on a scale of least important, average importance, above average importance, most important) a list of broad subjects. In Question 1, the respondents categorize the broad areas of inquiry in hybrid electric vehicles. In Question 2, the respondents categorize relevant skills and knowledge bases. In Question 2, the respondents categorize the specializations that could be offered for the program. Care is taken in the survey instrument to prompt the research subject to treat the rating scale as an ordinal scale, so that the ranking of each subject can be evaluated as the number of respondent who ranked a particular subject as "Most Important". Forcing the subject to "down-select" their responses to emphasize the most important subjects was estimated to be appropriate because the objective of the survey was to determine which of the subjects of study were of greatest importance. The list of subjects that were to be ranked by the research subjects was derived from the list of subjects that were found in textbooks (8,9,10), review articles (11), and courses at other institutions (12,13).

The survey was piloted by mechanical engineering graduate students and faculty at Colorado State University. In the telephone interviews, the same questions were used as prompts to elicit further details on the responses to the survey questions. Interviews were conducted and recorded, and surveys distributed and collected, after IRB approval was obtained. Invitations were sent to 47 individuals for participation in the study, replies were received from 15 persons (14 men and 1 woman), all of whom were able to perform the telephone interview.

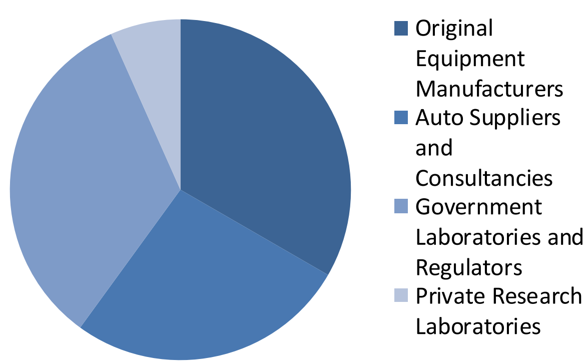

Figure 1. Breakdown of research subjects according to industrial affiliation (n=15)

3. Results

For the survey data, responses for the first two questions were quantified by summing the number of times that a particular subject was categorized as "Most Important". Scoring each subject in this way avoid problems of dissimilar scaling and subjectivity among respondents that might result if the survey responses were treated as a quantification of importance. In this case, we only evaluate each subject based on the number of times that it was selected as "Most Important". Where the respondent was unable to choose only one "Most Important" subject, the weight of their response was divided among their "Most Important" subjects. This serves to provide even weighting to each of the respondents. For the third question, the subjects were requested to select as many as might be appropriate, and so no such weighting is performed.

Question 1 assesses the respondent's view on the relative importance of various broad topics of hybrid electric vehicle engineering. The primary objective of Question 1 was to develop an understanding of which courses would contribute to the HEVE program. As a result of this survey, we saw a great deal of interest in the topics of Battery Design and Technology, Supervisory Hybrid Vehicle Controls, State of the Art Hybrid and Electric Vehicles, and the topic of Transmissions and Power Split Devices. These results are presented graphically in Figure 2. The other topics proposed were categorized as important by fewer of the respondents, and a few topics did not receive any "Most Important" responses (including motor design, history of HEVs, Vehicle Dynamics, and Ultracapacitors).

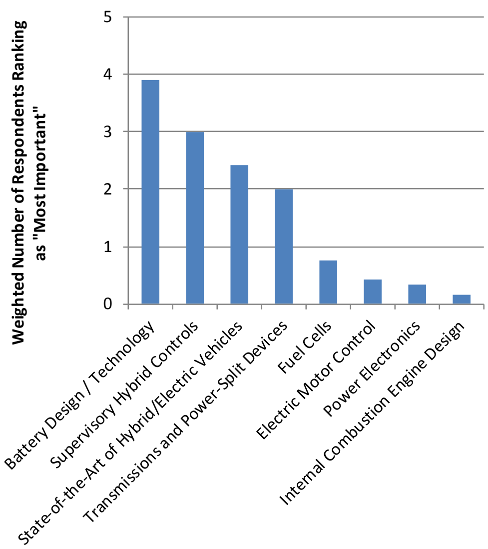

Figure 2. Analyzed responses to Question 1 regarding relative importance of the broad topics of HEVE

