Diversity Index: A New Perspective on Engineering Capstone Projects

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His research lab, Sustainable Design Labs, focuses on fusing analytical chemistry, sustainability design principles and data analytics to address Water and Sustainability grand challenges. Current thrusts focus on Smarter Riversheds, Microbial Fuel cells and advanced oxidation and separation processes.

Focused on co-creating long term partnerships that synergize community vision with Pitt's core competencies of research and education, Sanchez has built up Pitt Hydroponics in Homewood, founded Constellation Energy Inventor labs for K-12 students, and re-created the Mascaro Center's Teach the Teacher sustainability program for science educators in the region.

As a teacher he designed and created the Sustainability capstone course which has annually partnered with community stakeholders to address sustainability challenges at all scales. Past projects have included evaluating composting stations in Wilkinsburg, studying infrastructure resilience in Homewood, enabling community solar in PA, improving energy efficiency in McCandless Township, and improving

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ABSTRACT

Capstone courses in engineering usually lead to projects where student teams show their skills at providing engineering solutions for realistic problems, making use of the knowledge and training acquired through the entire college curriculum, and demonstrating student readiness to enter the job market or moving into research. These projects are often displayed at venues where judges from academia and industry conduct evaluations to assess those achievements. Grading rubrics are generally based on the engineering approach, ability to reach a solution, specific design content, innovation, team performance, and presentation and communication skills. It has become popular that these showcases turn into competitions, with prizes and recognitions awarded to selected projects. In this study, we took an additional perspective on these capstone courses and events by analyzing the composition of these teams in terms of diversity and the potential impact of this factor in the performance and results. We took the occasion of a large presentation of over 100 capstones projects by the Class of 2022 at the University of Pittsburgh, with the participation of more than 500 senior students, to assess the diversity of teams across the various departments of the School of Engineering. An additional population of almost 100 senior students from a department that does not participate in the event but offers a comparable capstone project was also included in the study. The evaluation of the projects was conducted by instructors and expert judges from industry and academia. Trends were examined between performance grades versus a diversity index, using metrics and characteristics previously reported. The diversity of the self-selected team members (most commonly 4-6), as measured by this diversity index, reveals a marked trend for teams to have a lower diversity index compared to their departmental, class, or course makeup, exposing some probable implicit biases on identity. Some other results show how diversity impacts team performance differently depending on the prevalent characteristic of the group. The analysis provided in this paper offers criteria and methodology applicable to institutions and situations to quantitatively assess diversity that can lead to practical guidelines and even policies.

Introduction

Diversity is currently sought as a necessary component of engineering education [1] required for the future workforce. In the words of William W. Wulf, then the president of the National Academy of Engineering, “without diversity we limit the set of life experiences that are applied, and as result we pay an opportunity cost – a cost in products not built, in designs not considered, in constraints not understood, and in process not invented” [2]. After emphasizing his conviction that “engineering is a very creative profession”, he went on to say that “[at a] fundamental level, men, women, members of minority groups, and people with physical disabilities experience the world differently. Those differences in experience are the “gene pool” from which creativity springs” [2].

Diversity continues to be a much debated and often confusing term, but it can be taken as “the distribution of differences among the members of a unit with respect to a common attribute” [3], equivalent to Blau’s heterogeneity except for the specific reference to a common attribute [4]. To date, the relation between team diversity and performance has not shown conclusive results: diversity based on bio-demographics (i.e., gender, ethnicity, age) appears to show no positive effect, while diversity based on acquired functionalities (i.e., education, skills) seems to show positive impact on team performance [5]. Studies on the relation of team diversity and performance have also shown contradictory results [5]. In addition, the intersection of individual characteristics with the culture of a specific team also plays a significant role that can lead to different outcomes due to member behaviors [6].

The most common metric used in research to assess diversity is based on the Blau’s heterogeneity index (Equation 1) [3], [5], where p_i is the fraction of members in the i^{th} group (the number of individuals in the group divided by the total population) [4]

$$HI = 1 - \sum p_i^2 \qquad (1)$$

A simple way to assess diversity is to highlight the percentage or fraction of diverse groups. The Census Bureau used both for the 2020 Census, with some other parameters like the prevalence ranking and mapping, and the diffusion score [7]. However, they also announced plans “to explore other diversity measures”, to overcome the limitations from available approaches [7].

The use of percentages is very common in reports assessing diversity in engineering careers and jobs [8], [9]. They can be used to track changes in representation regarding the general population. Historically in engineering, white-American-men is the reference group for with the largest percentage, and other people are classified into women and minority groupigs, where minorities are further identified by race or ethnic identities such as Black or African American, Hispanic or Latino, Asian, and American Indian/Alaskan Native [8], sometimes with additional categories as Native Hawaiian or Other Pacific Islander, and more than one race [7], [9] and person with disabilities [10]. Most of these reports show the concerns on the underrepresentation of women and minorities in engineering fields.

The simplest way to combine these percentages in one single index should be to define it as the total percentage or proportion of non-white-American-men, as this is the “prevalent” (largest percentage) characteristic in engineering fields. It could be referred to as the “minority index” given by Equation 2, where WAM accounts for the number of white-American-men in each population (Total)

$$MI = 1 - \frac{WAM}{Total} \qquad (2)$$

However, these indices (HI, MI) face some critical limitations. The HI requires clear divisions among groups, with every individual identifying with one distinct group. Conflicts in calculations and interpretation arise when the same individual is part of multiple groups (i.e., African-American woman), with increasing relevance for engineering diversity when adding cross-sectional categories based on sexual orientation (i.e., LGBQT+), disabilities, first-generation, or internationality. All these factors and more (i.e., economic status, rural/urban) could prove to be of impact in engineering education performance. The MI based on the concept of “minority” poses some challenges [7] and fails when used for groups where WAM is not the prevalent characteristic of the group, as it can be the case in many engineering project teams.

Rodriguez et al. have introduced a diversity index that integrates gender, race, ethnicity, sex orientation, and first generation as contributing attributes to measure diversity [11], [12]. More specifically, this diversity index is defined by eq. (3)

$$DI_P = 1 - \frac{Prevalent\ characteristic}{Total} + 0.1 * \frac{Secondary\ diverse\ characteristics}{Total} \qquad (3)$$

where the characteristics are “White American Men (WAM)”, “Women (W)”, “Non-Binary (NB)”, “Black or African American (AA)”, “Hispanic or Latino/a (H)”, “Asian, Middle Eastern, Native Hawaiian or other Pacific Islander, or American Indian or Alaska Native” (AO), “LGBQT+ (LGBQT)”, “With disabilities (D)”, and “First Generation (FG)”. Individuals are counted for every characteristic. The characteristic with most members within a group is set as the prevalent characteristic and reported by the index as the subindex (i.e., DI_W would refer to a diversity index for a group were women are the highest percentage). This index considers multiple characteristics in the same individual (i.e., woman, Latina, First generation) as additional contributions to diversity. These secondary characteristics are moderated by a factor of 0.1 (10%) as a preliminary approximation, pending further research on better estimates for this weighting factor.

