2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #49996

Operationalizing Instructional Complexity for the Curriculum Complexity Methodology: Rubric Development

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Introduction

This empirically backed theory/methods full paper draws on interviews with undergraduate students to create rubrics for instructional complexity that supplement traditional quantitative curriculum complexity analytics. The content of engineering courses is inherently demanding, and additional structural complexities within the curriculum can hinder students' academic progress, delaying enrollment in key courses, and ultimately extending time to graduation [1]. Curriculum complexity, a growing framework used in higher education, quantitatively evaluates the complexity of curricula and visualizes the pre- and co-requisite relationships that can make programs difficult to navigate [1]. Heileman & Zhang's [2] work shows that increased curricular complexity is associated with lower completion rates, and thus investigating curricular complexity has implications for retention and persistence.

Curricular complexity is modeled as a function of structural complexity, how the curriculum is structured, and instructional complexity, how courses are taught and supported [1]. Structural complexity models the curriculum as a network of interconnected courses and captures the pre/corequisite relationships between classes, the delay factors, degree of freedom, blocking factors, and centrality factors [1]. Structural complexity accounts for instances where a student may struggle to pass a given course in a given term and thus is set back a semester or more because they cannot move on to other courses. Nearly all of the literature to date on curricular complexity has focused primarily on quantifying and analyzing structural complexity (e.g., [2], [3], [4], [5], [6]). Heileman et al. [1] posit that instructional complexity is qualitative in nature and conceptualize it as a hidden variable, unable to be directly measured. In the existing curriculum complexity framework, instructional complexity is captured by using course pass/fail rates as a proxy variable [1]. Few others have attempted to quantify instructional complexity, with Waller [7], who proposed using grade anomaly rather than pass/fail rates, possibly being the only example. Waller [7] defined grade anomalies as a student's grade in one course relative to their performance in other courses and found this measure to be more robust than pass/fail rates.

Consequently, instructional complexity has been underexplored in the curriculum complexity literature. There is a noticeable gap in research that combines curriculum analysis tools with qualitative insights from students. We lean into the qualitative nature of instructional complexity, drawing on literature and empirical interview data about student success to develop a rubric tool that can be used in tandem with the existing curriculum complexity framework. Accordingly, we address the following research question: What other factors affect students' outcomes that are not captured in the current curriculum complexity methodology?

The goal of our work is to provide a tool for determining instructional complexity that, in conjunction with existing curriculum complexity metrics, can inform institutional decision making about curricular design and student support. Even when curricula are complex, strong instructional and academic support may mitigate negative outcomes and enable student persistence. Identifying these influences can help institutions make informed changes to improve both the student experience and graduation rates.

Theoretical Foundations

To frame our inquiry into instructional complexity, we draw on Reason, Terenzini, and Domingo's [8] conceptual framework for influences on undergraduate student learning and persistence. The framework hypothesizes that students come into college with a range of characteristics and experiences, including high school preparation, abilities, and sociodemographic traits. It posits that their development of academic competence is a function of their engagement with "the curriculum (e.g., the courses taken and major field of study), the classroom (e.g., pedagogical approaches and behaviors of instructors), and the out-of-class activities" [8, p. 154]. The framework also acknowledges that organizational structures, policies, and practices as well as faculty culture influence students' experiences in all three domains (e.g., curriculum, classroom, and out of class experiences). Taken together, all of these factors influence a student's learning and persistence through the college experience.

The conceptual framework guiding this study, shown in Figure 1, combines curriculum complexity with Reason et al.'s [8] framework. In keeping with Reason et al.'s framework, we hypothesize that students' pre-college experiences impact how they navigate the curriculum, in turn impacting their learning and persistence. We visualize curricular complexity as a combination of instructional complexity (as conceptualized in this work) and structural complexity (as conceptualized by prior work), both of which must be considered to gain a full picture of the factors influencing student learning and persistence. The dashed boxes highlight our contributions in this paper.

