AC 2012-4031: A METHOD FOR ASSESSING REQUIRED COURSE-RELATED SKILLS AND PREREQUISITE STRUCTURE

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A Method for Assessing Required Course-Related Skills and Prerequisite Structure

Abstract

The curricula in engineering and engineering technology programs should be dynamic with a goal of constant improvement and refinement. Unfortunately, this is often not the case; courses are developed, altered, and expanded in a piecemeal manner. Rarely is there a holistic top down examination of desired input and output skills for individual courses and a discussion surrounding course organization. Namely, as time progresses many programs end up with courses that developed not a developed curriculum. As part of a strategic planning exercise at a combined Manufacturing and Mechanical Engineering Technology Program, a team was tasked with examining the curriculum to determine if its organization and coverage were appropriate.

The first step in this process involves the solicitation of a set of skills that faculty desire from incoming students; faculty are also asked to provide a set of skills they hope students will acquire in their course. The entire list of skills is then clarified with duplicates eliminated. The list is then given to faculty and members of the program's industrial advisory committee (IAC) to determine if any skills are obsolete or missing from the list. This refined list serves as a basis for discussion regarding the addition or elimination of certain skills and their place in the curriculum. Finally, the courses incorporating the skill inputs and outputs associated with them are placed in a design structure matrix (DSM) to help determine prerequisite structure and identify any courses with cyclic dependencies.

This work presents general findings from this set of exercises and discusses relevant feedback from both faculty and IAC members. The findings highlight the importance of project management, communication skills, problem solving skills, and business knowledge. The DSM is used to identify key courses that interact with numerous other courses.

Introduction

Engineering and engineering technology educators spend a significant portion of their time with students explaining various aspects of design and design related tools. Unfortunately, these same faculty members rarely use the same tools they teach to examine, assess, and develop their own product: their curriculum. Gannod et al., note that the university's product is a curriculum that prepares students in their chosen field of study[1]. As such, the same tools that are often used in developing products in industry can in some cases be used to develop a curriculum that meets the needs of the customers for this product: the students and their employers (industry).

It is somewhat rare for a curriculum to be developed from scratch. Sometimes a new technology such as CAD can allow for the reassessment of the curriculum[2]. In other cases a new school or program may present an opportunity to re-evaluate engineering education; such as the Olin College of Engineering[3]. Other times a need for a specific set of skills, such as nuclear engineering, can call for the creation of a specific program[4]. In these cases the opportunity to create something new can inform ways to improve existing curricula. When developing a new curriculum to incorporate computer-aided engineering tools, the need for faculty and administrative involvement was noted [2]. During the development of the Olin curriculum, the needs for interdisciplinary work, teamwork, a business context for engineering, more design practice, and lifelong learning were highlighted; a sunset clause to re-evaluate the curriculum was also included[3]. When developing a new nuclear engineering program, component design skills, economics, and interdisciplinary problem solving skills were highlighted[4]. When creating a mechatronics curriculum Das et al., noted that the needs of industry and student competence as reasons for curriculum development [5].

Other work has highlighted various aspects of curriculum development and some of the goals and outcomes that are desired as part of the process. ABET along with a dynamic professional environment has resulted in a focus on professional skills [6]. Determining what tools are used by practicing engineers and how they spend their time can be used to inform curriculum development [7]. Harris and Cullen note the need to incorporate more self-learning into the curriculum [8]. As part of an industry sponsored product lifecycle management course, Chang and Miller focus on problem solving, project management, communication, and teamwork [9]. Earnest notes that the efficacy of the educational program is dependent on curriculum development and highlights the need to have clarity among stakeholders who include: curriculum developers, students, teachers, administrators, and industry [10]. Gadalla also notes the need of curriculum developers to consult industry [11]. Kuo also recognizes the importance of relevance to industry and notes the need for continuous improvement in curricula [12]. Again returning to the framework of Gannod et al., a curriculum can be viewed a product that needs to be verified and validated [1]. Verification is defined as building the product correctly, while validation is defined as building the right product[1]; this work is focused on curriculum validation.

One thing anyone familiar with product design will be familiar with is identifying customer needs or the voice of the customer (VOC). This is an integral part of any development project [13]. It is important to not only identify customer needs, but also the importance of those needs [14]. An understanding of customer needs and a focus on them are key for the success of any product [15, 16]; in this case the success of an educational curriculum.