This diversity index is intended to provide a more integrative consideration of diversities over the minority index that simply calculates the ratio or percentage of minorities (individuals who are not white American men) in a certain population. Though both indices tend to be similar for large groups with prevalent white-American-men composition, the minority index fails to address diversity at small groups, like student teams of 3-6 members commonly organized for capstone projects (i.e., a team of only women will report a minority index of 100%, but there is no diversity regarding gender).

This diversity index avoids the multiple subgrouping that would require the extension of the heterogeneity index when considering cross-diversities (i.e., it would require a subgroup identifier for African-American women, Latino women, Asian women, etc. someway losing track of the representation of the former “women” group). It also provides for an easier interpretation.

Methodology

Each academic year, the Swanson School of Engineering (SSOE) at the University of Pittsburgh organizes the “Design Expo”, a public event gathering the capstone design projects for the Departments of Bioengineering (BIOE), Civil and Environmental Engineering (CEE), Electrical and Computer Engineering (ECE), Industrial Engineering (IE), Mechanical Engineering and Materials Science (MEMS). In addition, it includes final project designs for the course of “Product Realization” (PR), and “The Art of Making: Hands-on system design and Engineering” (AOM). The 2022 event took place on April 22, at the University Club, with the participation of 436 students in 84 projects “that traverse the design space from problem identification, specification of objectives and constraints, conceptual development, to, in many cases, result in an actual prototype. In this way the EXPO provides an opportunity for students to display their creativity and ingenuity” [13]. Data on students’ characteristics for the diversity index were collected by the authors attending the EXPO, observing participants’ stereotypes, contrasting names on the brochure, and in some cases validating observations with databases (i.e., LinkedIn). Characteristics based on sexual orientation and first generation are largely unobservable and consequently are underestimated, as it has been discussed earlier [12]. Judges provided scores for five categories (1. Resolve a design problem, 2. Approach, 3. Innovativeness, 4. Presentation/Communication, and 5. Technical Performance) using rubric with performance scores ranging from 1-5, with 5 set as the highest performance score (Appendix 1). The metric used here to evaluate team performance is the average for the five categories (range 1-5).

Chemical Engineering (CHE) students normally do not participate in this forum. Their capstone course on “Systems Engineering II: Process Design” is oriented to the design of a midsize commercial plant to produce a common chemical (e.g., styrene monomer), following a rigorous sequence of detailed design specifications, chemical reactor design, separation units design, heat management, utilities selection and design, equipment costs, operating costs, and profitability analysis. It also includes considerations on public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors, making informed judgements and recognizing ethical and professional responsibilities in engineering situations, as required by ABET Student Outcomes 2 and 4 [14]. Students make final presentations of their projects to a panel of judges from industry and academia. Data on students’ characteristics for the diversity index were collected from the instructors of the two parallel sections for the spring 2022 course on 82 students and 14 projects, and for the summer 2022 course with 16 students and 3 projects. Judges used the rubric provided in Appendix 2, with scores for 12 categories in the range 0-3, with 3 set as the highest performance score. The weighted average (range 0-99) divided by 20 is used here as the metric for group performance, to achieve a similar range than for comparisons with the Design Expo projects (1-5). Only one section of 50 students reported performance values and it is taken as the reference for CHE in the analysis below.

Results and discussion

The diversity data for the capstone course projects is presented in Table 1. Some characteristics are significantly under-represented (NB, LGBQT, D, and FG) as they are hardly observable, and the method to collect data was restricted to direct observation. This problem may persist with the use of surveys to collect demographic data; though, it is expected to improve in further research. However, the authors advocate including these attributes at this early stage of developing and testing the proposed index to signal the necessary visibility of the potential impact of these identities on the analysis of diversity. Based on the experience of the authors, it is considered that these attributes are present here in a small proportion, except for First-Generation individuals, which will be given special consideration later in the paper. As secondary characteristics (LGBQT, D, FG) they are further attenuated by the 0.1 factor in the calculation of the index, resulting in a potential minor impact on results. A more detailed breakdown of "identities" should be considered, for example Hispanic and Asian individuals may add to the diversity of groups to different degrees depending on how recently their families immigrated to the US and how strongly they identify with their families' cultural values, beliefs, and traditions.

Table 1. Diversity data on engineering capstone course 2022 projects (Acronyms defined above). Notice that numbers in rows do not add to the total number of students as some students are counted several times by secondary characteristics.

Dept.	Projects	Students	WAM	W	NB	AA	H	AO	LGBQT	D	FG
School	93	468	217	176	1	14	9	91	2	1	0
BIOE	12	99	20	65	0	3	2	23	0	0	0
CEE	10	50	22	26	0	2	0	3	0	0	0
CHE	17	96	56	35	1	3	3	3	2	1	0
ECE	20	82	58	10	0	4	1	10	0	0	0
IE	11	46	10	22	0	2	2	25	0	0	0
MEMS	23	95	51	18	0	0	1	27	0	0	0

Capstone projects mainly require teams of 4-5 members. A few 3-member teams were operational in Mechanical Engineering projects. Up to 6-member teams were allowed in Chemical Engineering projects (with an average of 5.65), while Bioengineering capstone projects included more than 8 members per team (with an average of 8.25).

For the Class of 2022, the School of Engineering was characterized by a minority index of 53.63%, where women, African-American men, and Asian men slightly surpassed the number of White-American men. This result is mainly influenced by the prevalent presence of women in Bioengineering and in Civil and Environmental Engineering, and the prevalence of the Asian ethnicity in Industrial Engineering (Figure 1). Overall, the White-American-men characteristic is the prevalent factor, with low representation of African-American ethnicity (3%) and Hispanics (2%).