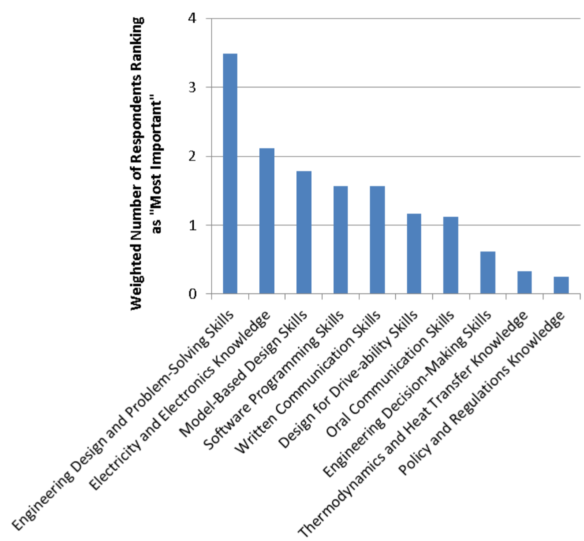

Figure 3. Analyzed responses to Question 2 regarding relative importance of the general skills required for employment in HEVE industries

Question 2 seeks to assess the respondent's view on the relative importance of general skills that students of hybrid electric vehicle should demonstrate advanced capabilities in. In this case, the objective of the question is to help to construct the learning objectives and coursework for the program. As shown in Figure 3, the results of the survey re-emphasize those "modern" skillsets of engineering education (that have been found in other similar industry surveys [2,5]) including problem-solving skills, electrical/computer science skills (including model-based design), and communication skills. Notably, environmental, marketing and economics skillsets were not categorized as "most important" by our survey respondents.

Question 3 seeks to assess those areas of HEVE where a specialization within the HEVE program would be of value to the student. As posed, the question asks the research subject to consider both the intrinsic value and the employability value of the specialization. As shown in Figure 4, the most popular specializations were those involved in general Vehicle Modeling and Control.

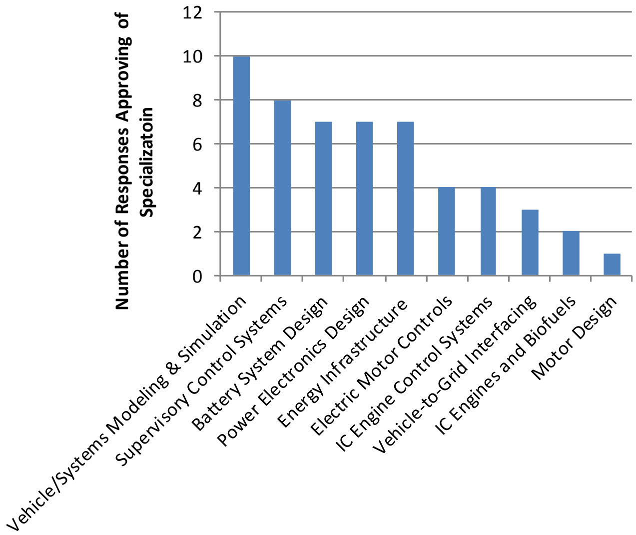

Figure 4. Analyzed responses to Question 3 regarding the relative importance of various specializations

It is worth noting that surveys *and* interviews were selected as the instruments for this study for reasons beyond follow up on the survey questions. In general, inquiries that followed up to the survey questions provided a means to elicit more detailed input on the subject of the HEVE curriculum. Although the interviews were too unstructured to lend themselves to qualitative coding and analysis, they provided a window into the more detailed concerns and need of the industry. As an example, one of the questions that we sought answers to was the role of fuel cell systems in the future of hybrid electric vehicles and HEVE education. The results of the surveys (see Figure 2) showed that only a few survey respondents categorized fuel cells as a "Most Important: topic. As a result of the interviews, we discovered that there are two primary "schools of thought" regarding fuel cells among our interviewees. Among the US OEMs, and most suppliers, and private research institutes, fuel cells were of very low interest. These respondents suggested that (in their assessment) fuel cell systems were a very long-term technology, and that students of fuel cells were not in demand in their companies.

> "If we can't make a natural gas infrastructure, how are we going to make hydrogen vehicles work? We don't see anything at all with regards to fuel cells."
> – Manager at an Automotive Consultancy

Among the foreign OEMs, and all of the national laboratories, the respondents emphasized the importance of fuel cells as one among a suite of technologies. These respondents suggested that students should understand aspects of fuel cell systems as an exemplar of electrochemical energy conversion, infrastructure challenges to transportation, and benefits of vehicle hybridization.