It should be recognized that an educational curriculum is not like a standalone item. The skills required at the conclusion of an educational program may require other intermediate inputs. How these skills come together and the order of the various courses that produces the end product is a key aspect of curriculum development. A tool that can help inform such organization is the design structure matrix (DSM). The design structure matrix is a tools that is used to analyze dependencies. It has been widely used in product development [13]. DSM's have been used in various contexts to make development more efficient[17] and improve product design[18]. DSM's have been used to improve communication[19] and highlight risk interactions [20]. In a curriculum development context, communication could be related to faculty that should be discussing skills that students need to have for follow-on courses, while risk identification is related to students not properly acquiring those skills. This work will use a combination of customer needs elicitation and DSM's to assess the existing curriculum for a combined Manufacturing and Mechanical Engineering Technology program.

Methods

This project began as part of a strategic planning exercise in the Manufacturing and Mechanical Engineering Technology Program at Texas A&M University. A small group of faculty was assigned to assess the curriculum to see if the courses offered were all relevant and to assess the current prerequisite structure. Given this dual mandate, a request was made of all teaching faculty to prepare a brief PowerPoint slide listing the desired incoming skills, expected outgoing skills and any laboratory or project component of their course. An example slide for one of the courses is shown in Figure 1. The expecting outgoing skills for the courses in the program were then taken and combined into a master lists that defined the overall required skillset. It should be noted that not all program courses were part of this exercise. There are nine (of thirty total) that are service courses provided by other departments.

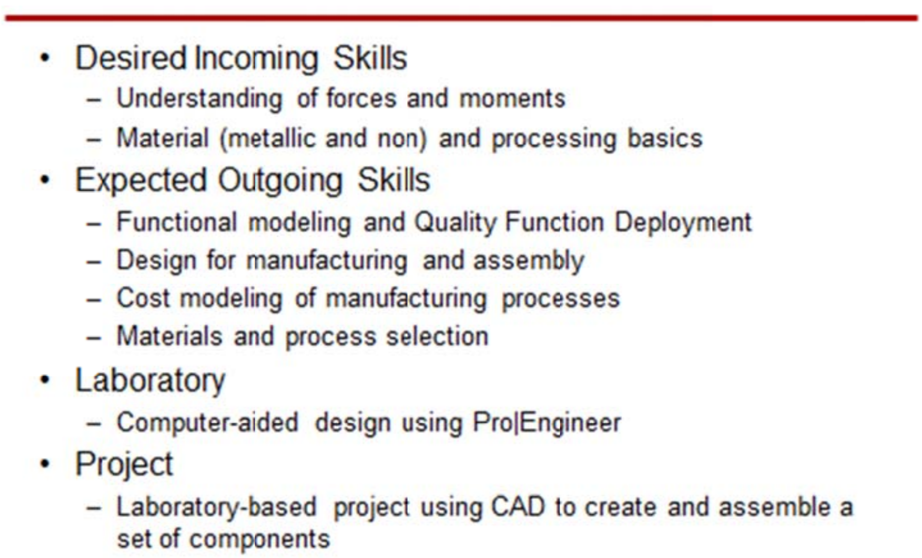

Figure 1. Representative PowerPoint Slide from Faculty Feedback Exercise

The master list of skills was examined to remove duplicate skills. This list was then used to elicit feedback from both the program's industrial advisory committee (IAC) members as well as program faculty members. During a recent IAC meeting, committee members were asked to list five skills that they deem necessary for program graduates. Eighteen committee members provided responses. These responses were requested free form (on blank sheet with no other prompting). These skills were then catalogued and searched based on specific key words. The results of this process are shown in Table 1.

After requesting the free response skills from IAC members, the master list of skills was distributed to the IAC members to determine which skills they deemed critical and which they deemed obsolete. They were asked to select five from both the critical and obsolete categories. The results from this feedback are shown in Table 2. Next the same master list of skills was distributed to the faculty; the faculty were asked to rate the skills on a scale from one to five (one – not important or necessary; five – critical skill). The results from the faculty feedback are listed in Table 3.

The next step in the curriculum assessment process was to create DSM's for the program courses. The DSM row shows a particular course (they are listed in numerical order regardless of prerequisite). The columns show the required interactions. If a particular course is needed prior to another course, an "X" is placed in that column that intersects with the row representing the necessary course. These were assembled using two methods. Like most university curricula, there is a defined set of prerequisites for the courses in the program. A DSM was created using the university course catalogue and the defined course prerequisites. The DSM using the course catalogue is shown in Figure 2. A second DSM using the list of stated desired incoming skills was also created. That second DSM is shown in Figure 3. Next the two matrices were compared. This comparison DSM is shown in Figure 4; in this matrix courses that are listed as prerequisites in the course catalogue, but not according to necessary input skills are shown with a "C". Courses that are listed as an input skill requirement, but not a prerequisite according to the catalogue are listed with an "F".