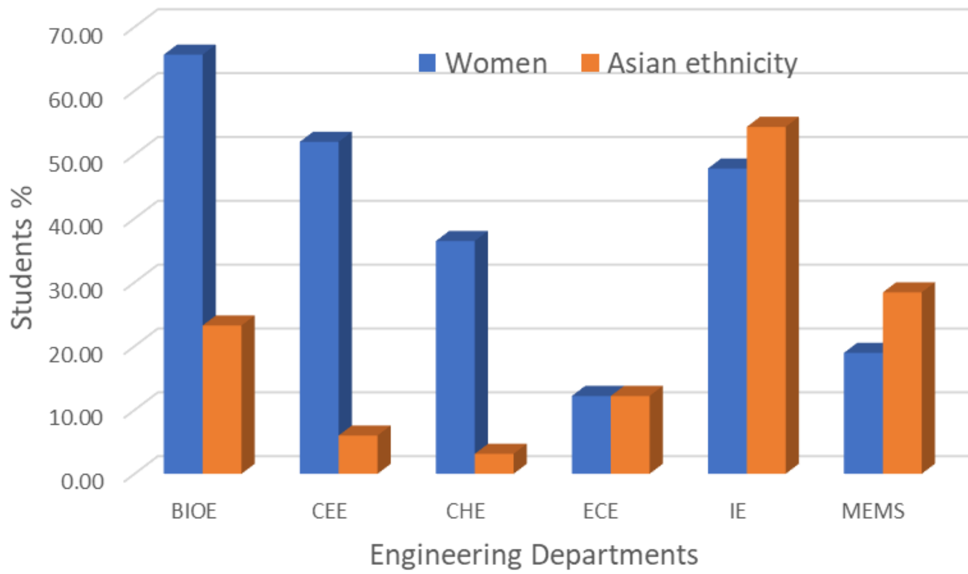


Figure 1. Presence of Women and Asian ethnicity in engineering careers at the School of Engineering Class of 2022

As discussed earlier [11], the minority index is not a reliable measurement of diversity, as it is based on the reference to the White-American-men characteristic. More insight is derived from the calculations of the diversity index as presented in Table 2.

Table 2. Diversity Index by Departments at the School of Engineering (Class of 2022)

Department	MI	DI	Prevalent
School	0.54	0.55	WAM
BIOE	0.80	0.36	Women
CEE	0.56	0.49	Women
CHE	0.42	0.43	WAM
ECE	0.29	0.29	WAM
IE	0.78	0.49	AO
MEMS	0.46	0.47	WAM

The average diversity for the School of Engineering (0.55), close to the minority index (054), exhibits strong variations at the Department level. The lowest diversity index (0.29) is observed at the department of Electrical and Computer Engineering, with a large presence of White-American men. The second lowest diversity index was calculated for the department of Bioengineering (0.36), which also had the highest minority index (0.80), due to the high proportion of women in the department. All the other departments share a 0.43-0.49 range in diversity index, including the department of Industrial Engineering, with the second largest minority index (0.78) due to the prevalent presence of students of Asian ethnicity and women. These illustrate the differences between the minority index and the diversity index in evaluating diversity. It is significant that while the School of Engineering is characterized by a diversity index of 0.55, every department of the School of Engineering has a significantly lower diversity index, as low as 0.29, with an average (department-based) of 0.42.

The reduction and dispersion of diversity is further accentuated at the teams' level, where diversity may have a larger impact, because it is the space where students interact for their learning experiences and development of skills. Figure 2 shows an example for the Department of Bioengineering. The self-selection of members led to the spread of the former entire group (class for the department) diversity index (0.36) into a broad range from 0.10 to 0.64 for project teams, with an average (team-based) of 0.34, less than the department's (group) diversity index, though half of the teams displayed a diversity index above the group index. Table 3 reports summary data for the six departments.

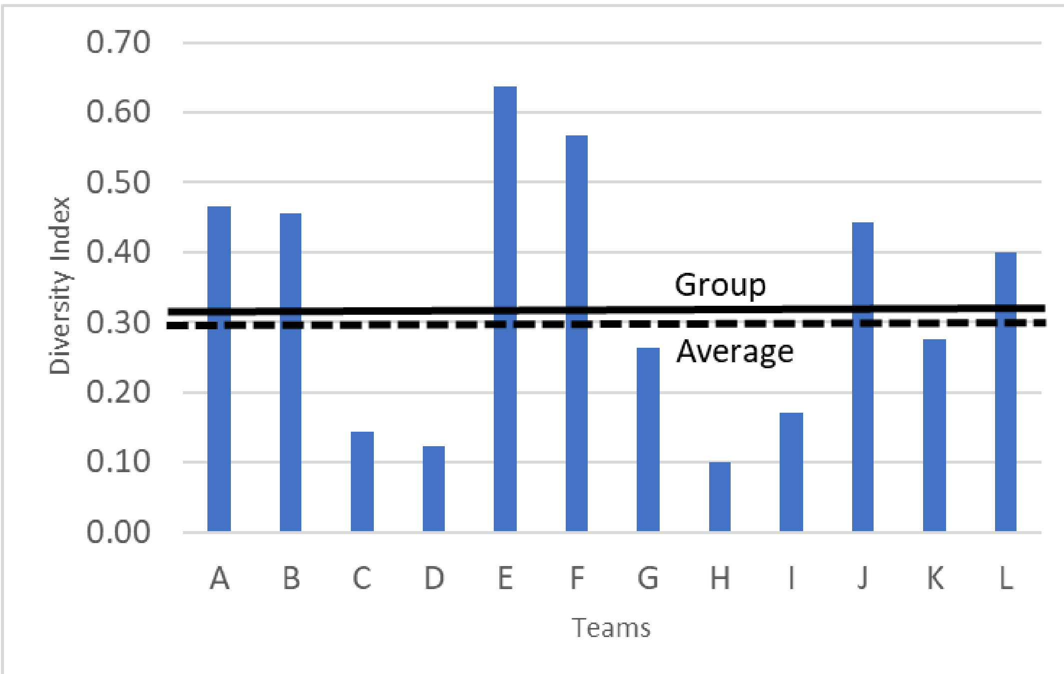


Figure 2. Diversity index for capstone project teams at the Dept. of Bioengineering (2022)

Table 3. Diversity index analysis at teams' level for the six departments of engineering.

Department	BIOE	CEE	CHE	ECE	IE	MEMS
Group Diversity Index	0.36	0.49	0.43	0.29	0.49	0.47
Average Teams Diversity Index	0.34	0.31	0.35	0.29	0.36	0.21
St. Dev. For Average Teams DI	0.18	0.22	0.13	0.17	0.19	0.20
Maximum Team Diversity Index	0.64	0.62	0.62	0.53	0.55	0.60
Minimum Team Diversity Index	0.10	0.00	0.14	0.00	0.03	0.00
Teams with Diversity Index above group, %	50.00	20.00	23.53	35.00	45.45	13.04
Teams with Diversity Index equal to 0, %	0.00	10.00	0.00	15.00	0.00	39.13

The team-based average for the diversity index is always less than the former group diversity index, except for ECE where both values are the same at the very bottom of range. The reduction in the number of individuals (team vs group) and the inclination to uniformity on selecting members of “equal likeness” can be taken as the driving factors. It is worth noticing that the variability of the average team’s diversity index between departments, measured by the range (0.21-0.36), shows higher variability than the group diversity index within departments (0.29-0.49). Departments with low diversity index (BIOE, ECE) have little room to increase their diversity index, while those with larger indices display a significant decrease, down to less than a half, as is the case for the MEMS department.