> "Learning about fuel cells in conjunction with other technologies is important."
> "Of course they need to know the basic operations of fuel cells. If you have an understanding of the state of the art of [batteries and fuel cells], then you can

understand the tradeoffs among the technologies." – Manager at a National Laboratory

In this case, we learned that fuel cell systems would be a topic of importance to industry as long as it was not a subject of solitary study, but was put within the context of other technological, infrastructural, and energy systems.

Interviews were recorded and interviewees asked if we could use "snippets," or small audio segments, of their interviews in our classes to demonstrate to students, in the words of those most connected to the field, why topics were interesting or valuable for an engineer to study.

4. Discussion and Implementation

On the basis of these survey results, four courses were developed in two years to support the HEVE program. The first of these courses was *MECH 523 - Battery and Fuel Cell System Design for Vehicles*. This course is a response to the demand for battery design and technology coursework that was the most highly rated area of study for the respondents to Question 1. The second of these courses is *MECH 527 - Hybrid and Electrified Vehicle Powertrains*. This course focuses on developing knowledge of hybrid vehicle architectures, powertrain configurations, and power split dynamics. A lower emphasis is placed on vehicle modeling and control. The third course is *MECH 580-A1 - EV/HEV Computational Systems Design and Control*. This course provides the advanced materials and strong focus on vehicle supervisory controls and optimization. Finally, in the graduate level course, *ENGR 680-A4 Transportation Electrification*, the students spend more time on researching the state of the art in hybrid and electric vehicle technologies. With these 4 courses now developed, we believe that the CSU HEVE program provides excellent coverage to the topics of most importance, as derived from this industry survey.

In developing the learning objectives for each of these courses, we sought to align the learning objectives to the requirements as derived from the industry responses to Question 2. Each of the 4 courses requires the students perform design, team projects, written reporting, oral presentations, and MATLAB™ programming. Electronics and electrical engineering knowledge are concentrated in the MECH 527 and MECH 680 courses, with an emphasis on power systems, electric motor fundamentals, battery design and interaction, and system controls. Industry had indicated they could teach specifics not learned in classes, if the students could both bring a fundamental understanding of the topic and be self-directed learners, so the course learning objectives emphasized these skills over deep knowledge; this also meant, unfortunately, that we decided not to take action on the responses to Question 3 to develop specializations within the HEVE program, but rather allow employers to engage graduates as they found the need to. Serving as a map of the intersections of course learning objectives and industry interests, Figure 5 demonstrates how these courses were laid out. Note that some overlap in courses exists, with the intention of developing a deeper understanding of these topics and repeated exposure to these fundamentals.

The process that readers could use to replicate our work is relatively simple and should be familiar to qualitative researchers. First, a survey instrument should be designed and piloted, per standard survey design methods, and approved by the appropriate IRB. Second, distribute the surveys and be sure to collect relevant contact info to facilitate the phone interview. Third, conduct the phone interviews, but being sure to integrate survey responses with the interview questions, to deepen the feedback obtained. Next, with results in hand, the analysis begins. It is essential here, at the fifth step, to review all the interview recordings and parse out themes, as is common in qualitative analysis. Sixth, we found it especially valuable to separate small audio segments, or snippets, of the interviews by theme so that they can all be reviewed together. This allowed us to synthesize the key messages that we heard in the interviews, and lead them into learning objectives. At this crucial seventh and final step, we found that a small committee of reviewers (all IRB approved) was most helpful to parse out the themes from diverse viewpoints. Then and only then were we able to move the findings into the goals of our courses, comprising a list of things we wanted to ensure students left our program with before entering the industry. This list of learning objectives was, as such, attained from incremental steps from start to finish, leaving a clear train of reason and backing to their creation, which was later traced back to ensure thorough and clear connections to the input we received.