Results

Table 1 shows the free responses from IAC members. All keywords that received two or more mentions are shown. Four of the six professional skills cited by Shuman[6] are well represented in the results: teamwork, learning, ethics, and communication (engineering in a global context and knowledge of contempary issues were not in the results). Other skills identified by others with a focus on curriculum development are also represented. These include problem solving, teamwork and learning [3, 8, 9, 12].

Table 2 shows the responses for skills that IAC members felt were critical. There was a natural partition at those skills receiving more than four critical votes. It should also be noted that some IAC members listed more than the instructed five skills as critical. Again, the list is in agreement with many of the skills cited in previous curriculum development work. There are some skills that are unique to the manufacturing nature of the program (i.e., automation, fabrication processes, design for manufacturing and assembly). These skills are also in agreement with the average ratings given by the faculty shown in Table 4. The top five critical skills selected by the IAC members were all represented in the top ratings by faculty members (again chosen due to the natural break presented by those receiving an average rating equal or above 4.00).

Table 1. Free Response Feedback from IAC Members

Skill	**Number of Responses**
Project management	11
Communication	11
Business/Finance	8
Problem solving	5
Leadership	5
Ethics	2
Learning	2
Quality	2
Teamwork	2

Table 2. IAC Feedback Regarding Critical Outgoing Skills

Responses	**Skill**
11	Problem solving skills
9	General project management
8	Ability to apply theory to real world applications[1]
7	Proper communication in professional manner
5	Be able to select a process based on needs for fabrication
5	Knowledge of automation and control technologies
4	Ability to complete a project within budget, scope, and time
4	Design for manufacturing and assembly
4	Estimation of time, cost, and scope limitations in projects
4	Lean manufacturing
4	Master production scheduling, capacity planning, materials requirement planning
4	People management

The first DSM shown in Figure 2 is taken from the prerequisite structure defined by the university course catalogue. The courses are listed in numerical order. It should be noted that three interactions that are shown below the diagonal are due to courses that while they have higher numbers are actually meant to be taken prior to their input course (e.g., 376[2] is supposed to be taken prior to 363). This means that the matrix is upper right triangular and thus a feed forward situation. The courses that are the required inputs for the most other courses are 152 (the second calculus course) and 181 (an introductory manufacturing course). These two course are critical to student progression. This could be used to advise students to take these courses early and to ensure that they focus on them to receive a passing grade. This could also be used to direct

[1] This is an output skill from the senior capstone course and thus a general skill.
[2] Note course prefixes have been removed to disguise the university

resources to ensure that students are able to take this course (e.g., increase the number of available sections).

Table 3. Faculty Ratings of Outgoing Course Skills

Rating	Skill
4.88	Problem solving skills
4.88	Proper communication in professional manner
4.75	Ability to apply theory to real world applications
4.29	Be able to select a process based on needs for fabrication
4.25	General project management
4.14	Design for manufacturing and assembly
4.14	Knowledge of manufacturing processes
4.14	Major material properties and their characterizations
4.14	Materials and process selection
4.14	Part design and/or selection
4.00	Ability to prepare a project proposal
4.00	Basic knowledge of Statics and Dynamics of rigid bodies
4.00	Continuous quality improvement using control charts, process capability and design of experiments
4.00	Material, fabrication, metrology relationship
4.00	Statistical thinking

The second DSM was created using the required incoming and expected outgoing skills feedback from the faculty. It should be noted the in some cases these are service courses and faculty feedback was not available. In the cases where physics or calculus skills were defined as required incoming skills, the second calculus course was defined as the incoming requirement and the physics skills were based on the content of the relevant course. This DSM matrix is shown in Figure 3. Again if actual suggested course order were included, all interactions are in the upper right triangle of the matrix. According to the faculty skill interactions, the most relevant course (with six interactions) is again 181. Other courses with a significant number of interactions (greater than four) include 275 and 361 which each have five interactions.