The standard deviation also shows one measurement of the relative dispersion of the diversity indices in teams. It is very broad for the MEMS department, with a value close to the average, and more constrained for CHE, with a value about one third of the average. However, the full dispersion can be assessed by the maximum and minimum values for the diversity index. The largest value for a single team is found in the BIOE department, though closely followed by CEE, CHE, and MEMS. The lowest value is 0.00, corresponding to teams with no diversity as measured by the characteristics of the index presented here. In this regard, the count of teams with no diversity provides an indication of the departure from a “balanced” composition of teams, as can be observed by the highest value of 39% of teams with no diversity for MEMS, while other departments do not include teams with zero diversity (BIOE, CHE, and IE). Another interesting perspective is given when examining the percentage of teams with a diversity index higher than the former group/department diversity index, reaching as high as 50% for the BIOE (strongly determined by the low diversity index of the group) and as low as 13% for MEMS (accompanying the already noted high percentage of teams with zero diversity).

A special note needs to be made about the data for the CHE department. The data presented in Table 3 corresponds to the compounded data for three different sections. This provided a constrained framework for the selection of members as they were restricted to each section. Detailed data is provided in Table 4.

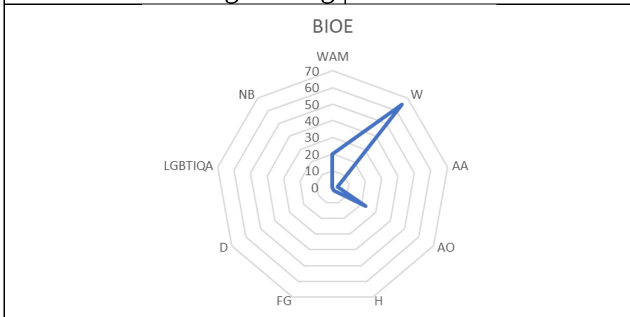
Table 4. Diversity index analysis at teams’ level for the three sections of the CHE department

Department/Section	CHE	A	B	C
Students	96	50	30	16
Group Diversity Index	0.43	0.37	0.51	0.45
Average Teams Diversity Index	0.35	0.33	0.45	0.20
St. Dev. For the Average Teams DI	0.13	0.12	0.10	0.00
Maximum Team Diversity Index	0.62	0.50	0.62	0.20
Minimum Team Diversity Index	0.14	0.14	0.33	0.20
Teams with Diversity Index above group, %	23.53	37.50	16.67	0.00
Teams with Diversity Index equal to 0, %	0.00	0.00	0.00	0.00

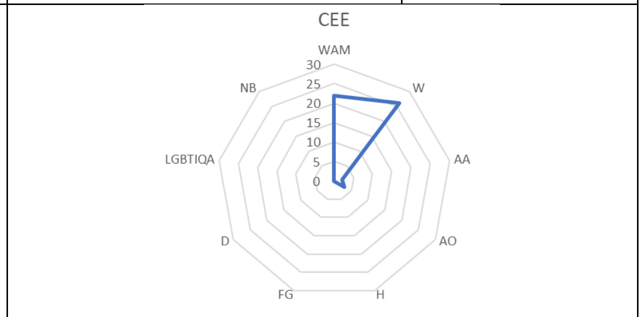
Table 4 confirms the same reduction in the diversity index from the group to the average of teams. The reduction is more accentuated for section C where the three groups were configured with identical index (0.20), two groups with the prevalent WAM characteristic, the other group with the prevalent Women characteristic, in an example of marked segregation by gender. Section B displayed a higher team diversity index (starting with the highest group diversity index), while Section A displayed a larger percentage of teams with diversity index above the reference for the group. No teams had a zero-diversity index.

A pictorial representation of this diversity index can also provide insights to assess diversity. Figure 3 depicts radar diagrams for the capstone project teams by departments.

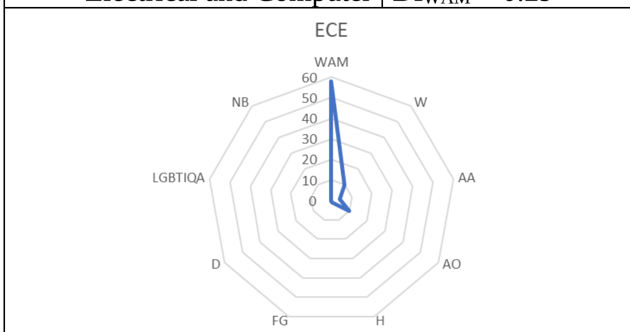
Bioengineering | $DI_W = 0.36$



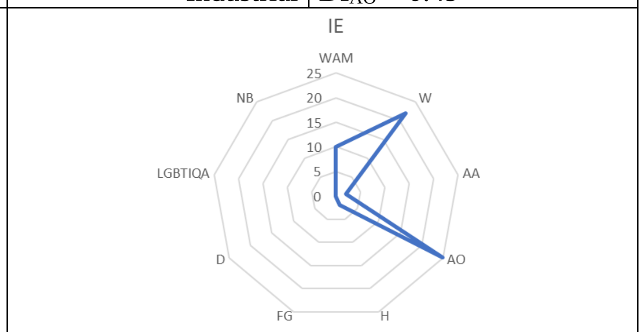
Civil and Environmental | $DI_W = 0.49$



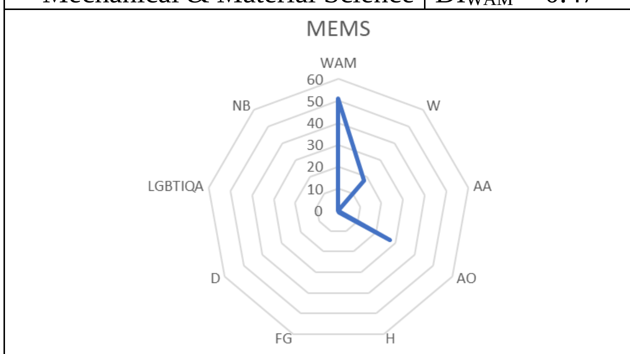
Electrical and Computer | $DI_{WAM} = 0.29$