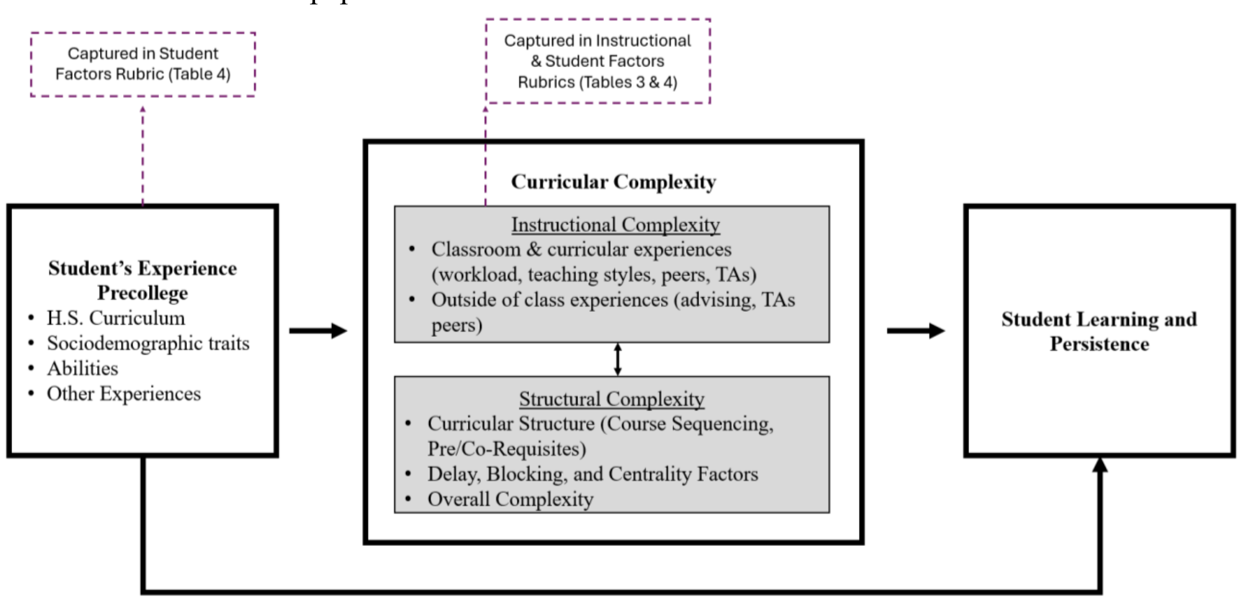

Figure 1. Conceptual Framework Connecting Curricular Complexity to Influences on Undergraduate Student Learning and Persistence (Adapted from Reason et al. [8])

Methods

We draw on semi-structured qualitative interviews [9] with undergraduate students to characterize instructional complexity and develop rubrics that can be used alongside existing curriculum complexity maps to determine if a department is providing sufficient support to help students navigate the curriculum.

Setting and Participants. We interviewed 18 students from a large, land-grant, R1 university in the mid-western United States. At this university, students begin in their major or as "pre-engineering" students; all students in our sample were enrolled in a specific major. While there is no uniform first-year program, there are first-year engineering seminar courses that introduce students to professional skills related to engineering. There are engineering-centric living and learning communities and community-based scholarship programs that a subset of students participate in.

All undergraduate engineering students at the university were invited to participate in the research via an email sent through a listserv. The email directed interested students to complete a screening survey. The screening survey received 188 valid responses, and 112 of those students indicated a willingness to participate in the interview. We used maximum variation sampling to select students across engineering majors, year of study, and racial and gender identity. We invited 40 students to participate in the interview, and 18 students completed the interview. Demographic information is provided in Table 1. Interviews were conducted in late April 2025, so it is likely that students were preparing for final exams and that the timing impacted participation in our study. Additionally, the NSF grant funding the data collection was cancelled during the data collection period, which impacted our team's capacity to follow up with invited participants or invite more participants.

Table 1. Demographics of Interview Participants (n=18)

Year of Study		Discipline		Racial Identity		Gender Identity	
First	17%	Biological Systems	11%	Asian or Asian American	17%	Man	33%
Second	17%	Civil	17%	Black or African American	6%	Woman	44%
Third	28%	Computer Engineering	6%	Biracial or Multiracial	17%	Non-binary / Nonconforming	11%
Fourth	28%	Computer Science	17%	Hispanic or Latino/a/x/e	22%	Transgender	6%
Fifth	11%	Electrical	6%	Middle Eastern or North African	11%	Prefer not to say	6%
		Environmental	6%	Native Hawaiian or Pacific Islander	6%		
		Mechanical	28%	White or European American	44%		
		Other	6%				