The third DSM shows the differences between the prerequisites listed in the course catalogue and those defined by desired incoming and expected outgoing course skills as defined by the faculty. Those interactions that are in agreement between the previous two matrices are shown with an “X”. Interactions that are listed in the course catalogue, but not required according to faculty skill input are shown with a “C”. Those required by faculty skill feedback, but not listed in the course catalogue are shown with an “F”. It should be noted that some skills are requested by the faculty that would be deemed redundant in the course catalogue. This would occur if skills required for a prerequisite for a prerequisite course are requested (e.g., statics - 275 and mechanics of materials – 376 needed for 363). However, this matrix could also be used to identify prerequisites that should exist – those shown with an “F”; it can also highlight those prerequisites that are unnecessary – those with a “C”. Additional faculty feedback will be necessary to determine if that is indeed the case. However, the DSM tool does highlight where attention for such discussion should be focused. Again, the critical courses can be identified based on the number of interactions. Again 181 is a key course with eight interactions. It is followed by the MATH 152 calculus course with seven interactions. The first physics, course PHYS 218 (mechanics), as well as ENTC 275, ENTC 281, and ENTC 361 all have five interactions. Given that the matrices are upper triangular both from the catalogue and faculty skill perspectives, there is no need to partition or reorder the DSM.

		MATH 151	MATH 152	CHEM 107	PHYS 208	PHYS 218	STAT 211	ENDG 111/10	ENTC 181	ENTC 206	ENTC 207	ENTC 275	ENTC 281	IDIS 300	ISEN 302	ENTC 303	ENTC 313*	ENTC 320	ENTC 361	ENTC 363	ENTC 370	ENTC 376	ENTC 380	ENTC 381*	ENTC 383	ENTC 402	ENTC 410	ENTC 412	ENTC 422	ENTC 429	ENTC 463
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
MATH 151	**1**		X			X																	X								
MATH 152	**2**				X		X					X			X																
CHEM 107	**3**									X	X													X							
PHYS 208	**4**													X										X							
PHYS 218	**5**				X							X									X										
STAT 211	**6**																	X													
DG 111/105~	**7**								X																						
ENTC 181	**8**												X				X		X				X								
ENTC 206	**9**												X						X												
ENTC 207	**10**																X		X			X									
ENTC 275	**11**															X			X			X									
ENTC 281	**12**																									X					
IDIS 300	**13**																										X			X	
ISEN 302	**14**																											X		X	
ENTC 303	**15**																													X	
ENTC 313*	**16**																														
ENTC 320	**17**																													X	
ENTC 361	**18**																										X			X	X
ENTC 363	**19**																													X	X
ENTC 370	**20**																														
ENTC 376	**21**																			X						X					
ENTC 380	**22**																								X		X				
ENTC 381*	**23**																														
ENTC 383	**24**																										X			X	
ENTC 402	**25**																														
ENTC 410	**26**																														
ENTC 412	**27**																														
ENTC 422	**28**																														
ENTC 429	**29**																												X		
ENTC 463	**30**																														

Figure 2. DSM of Major Courses Using Catalogue Dependencies[3]

[3] * is used to identify elective courses; ~ is used to identify service course for which no faculty input regarding skills was received.

		MATH 151~	MATH 152~	CHEM 107~	PHYS 208~	PHYS 218~	STAT 211~	ENDG 111/105~	ENTC 181	ENTC 206	ENTC 207	ENTC 275	ENTC 281	IDIS 300~	ISEN 302~	ENTC 303	ENTC 313*	ENTC 320	ENTC 361	ENTC 363	ENTC 370	ENTC 376	ENTC 380	ENTC 381*	ENTC 383	ENTC 402	ENTC 410	ENTC 412	ENTC 422	ENTC 429	ENTC 463
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
MATH 151~	**1**	■																													
MATH 152~	**2**		■									X				X					X			X							
CHEM 107~	**3**			■						X	X																				
PHYS 208~	**4**				■					X																X					
PHYS 218~	**5**					■				X		X							X		X										
STAT 211~	**6**						■											X													
ENDG 111/105~	**7**							■	X														X				X				
ENTC 181	**8**								■								X	X	X					X	X				X		
ENTC 206	**9**									■			X						X			X									X
ENTC 207	**10**										■						X		X			X									X
ENTC 275	**11**											■				X			X	X		X	X								
ENTC 281	**12**												■											X	X		X		X		
IDIS 300~	**13**													■									X								
ISEN 302~	**14**														■													X		X	
ENTC 303	**15**															■															
ENTC 313*	**16**																■									X					
ENTC 320	**17**																	■													
ENTC 361	**18**																		■						X		X		X	X	X
ENTC 363	**19**																			■									X		X
ENTC 370	**20**																				■										
ENTC 376	**21**																			X		■				X					
ENTC 380	**22**																						■		X		X	X			
ENTC 381*	**23**																							■							
ENTC 383	**24**																								■						
ENTC 402	**25**																									■					
ENTC 410	**26**																										■				
ENTC 412	**27**																											■			
ENTC 422	**28**																												■		
ENTC 429	**29**																													■	
ENTC 463	**30**																												X		■