Industrial | $DI_{AO} = 0.49$



Mechanical & Material Science | $DI_{WAM} = 0.47$



Chemical | $DI_{WAM} = 0.43$

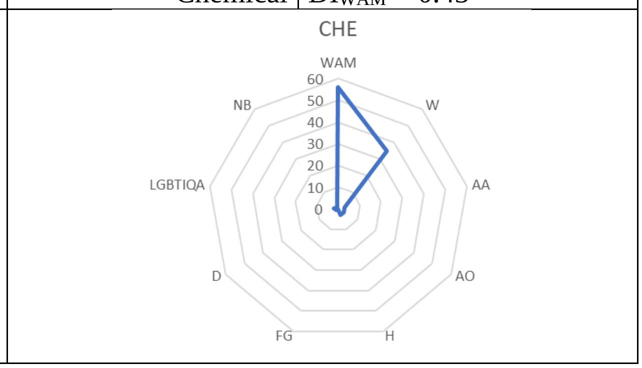


Figure 3. Pictorial representation of the diversity index calculation and composition for six departments of engineering. The numbers inside the diagrams refer to the number of students in the department presenting their projects. For other acronyms see above

The significant difference in appearance is a first indication of how the index can provide a “descriptive characteristic” for a given group made of various identities. The heavily uniform (low diversity) of the Electrical and Computer Engineering with prevalent White-American-men characteristic, contrasts immediately with the prevalence of Women in Bioengineering, or Asian in Industrial, or the more gender balance for Civil and Environmental. It also shows the critical underrepresentation of African-American and Hispanics. The “blank left side” is mainly due to lack of reliable data currently.

The previous results and analysis show the potential of this metric (diversity index) to describe and assess diversity in a very broad range of applications, from institutions down to project teams in engineering education (and potentially in other areas). It can be used to track variations in diversity through time or to develop pedagogical strategies (i.e., modify team composition or grade adjusted by diversity).

Another potential application of the diversity index is to explore correlations with performance. This is illustrated in Figure 4.

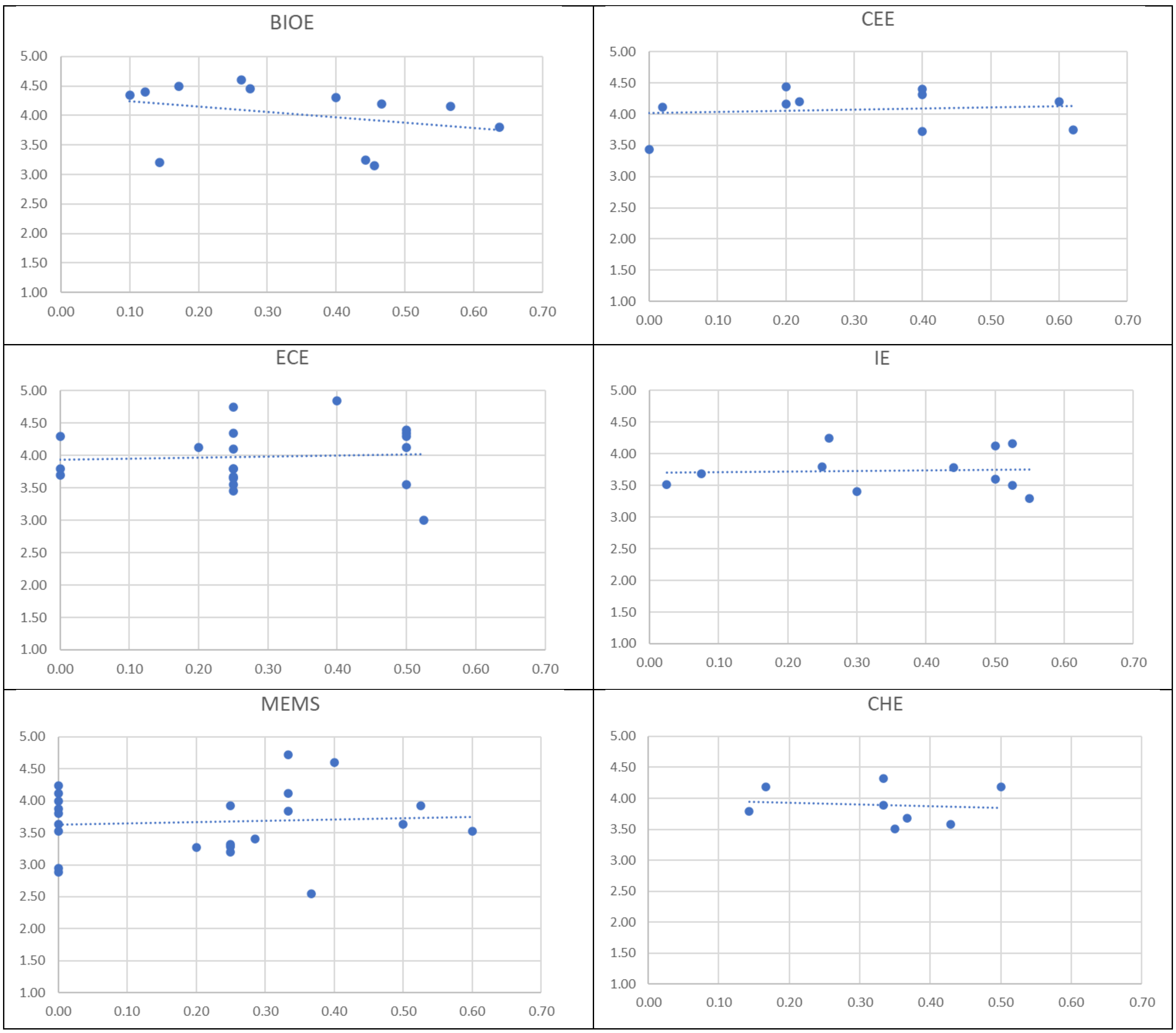


Figure 4. Graphical correlations between team performance and diversity index for capstone project from six departments of engineering. Plot ordinates report normalized scores (range 1-5), abscissas report diversity index.

It was preliminary assessed by examining the scores assigned to the projects presented at the EXPO event. Multiple judges used a grading scale from 1 to 5 to evaluate projects in six categories: Solution to a design problem, approach, innovativeness, presentation and communication skills, and technical performance and overall impact, as illustrated in Appendix 1 judging rubric. Average values were calculated by equally compounding all six categories.