Data Collection. The purpose of the interviews was to understand barriers and supports for student retention at the university of interest. Semi-structured interviews allowed for a deep understanding of personal, academic, and institutional factors influencing student outcomes while allowing the researchers to ask follow-up questions. The interviews were conducted via Zoom by two graduate student researchers. Each session lasted 30 to 90 minutes and was audio recorded and later professionally transcribed. All but one participant completed a live Zoom interview with someone from the research team; one participant responded to the interview questions in writing, asynchronously. All participants received a $20 Visa e-gift card for participating in the research. The interview protocol included questions addressing the following areas: major choice and persistence, policies and advising, interactions with peers, academic preparation, career readiness and personal growth, well-being, and institutional improvements. The interview questions that are relevant to this paper are included in Table A1 (appendix).

Data Analysis. The goal of analyzing the interviews was to determine what kinds of support and barriers affect how students navigate the engineering curriculum but are not represented in a curriculum complexity map. Dedoose, a qualitative analysis software, was utilized to code and identify such supports and barriers. We developed an initial a priori coding scheme based on existing literature and our theoretical framework [10]. We then used emergent coding to add to the coding scheme based on codes that emerged from the data [10]. The first author conducted the qualitative coding, with feedback from the second author throughout the coding process. Our codebook detailing barriers and supports that were present in our data is provided in Table 2. Note that we provide a rich description of our analysis process below and focus our findings section on the main contribution of this work: the rubrics.

Table 2: Code Book from Interviews (n = 18)

Category	**Theme**	**Definition**	**Frequency of code**	**# of Participants**
Barriers	Workload Factors	Any mention of difficulty of classes, amount schoolwork, internships, and skills learned	75	17
	College Readiness	Any mention of preparedness for college, AP courses, college in high school, and thoughts going into college	30	14
	Well-Being	Any mention of mindset, mental load, mental health, and thoughts/feelings about continuing engineering	36	12
Supports	Advising	Any mention of advisors and advice received	69	18
	Peer Support and Interactions	Factors from peers or outside socialization that influenced the student in anyway	112	18
	Teaching Styles	Any mention of how a teacher taught and how it affected the student	91	16
	Teaching Assistants	Anything on how TA/tutors helped or didn't help student	17	8

We define a barrier as a factor that could prevent students from succeeding in engineering. In our initial coding scheme, based on existing literature and the theoretical framework, we identified the following potential barriers: delay and blocking factors, pre/co-requisites, course sequencing, scheduling factors, workload factors, college readiness, financial factors, and well-being factors. In our data, we found three types of barriers to be the most salient in students' experiences – workload factors, college readiness, and well-being. We define a support as a factor that could aid students in succeeding in engineering. In our initial coding scheme, we identified the following potential supports: advising, teaching styles, social factors, TAs, group work, student services, and outside resources. We then narrowed in on the factors that are not captured in curriculum complexity maps but contribute to instructional complexity and/or students' ability to successfully navigate a complex curriculum. This process led us to categorize supports as advising, peer-support and interactions, teaching styles, and teaching assistants.

However, through conversation amongst the author team and reviewing transcripts, we recognized that each theme we identified could serve as a support *or* a barrier. For example, college readiness could support student success if a student took AP courses and had people in their life advising them about college but could serve as a barrier if students had no access to AP or college courses. This realization led us to create a rubric, which explains how each category can make the engineering curriculum harder or easier to navigate. The data informed the initial criteria. In instances where the criteria were unbalanced (i.e., more "harder" than "easier) and not matched (i.e., only one valance of the criterion was present), we added the criterion's inverse. For example, from our data, we identified the criterion "competitive peer atmosphere" made the curriculum harder to navigate. We then added "collaborative peer atmosphere" to the easier to navigate column to represent the inverse of this criterion. We made this choice because, while students in our study may have had the "harder" experience, the inverse would make the curriculum easier to navigate and might be present in other contexts or samples of students.