5. Conclusions

The results of the industry survey included the down-selection of topics for the 4 program courses, learning objectives for the courses, and certificate guidelines. Interestingly, the needs assessment study revealed a set of priorities for the aforementioned outcomes that contrast with the typical goals and objectives of higher education courses. For one, skills, such as problem-solving and computer simulation, were rated far more important by stakeholders than most engineering faculty members typically allot for in their courses. Similarly, stakeholders responsible for hiring said that they are not as interested in deep technical knowledge in engineers as they are in awareness of the state-of-the-art and existing problems in the hybrid-electric vehicles. As well, every stakeholder emphasized the importance of communication skills and hands-on experience. As such, the program learning objectives and certificate guidelines were created around these findings, leading to a program that promises to be well-designed to prepare graduates to find work in the hybrid-electric vehicle engineering industry. Since the instigation of the HEVE program in 2010, more than 100 undergraduate and graduate mechanical and electrical engineering students have passed through these courses.

This paper demonstrates how a needs assessment may be conducted to inform the design of an engineering program's learning objectives, exemplified by creation of a hybrid-electric vehicle engineering program focused on job placement and career development. CSU's HEVE program is one of 9 that were developed under the Vehicle Technologies Office Communications and Education Group, and is one of dozens of automotive engineering education programs in the US. The approach presented in this paper is well-structured to develop or re-inform the objectives of such programs quickly and effectively.

	Scope								Skills									
	Battery Design / Technology	Supervisory Hybrid Controls	State-of-the-Art of Hybrid/Electric Vehicles	Transmissions and Power-Split Devices	Fuel Cells	Electric Motor Control	Power Electronics	Internal Combustion Engines	Engineering Design and Problem-Solving Skills	Electricity and Electronics Knowledge	Model-Based Design Skills	Software Programming Skills	Written Communication Skills	Design for Drive-ability Skills	Oral Communication Skills	Engineering Decision-Making Skills	Thermodynamics and Heat Transfer Knowledge	Policy and Regulations Knowledge
MECH 527 - Hybrid and Electrified Vehicle Powertrains	+		+	+	+	++	+	++										
I. Literacy with technical writings about hybrid-electric vehicles, their components, and technical and economic challenges that engineers in the field must solve.													+					
II. The ability to concisely explain background, strengths, and weaknesses of various existing vehicle powertrain components and system configurations.														+	+			+
III. The ability to identify and describe all HEV powertrain components and system configurations.													+		+			
IV. The ability to calculate parameters of HEV powertrain components and systems and vehicle dynamics under static and dynamic conditions.										+							+	
V. Skill with evaluating design tradeoffs for basic HEV powertrain components and systems and vehicle dynamics.									++							++		
VI. Proficiency constructing and simulating models that account for basic aspects of HEV vehicle dynamics, IC engines, electric motors, energy storage, control systems, and regenerative braking, and their system interactions.										++	++	++					++	
VII. Proficiency methodically designing and simulating an HEV with consideration for basic aspects of HEV vehicle dynamics, IC engines, electric motors, energy storage, control systems, and regenerative braking, and their system interactions.											++	++						
MECH 523 - Battery and Fuel Cell System Design for Vehicles	+++	+	+		+++													
I. For primary battery chemistries, analyze the performance of the electrochmical cell using the tools of the undergraduate curriculum including thermodynamics, materials science, chemistry, and heat transfer										++							++	
II. Based on these analyses construct system-level design and simulation tools that can campture the tradeoffs central to battery system utilization and -in practice engineering											+	+						
III. For the primary fuel cell technologies, analyze the performance of the electrochmical cell using the tools of the undergraduate curriculum including controls, mechatronics, and statistics.										++								
IV. Based on these analyses construct system-level design and simulation tools that can campture the tradeoffs central to battery system utilization and -in practice engineering									++							++		
V. Combine the simulation tools devleoped in the previous modules to complete a hybrid fuel cell battery system model that can be sized and optimized for cost and performance objectives									+++		++							
MECH 580-A1 - EV/HEV Computational Systems Design and Control		+++		++				+										
I. Identify and describe HEV powertrain configurations including energy management schemes													+		+			
II. Evaluate design tradeoffs for HEV configurations based on simulation and design requirements for vehicle energy consumption and various use cases									+++									
III. Perform computational component-level design and energy management strategy design for HEVs									+++		+++	+++				+++		
IV. Use simulation results as decsion support for the development of optimized vehicle systems									+++		+++	+++				+++		
ENGR 680-A4 *Transportation Electrification*			+++				+++											
I. Describe the generation, distribution, storage, and use of electricity in the transportation energy sector										+++								
II. Analyze the componnets, function and types of electric energy devices that are currently in use in electric vehicles									+++									
III. Quantify the degree to which the makeup of the US electric grid is dependent on the geographical, economic, political, and social landscape of the US																		
IV. Provide a methodology for lifecycle and well-to-wheels energy comparison of electricity to other fuels as an energy source for transportation									+++									+++
V. Evaluate energy pathways, vehicles, and technologies for attributes of consumer acceptability sustinability, and economics.													+		+	++	++	+++