Performance results are dispersed in a narrow range (3.5-4.5) restricting the development of correlations. The isolation of the diversity index as a single variable impacting team performance further constrains such an attempt (i.e., seven ECE teams with DI_{WAM}=0.25 resulted in performance values covering the entire range from 3.45 to 4.75, and similarly for nine MEMS zero-DI teams with performance range of 2.88-4.24).

However, as a preliminary point of consideration, a general slight trend is observed for performance improvement with the diversity index except for the BIOE and CHE departments, where the trend is the opposite. For the BIOE projects, three performance evaluations fall well below the trend (one of them at DI_{WAM}=0.44, Average=3.25, the only group with the prevalent WAM characteristic). This suggests that closer examination of the effect of the prevalent characteristic should be accounted for, not only on the value for the diversity index itself. This is illustrated in Figure 5.

For BIOE, CEE, IE and MEMS data show a slight trend to lower performance with increasing diversity index when the team is characterized by the prevalent presence of Women. The opposite trend is observed to higher performance with increasing diversity index for groups characterized by prevalent WAM (though there are some exceptions for CHE and IE), and no conclusive trend for prevalent AO (two opposite trends for IE and MEMS). The results for BIOE show a marked trend, though in a relatively narrow range for the diversity index (3.8-4.6), and impacted by two outlier data points. Similar trend is depicted for IE and MEMS regarding teams with prevalence of Women, but with reduced data points. Results for CEE show a more moderate trend. The dispersion of data for teams with prevalence of WAM does not a strong confirmation of the increasing trend in performance with increasing diversity index. The same applies to teams with prevalence of AO.

Certainly, the nature and scope of this data does not support conclusive results on the correlation between performance and diversity, it may even be taken as suggesting that there is no strong correlation, other than the observed slight trends, but it provides for a clear illustration of how research can be organized to test for the impact of diversity on some measurements of performance. Further research would require integrating other factors (variables) also impacting performance (knowledge, family and school background, economic situation, community support, etc.).

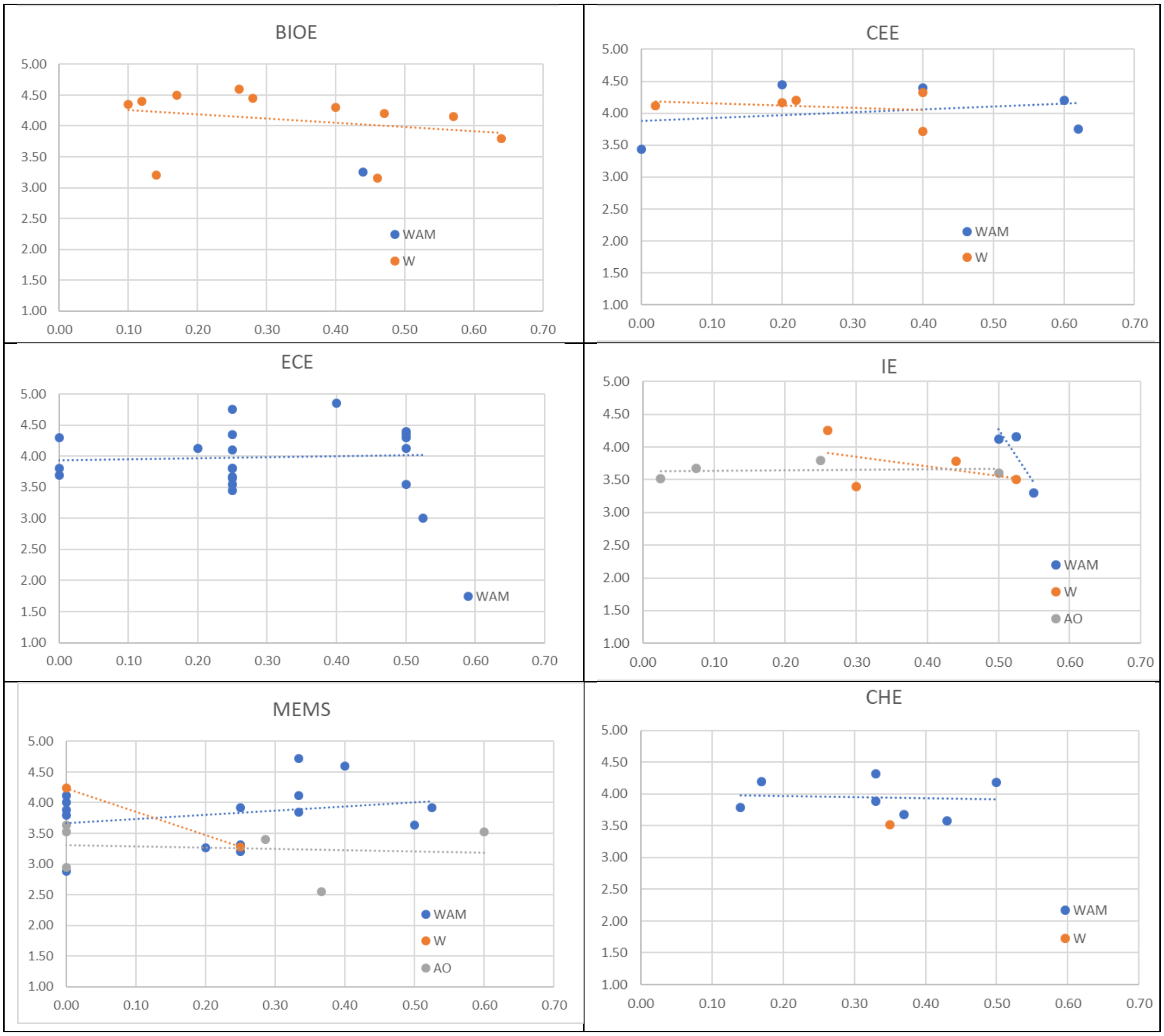


Figure 5. Graphical correlations between team performance and diversity index, with prevalent gender or ethnicity differentiation. Plot ordinates report normalized scores (range 1-5), abscissas report diversity index.

Only one attempt was made at this point, to prove the point, surveying spring CHE courses for First-Generation FG students, with the result of 7.3%. A previous survey at the school level reported a 10.4% for FG in senior year. Only one section from the spring term completed all the data required for comparisons, as illustrated in Figure 6. The percentage of FG in that section reached 12%, resulting in an increase on the DI_{WAM} from 0.37 to 0.38. The change is more visible in the radar representation. No significant impact on the correlation with performance despite the variations on the diversity index for some teams. As this is a secondary characteristic, moderated by a factor of 0.1 in the current calculation of the diversity index, the corresponding impact is significantly reduced. It is expected to be much less for the other under-represented characteristics.