In revising the rubric, we decided to split the rubric into two – one focused entirely on instructional factors and another focused on student factors. During this revision, we added "finances" as a category in the student factors rubric, based on our data and prior work [11], and removed "well-being." We were concerned that practitioners might attempt to use our student factors rubric as a diagnostic tool, and we did not want students to potentially feel pressured to disclose information about their mental health or well-being. We encourage those using our work and engaging in curriculum complexity work more broadly to be aware of the mental health challenges that students face, which are well-documented in higher education and engineering education (see [12], [13], [14], [15], [16], [17]).

Positionality. The author team is comprised of an undergraduate engineering student (first author) and a tenure-track faculty member (second author). Throughout this study, the first author's perspective as an undergraduate student influenced how she interpreted the data. Through the reflexivity process, she identified her belief that student success is a two-way street, requiring students to put in effort to succeed and institutions to provide proper resources for students to succeed. In analyzing the data, she saw many similarities to her own experiences and her peers' experiences. The rubrics evolved from joint conversations about wanting to add to curriculum complexity diagrams beyond stating the issues that students face.

The faculty mentor's experiences as an undergraduate and graduate STEM student and now as a faculty member in a traditional engineering department shaped the perspective that she brought to this work. She has experienced first-hand how supporting students, whether through advising or intentional course design, can help them succeed in a challenging curriculum. She has also researched and thought deeply about the role of challenge and difficulty in the engineering curriculum, including what types of challenges are necessary and unnecessary to educate work-ready engineers. Her experiences and prior work, in conjunction with existing literature on curricular complexity, led the team to challenge the assumption that high complexity is bad. Collaborating with the first author helped mitigate her preconceptions, and their different roles in engineering education helped them view the data from multiple perspectives.

Findings: Instructional Complexity Rubrics

We developed two rubrics, shown in Tables 3 and 4, for instructional complexity to supplement curriculum complexity diagrams and structural complexity statistics. The rubrics describe how academic and personal factors influence how a student navigates through the curriculum. The factors are divided into the top four most relevant categories based on how much each code occurred in the interviews. For each category, the rubric provides criteria that, if met, can make the curriculum easier or harder for students to navigate.

Table 3 covers instructional factors and is written at the course and curriculum level. Instructional factors include workload, teaching styles, advising, and teaching assistants (TAs). The instructional factors rubric is designed to capture the classroom and curricular experiences that an academic program or individual faculty members have control over. Table 4 covers student factors and is written at the individual student level. Student factors include peer support and interactions, college readiness, and finances. The student factors rubric is designed to capture the factors that students have control over. While it may seem that student characteristics are unrelated to instructional complexity – defined as how courses are taught and supported – we argue that they are a necessary lens to consider when contextualizing a curriculum complexity diagram and structural complexity scores.

Use Cases for Rubrics. We envision several potential use cases for these rubrics. Curriculum committees who are using Curriculum Complexity analytics to revise their curriculum could use these rubrics to contextualize their complexity score. For example, if a program's revision will add structural complexity, the rubrics can help them decide if more support structures are needed to help students succeed. In this vein, a highly structurally complex curriculum might be okay if the instructors use evidence-based teaching practices and demonstrate care for students, if advisors are available and knowledgeable, and if the workload is intentional. That is, if the majority of the criteria in the "easier to navigate" column are met, students may not face as many barriers as they navigate a complex curriculum. Students may, in fact, persist and graduate at higher rates than would be predicted by only the structural complexity scores. The inverse can be true as well; reducing the complexity of a curriculum but not considering instructional complexity can yield a curriculum that is still difficult to navigate. For example, a curriculum that has a low or average structural complexity may lack the supports needed to help students navigate it (i.e., high instructional complexity meaning the majority of the criteria in the "difficult to navigate" column are met), and thus students may persist and graduate at lower rates than would be predicted by the structural complexity scores.

College leadership who oversee undergraduate programs could use these rubrics to holistically assess the structural complexity of their curricula. For example, an institution may realize that most of its students have financial aid and must work jobs to cover their expenses, or that a portion of its students do not have access to college courses (or equivalents) while in high school. This awareness can then drive decision-making about the support systems needed to help students succeed.

Advisors and instructors who work with undergraduate engineering students could use these rubrics as a guide for providing support for a student. For example, an advisor might ask their advisee about their peer group and encourage them to take advantage of opportunities to meet and work with other students. An instructor might realize the importance of peer support and incorporate structured peer interactions into their course. Ultimately, we intend for these rubrics to be used to start conversations about support systems that might be needed to help students successfully traverse through the challenges of an engineering curriculum.