Figure 3. DSM of Major Courses Using Reported Instructor Skill Dependencies

		MATH 151~	MATH 152~	CHEM 107~	PHYS 208~	PHYS 218~	STAT 211~	ENDG 111/105~	ENTC 181	ENTC 206	ENTC 207	ENTC 275	ENTC 281	IDIS 300~	ISEN 302~	ENTC 303	ENTC 313*	ENTC 320	ENTC 361	ENTC 363	ENTC 370	ENTC 376	ENTC 380	ENTC 381*	ENTC 383	ENTC 402	ENTC 410	ENTC 412	ENTC 422	ENTC 429	ENTC 463
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
MATH 151~	1		C			C																	C								
MATH 152~	2				C		C					X			C	F					F			F							
CHEM 107~	3									X	X													C							
PHYS 208~	4									F				C										C		F					
PHYS 218~	5				C					F		X							F		X										
STAT 211~	6																	X													
ENDG 111/105~	7								X														F				F				
ENTC 181	8												C				X	F	X				C	F	F				F		
ENTC 206	9												X						X			F									F
ENTC 207	10																X		X			X									F
ENTC 275	11															X			X	F		X	F								
ENTC 281	12																							F	F	C	F		F		
IDIS 300~	13																						F				C			C	
ISEN 302~	14																											X		X	
ENTC 303	15																													C	
ENTC 313*	16																									F					
ENTC 320	17																													C	
ENTC 361	18																								F		X		F	X	X
ENTC 363	19																												F	C	X
ENTC 370	20																														
ENTC 376	21																			X						X					
ENTC 380	22																								X		X	F			
ENTC 381*	23																														
ENTC 383	24																										C			C	
ENTC 402	25																														
ENTC 410	26																														
ENTC 412	27																														
ENTC 422	28																														
ENTC 429	29																												C		
ENTC 463	30																												F		

Figure 4. Combined DSM Showing Conflicting Dependencies

Discussion

A methodology for assessing a curriculum has been presented. This methodology could also be used to develop a curriculum. The methodology centered around input from both faculty and industry; this is keeping in line the prescription of Earnest to have clarity among stakeholders [10]. The skills that faculty expected that students would have at the end of their courses served as the basis for the assessment of the curriculum. These along with free response skills from members of the industrial advisory committee were used to validate[1] that the curricular product offered by the program was correct.

The faculty and IAC members were asked to identify the importance of the various skills that were identified. There was broad agreement between faculty and the IAC members as to which skills were critical or highly important. These included: problem solving, project management, communications, the ability to apply theory, and manufacturing process selection. The skills identified by faculty and IAC as critical are also in agreement with those found in the literature related to engineering education (e.g., those cited by Shuman as professional skills[6]).

The design structure matrix was used to identify the interactions among courses based on catalogue prerequisites and cited faculty desired skill inputs and outcomes. The DSM's showed that the courses are not in a coupled or misaligned sequence. This is due to the upper triangular nature of the DSM for program courses. The DSM shows which courses are critical in the program (i.e., have the most interactions). This information could serve as a basis to focus student, faculty, and administrative efforts and resources on these critical courses. Given some disagreement between the prerequisite structure shown dictated by the skill sets and that dictated by the course catalogue, there may be an opportunity to increase or remove some prerequisites from the course catalogue; these results will serve as the basis for that discussion.

The discussion viewed above should be viewed within some limitations. First, while two key stakeholder groups were involved in this process; two others were not: students and administration. Future work will attempt to include their feedback with respect to which skills are most important. Another limitation of the work was limited input that faculty had. Ideally, all faculty (as opposed to solely the instructor of record) would be involved in an iterative and dynamic process to determine which skills were necessary for courses and which skills they expect students to emerge from those courses having mastered. Another limitation is the lack of input from faculty that are responsible for service courses (these represent almost a third of total program courses). Future work will attempt to remedy these limitations.

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