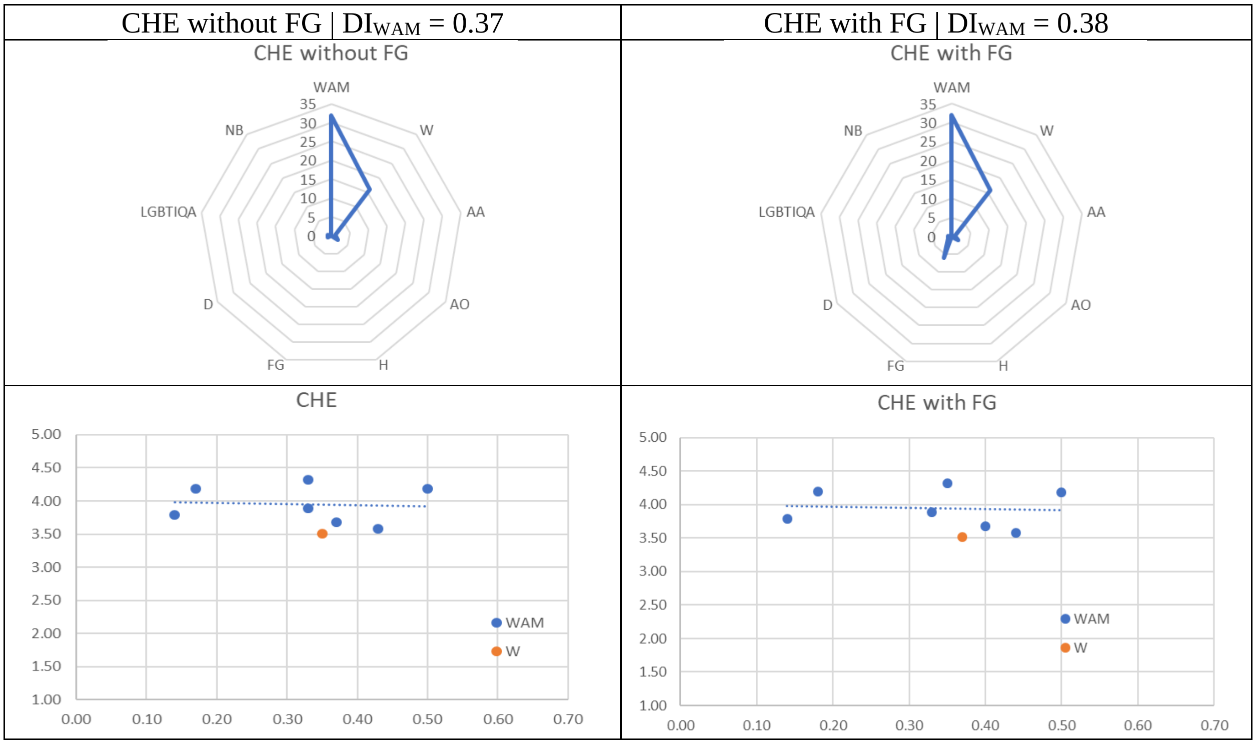


Figure 6. Impact of adding data on First Generation attribute to the calculation and representation of the diversity index and its correlation with team performance. The numbers inside the diagrams refer to the number of students in the department presenting their projects. For other acronyms see above. Plot ordinates report normalized scores (range 1-5), abscissas report diversity index.

Conclusions

The capstone projects are generally the most intensive and lasting experience for engineering students, ready to get into the job market. They offer the opportunity to consolidate and develop the teamwork skills they will take to their jobs. Awareness of the impact and handling of diversity in engineering teams is of increasing concern and promising results. This supports the convenience of research on diversity metrics and relation to team performance. A diversity index is proposed including nine attributes on gender, ethnicity, sexual orientation, disabilities, and first generation. It offers the advantage of previous metrics of a wider range of applicability from entire institutions down to classroom teams. It provides for a quantitative balanced number and a pictorial representation to characterize groups (classroom teams, engineering departments, schools, etc.). It has been tested here with teams of engineering senior students (a population of about 600 students Class 2022) presenting their capstone design projects. This preliminary research based on observation of team composition and project performance evaluations by judges at final presentations has illustrated several trends. Diversity reduces when teams are left to self-selection of members. There is no evidence of strong correlation between team diversity and overall team performance in these projects, but some trends to improve in performance with increasing diversity when the prevalent team characteristic is White-American-men, and to downgrade when the prevalent characteristic is Women. Further research is needed to validate data with surveys based on self-identity and other factors impacting team performance.

The diversity index can be used by instructors to assess team member selection upon students' self-identification. It can be arranged to make every team's diversity index as close to the group as possible. It can also be arranged to develop educational research on the impact of diversity on team performance, both from the perspective of results (scores in assignments) and in terms of behavior (teamwork assessment). It can also be used to adjust grades promoting diversity in self-selecting teams (i.e., offering bonus points for a range of higher diversity index values).

Maybe most significantly could be the use of the diversity index to call the attention to diversity among engineering students. It conveys a structure that resonates with their learnings (i.e., statistics, correlations, plots, diagrams). It provides for quantitative assessments. Instructors can use it in and early period of the course to profile the diversity of the group and teams, and discuss strategies to foster a culture of inclusivity, equity, and belonging to enrich the learning experience.

References

[1] L.M. Weber and R.A. Atadero. "Work in Progress: Incorporation of Diversity and Inclusion into the Undergraduate Chemical Engineering Curriculum". *Paper presented at 2021 CoNECD, Virtual -1pm to 5pm Eastern Time*. [Online] Available: https://strategy.asee.org/36145, https://peer.asee.org/work-in-progress-incorporation-of-diversity-and-inclusion-into-the-undergraduate-chemical-engineering-curriculum , [Accessed June 4, 2022]

[2] W.W. Wulf. "Diversity in engineering". *Leadership and Management in Engineering*, vol. 1, no. 4, pp. 31-35, 2001

[3] D.A. Harrison and K.J. Klein (2007). "What's the difference? Diversity constructs as separation, variety, or disparity in organizations" *The Academy of Management Review*, 32 (4) [Online] Available: http://dx.doi.org/10.5465/AMR.2007.26586096 [Accessed June 4, 2022]

[4] P. M. Blau. *Inequality and heterogeneity. A primitive theory of social structure*. The Free Press. New York, 1977

[5] M. Usher and M. Barak. "Team diversity as a predictor of innovation in team projects of face-to-face and online learners". *Computers and Education*, 144 (2020) 103702. [Online] Available: https://doi.org/10.1016/j.compedu.2019.103702 [Accessed June 4, 2022]