<u>**Limitations**</u>

As with any qualitative work, our rubrics must be transferred with care to specific institutional contexts. First, we stress that not all students face the same barriers. Each student's background and support system is unique, and some students will face more barriers in obtaining an engineering degree than others [18], [19], [20]. Our rubrics are not comprehensive lists of all of the potential barriers that students might face, and we encourage researchers and practitioners to use our work as a starting point and adapt our rubrics to their own context. Second, this work is limited in its collection of data from only one institution. While we included multiple disciplines in our sample, our results are impacted by the context of the institution we sampled at.

Lastly, we do not recommend giving the rubric to students as a "self-evaluation" tool, as it could lead them to a "self-fulfilling prophesy"; if they fall into the "harder to navigate" columns, they might develop a believe that engineering is going to be harder for them than their peers, increasing the risk for attrition. While the rubrics can be used to inform conversations with students, they should not be used as a diagnostic tool.

Table 3: Instructional Complexity Rubric – Instructional Factors (Course and Curriculum Level)

Category	**Curriculum can be easier to navigate if…**	**Curriculum can be harder to navigate if…**
1. Workload	☐ Topics are effectively taught through the course ☐ It develops students' problem solve and time management skills ☐ The learning environment feels professional ☐ Students apply information taught through internships, co-ops, clubs, etc.	☐ Students must learn topics on their own ☐ Students find classes and topics difficult, and little support is available ☐ Learning too much back-to-back ☐ Class is fast-paced and workload is high ☐ Classes offered at limited times ☐ Exams are misaligned with homework
2. Teaching Styles	☐ Evidence-based teaching practices are used ☐ Teaching uses hands-on approaches and focuses on applications and examples ☐ Frequent and effective communication between instructors and students ☐ Instructors demonstrate care for students ☐ Mix of group and independent work	☐ Classes are primarily lecture based, with little to no active learning components ☐ Infrequent and/or ineffective communication between instructors and students ☐ Students with disabilities are not accommodated ☐ Instructor discourages group work / peer interactions ☐ Students are negatively singled out by instructor
3. Advising	☐ Advisor communicates requirements and guides students through curriculum ☐ Advisor is easily available ☐ Advisor is knowledgeable in curriculum requirements ☐ Exceptions can be made to help students traverse co/pre-requisite requirements; knowledge of exceptions is made available to students in need	☐ Advisor is not easily available, and communication is limited between student and advisor ☐ Students change advisors during their degree ☐ Advisor is not knowledgeable of curriculum and may mislead students on requirements ☐ No exceptions are made to co/pre-requisite requirements
4. TAs	☐ TA is easily available. ☐ TA is friendly. ☐ TA teaches well and can explain content in multiple ways	☐ TA is not available or not approachable ☐ TA is rude or unfriendly ☐ TA does not teach well or can only explain content in one way

Table 4: Instructional Complexity Rubric – Student Factors (Individual Student Level)

Category	Curriculum can be easier to navigate if the student …	Curriculum can be harder to navigate if the student…
1. Peer Support and Interactions	☐ Has a positive social group ☐ Feels a sense of community ☐ Has had positive experiences working in groups in class ☐ Has access to peer support to complete school work, when appropriate ☐ Is involved in clubs and has had positive experiences ☐ Receives advice from peers on classes ☐ Has a consistent peer group throughout degree program ☐ Collaborative peer atmosphere	☐ Has a poor social group ☐ Does not feel a sense of community ☐ Has had negative experiences working in groups in class ☐ Primarily completes school work alone ☐ Does not interact with other students or give/receive support from other students ☐ Has trouble communicating with other students (e.g., language barrier) ☐ Made friends in introduction classes but doesn't have class with them anymore (changing friend groups) ☐ Competitive peer atmosphere
2. College Readiness	☐ Started college with course credit (AP/IB/dual enrollment/etc. courses); credits transferred easily ☐ Understood the topics taught in high school, particularly in math and science ☐ Has people in their life who helped them prepare for college (counselor, parents, sibling, etc.)	☐ Did not start college with course credit or credits did not transfer ☐ Did not take AP/IB/dual enrollment or college courses before starting degree ☐ Did not understand the topics taught in high school, particularly in math and science ☐ Does not have people in their life who helped them prepare for college
3. Finances	☐ Has sufficient scholarships, grants, or financial support from family to cover tuition and living expenses. ☐ Doesn't need to work a job to earn money for my expenses.	☐ Has little to no help with financial obligations ☐ Does not have sufficient scholarships, grants, or financial support to cover their tuition and living expenses ☐ Has to work a job to earn money for their expenses.