Figure 5. Table demonstrating the alignment between the learning objectives for the courses developed to populate the HEVE program and the responses from survey regarding the scope of the program (Question 1) and the skills that the program will train in (Question 2). The number of plusses indicates the strength of the alignment.

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Appendix:

Questions posed in survey

Question 1) Which of these broad areas of Hybrid/Electric Vehicle Engineering do you feel are most, average, and least important for students to become ADVANCED/WELL VERSED in? Please try to reserve "Most important" for only those of greatest importance.

Areas	**Select One**			
History of Hybrid/Electric Vehicles	Least important	Average Importance	Above Average Importance	Most Important
State-of-the-Art of Hybrid/Electric Vehicles	Least important	Average Importance	Above Average Importance	Most Important
Power Electronics	Least important	Average Importance	Above Average Importance	Most Important
Electric Motor Design	Least important	Average Importance	Above Average Importance	Most Important
Electric Motor Control	Least important	Average Importance	Above Average Importance	Most Important
Internal Combustion Engine Design	Least important	Average Importance	Above Average Importance	Most Important
Battery Design / Technology	Least important	Average Importance	Above Average Importance	Most Important
Ultracapacitors/Supercapacitors	Least important	Average Importance	Above Average Importance	Most Important
Fuel Cells	Least important	Average Importance	Above Average Importance	Most Important
Transmissions and Power-Split Devices	Least important	Average Importance	Above Average Importance	Most Important
Supervisory Hybrid Controls	Least important	Average Importance	Above Average Importance	Most Important
Vehicle Dynamics	Least important	Average Importance	Above Average Importance	Most Important

Question 2) Of the following skills and knowledge topics, which do you think are most, average, and least important for Hybrid/Electric Vehicle Engineering students to be ADVANCED in? Please try to reserve "Most important" for only those of greatest importance.

Skills and Knowledge	Select One			
Electricity and Electronics Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Electromagnetics Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Thermodynamics and Heat Transfer Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Software Programming Skills	Least important	Average Importance	Above Average Importance	Most Important
Model-Based Design Skills	Least important	Average Importance	Above Average Importance	Most Important
Policy and Regulations Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Environmental Issues Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Engineering Design and Problem-Solving Skills	Least important	Average Importance	Above Average Importance	Most Important
Engineering Decision-Making Skills	Least important	Average Importance	Above Average Importance	Most Important
Marketing Skills	Least important	Average Importance	Above Average Importance	Most Important
Economics Knowledge	Least important	Average Importance	Above Average Importance	Most Important
Design for Drive-ability Skills	Least important	Average Importance	Above Average Importance	Most Important
Written Communication Skills	Least important	Average Importance	Above Average Importance	Most Important
Oral Communication Skills	Least important	Average Importance	Above Average Importance	Most Important

Question 3) Which of the following do you feel we should offer as specializations within the Hybrid/Electric Vehicle Engineering program? (select as many as you feel appropriate) NOTE: A specialization would mean the student focuses on developing expertise in this area, with the goal of being hired directly into jobs in said area.

Specializations	Select One			
Battery System Design	Least important	Average Importance	Above Average Importance	Most Important
Power Electronics Design	Least important	Average Importance	Above Average Importance	Most Important
Supervisory Control Systems	Least important	Average Importance	Above Average Importance	Most Important
Electric Motor Controls	Least important	Average Importance	Above Average Importance	Most Important
IC Engine Control Systems	Least important	Average Importance	Above Average Importance	Most Important
Vehicle/Systems Modeling & Simulation	Least important	Average Importance	Above Average Importance	Most Important
Vehicle-to-Grid Interfacing	Least important	Average Importance	Above Average Importance	Most Important
Energy Infrastructure	Least important	Average Importance	Above Average Importance	Most Important
Motor Design	Least important	Average Importance	Above Average Importance	Most Important
IC Engine and Biofuels	Least important	Average Importance	Above Average Importance	Most Important