<u>Discussion and Conclusion</u>

Our work adds to ongoing efforts to use curriculum complexity to inform decision-making and improve student success outcomes (e.g., [5]-[10]). Existing efforts have focused on quantifying curriculum complexity by defining variables to describe the overall complexity of a curriculum and the delay and blocking factors of individual courses [1]. While these efforts have been successful at improving graduation and retention rates at certain institutions [3], there are some cases where using curriculum complexity has resulted in more complex curriculums, particularly for transfer student populations [21]. The existing curricular complexity methodology is highly advantageous towards the policy goal of informing institutional and department level decision making. However, the existing methodology does not account for the wealth of literature about the qualitative factors impacting a student's ability to successfully navigate through a curriculum.

Structural complexity is only half of the curriculum complexity picture; lowering structural complexity does not translate one-to-one to increased persistence. For example, a sole focus on lowering complexity scores could be achieved by combining courses (e.g., statics and dynamics) or removing pre-requisites (e.g., statics is no longer a pre-req for dynamics), but both of these avenues increase the instructional complexity and make the curriculum harder for students to navigate. We must consider the moderating variables (instructional complexity and student factors), which are well-researched, in order to see a complete picture of persistence. Our work attempts to bridge this gap, developing practical rubrics that surface the qualitative factors implicit in curricular complexity. We intend these rubrics to be simple tools that decision makers can use to contextualize the statistics they receive from a curriculum complexity analysis. With further refinement through a systematic literature review, broader empirical study, and feedback from stakeholders, these rubrics could be integrated into the curriculum complexity methodology, perhaps in the form of checklists.

Currently, when curriculum complexity data is used in practice to inform decision making around curriculum redesign, it is easy for practitioners to assume a complex curriculum is inherently bad. While the extreme cases should warrant implicit concern – for example, one study found a maximum complexity value of over 800 despite a mean structural complexity value of 313 [6] – cases within a standard deviation of the mean should consider structural complexity in conversation with instructional factors, students' backgrounds, support provided to students, and persistence rates. Moreover, benchmarking against other programs (within and beyond one's own institution) does not tell the whole story. Two programs could have the same complexity score, but instructional methods, the institutional and student profile, TA and advising support, college readiness, and other factors can influence how difficult a curriculum is for students to navigate. The rubrics can bring nuance to the complexity conversation, helping inform whether more student support is needed (e.g., advising, student support planning, classroom activities to facilitate peer connection). We hope that decision makers will ask, "How can we support our students through this complex curriculum?", and will use our rubrics as a guide to answering that question.

Future Work

We encourage future work on the instructional complexity construct within curricular complexity and hope that researchers and practitioners will build upon our work. Future studies could use literature and empirical data to add to or validate our rubrics. Studies could test and refine our rubrics through interviews or focus groups with faculty who make curriculum decisions. Future studies could explore other ways to quantify instructional complexity or develop additional, practical tools to facilitate conversation and decision making around student support.

Acknowledgements

This work was made possible by support from the National Science Foundation #2408749 and #2244323. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Appendix.

Table A1. Relevant Interview Questions

1. What (if anything) have you found to be particularly challenging about being an engineering student?
2. Are there any specific policies or rules (university, college, department, or course) that have made it more difficult for you to earn a degree in engineering? If so, tell me about them. If not, why not?
3. Can you talk to me about how advising has gone for you?
4. Are there any changes that you wish your department or the college would make to make it easier for you to earn your degree? If so, tell me about them. If not, why not?
5. How have you interacted with your peers throughout your time in engineering?
6. Do you feel connected to any of your peers in engineering? Tell me more.
7. How do you feel about working with others (in your courses)?
8. Can you think of a class that has done a particularly good job at getting you to collaborate with your peers? Tell me about it.
9. Can you think of a class that did not do a good job at getting you to collaborate with your peers? Tell me about it.