[6] D. A. Trytten, R. Pan, C. E. Foor, R. L. Shehab, and S. E. Walden. "Inclusion or Exclusion? The Impact of the Intersection of Team Culture and Student Identity and Pathway on Team Diversity". *Paper presented at 2015 ASEE Annual Conference and Exposition*. Seattle, Washington, June 14-17, 2015. [Online] Available: https://peer.asee.org/24273 [Accessed February 9, 2023]

[7] E. Jensen, N. Jones, K. Orozco, L. Medina, M. Perry, B. Bolender, and K. Battle. "Measuring racial and ethnic diversity for the 2020 Census". *US Census Bureau*, 2021 [Online] Available: https://www.census.gov/newsroom/blogs/random-samplings/2021/08/measuring-racial-ethnic-diversity-2020-census.html [Accessed February 9, 2023]

[8] N. J. A. Mamaril and K. D. Royal. "Women and minorities in Engineering. A review of the literature". *Paper presented at the 2008 Mid-western Educational Research Association*, Columbus, OH. [Online] Available: https://files.eric.ed.gov/fulltext/ED506512.pdf [Accessed February 9, 2023]

[9] A. Burke, A. Okrent, and K. Hale. "The state of U.S. Science and Engineering 2022". *National Science Board, Science and Engineering Indicators*, Alexandria, VA, 2022. [Online] Available: https://ncses.nsf.gov/pubs/nsb20221/ [Accessed February 9, 2023]

[10] National Center for Science and Engineering Statistics (NCSES). "Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023". Special Report NSF 23-315. Alexandria, VA. *National Science Foundation*. [Online] Available : https://ncses.nsf.gov/wmpd [Accessed February 9, 2023]

[11] J. Rodriguez, A. Dukes, and J.A. Keith. "A Diversity Index to assess college engineering team performance". *Paper presented at 2022 ASEE North Central Section Conference,* Pittsburgh, PA, March 19, 2022, Paper ID #36074. [online] Available: https://peer.asee.org/39225 [Accessed February 9, 2023]

[12] J. Rodriguez, J.A. Keith, and A. Dukes. "A Diversity Index to assess college engineering team performance and tracking institutional changes on diversity". *Paper presented at 2022 AIChE Annual Meeting*, Phoenix, AZ, November 14, 2022

[13] Swanson School of Engineering. "Design Expo". *Brochure*. University of Pittsburgh, University Club, April 22, 2022.

[14] *ABET criteria for accrediting engineering programs*, 2019-2020. [Online] Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/ [Accessed January 22, 2022]

Appendix 1. University of Pittsburgh | Swanson School of Engineering | Design EXPO Judging Rubric

Attribute	Unacceptable	Acceptable	Commendable
	1 2	3 4	5
Resolves a Design Problem	Insufficient information about the design problem/opportunity is given; project goals and benefits are poorly stated,irrelevant, or missing. Most or all-important project objectives have notbeen identified. Little to noinformation is obtained to support design recommendations	Sufficient information about the design problem/opportunity is given; the purpose and goals of the project are relevant and adequately explained. Important objectives are identified but 1 or 2 minorones are missing. Sufficient information isobtained but more is needed to support design recommendations	Thorough and relevant information about the design problem/opportunity is given; projectpurpose is broadly significant; goals are clear and easy to identify. All important project objectives are identified. All relevant information is obtained and used to support design recommendations
Approach	The approach to the problem is weak or flawed. 1-2 alternatives are considered. Analysis contains conceptual/procedural errors and does not apply all relevant engineering knowledge.	Approach to the problem is adequate. At least three alternatives are considered;analysis is complete but contains minor procedural errors.	The approach to the problem is strong and solid and considers all aspects. Three or more alternatives are considered; each is correctly analyzed for technical feasibility.
Innovativeness	Solution and or alternatives lacks creativity. The application, design or proposed solutions are readily available.	Solution and or alternatives considered arepotentially innovative, but more work is needed; does not illustrate potential for improved outcomes.	The solutions and alternatives considered are innovative. Team considered or demonstrated: a new use of an existing technology, use of material, manufacturing, or changes that lead to improved outcomes
Presentation Communication	Presentation/Poster is either dull (did not capture attention), overly creative (hard to follow), or poorly organized. Students were unprepared, misunderstood questions and did not respond appropriately. Poor writing and verbal skills	Presentation/Poster holds viewer's attention and includes acceptable graphics and tables. Students were prepared and understood questions but sometimes had difficulty responding. Writing is mostly clear. Adequate verbal skills	Presentation/Poster captures viewer's attention and includes interesting, appropriate tables and professional graphics. Organization is crisp. Students were fully prepared, anticipated questions and responded with more information than required. Excellent writing and verbal skills.
Technical Performance. Overall Impact.	Information is missing or difficult to understand. Further explanation is often needed. Design is underdeveloped and incomplete. I left the student group rather disappointed and confused. The project was not presented in a way that was compelling or effective	Information is present but at times is difficult to understand. Design is acceptable and complete. I enjoyed the student group's discussion and project. I learned a lot about the problem/opportunity. The student(s) conveyed interest and enthusiasm for their work	Information is thorough and at times enriches knowledge and interest. The design is thorough, robust, and usable. The student group and project were engaging and increased my knowledge and interest in this area

Appendix 2. CHE CAPSTONE DESIGN PROJECT PRESENTATION EVALUATION

Team Name ______________________________ Evaluator ____________________

Topic (Weight)	Unacceptable (0)	Marginal (1)	Acceptable (2)	Exceptional (3)	Points
Product Demand and Raw Materials Availability and Pricing (2)	Little or no understanding of the market. Incapable of producing a profitable product.	Some understanding of the market. Major deficiencies that will affect the ability to produce a profitable product.	Overall sound understanding of the market. Does not significantly impair solution.	Clear and thorough understanding of market and ability to produce a profit.	
Process Flow Diagram (3)	Process flow diagram is clearly infeasible.	Some deficiencies in process flow diagram.	Process flow diagram meets desired objectives.	The final process flow diagram clearly meets or exceeds desired objectives.	
Material and Energy Balances (3)	Erroneous material and energy balances.	Some deficiencies in the completion of the material and energy balances.	Adequate completion of material and energy balances.	Clear and concise completion of material and energy balances.	
Design and Cost of Major Pieces of Equipment (5)	Erroneous design and/or costing of major pieces of equipment.	Some deficiencies in proper design and costing of major equipment.	Effective design and costing of major equipment.	Critical design and costing of major equipment ensuring reasonable results.	
Process Optimization/Energy Conservation (3)	Erroneous results provided by process optimization / energy conservation.	Some deficiencies provided by process optimization / energy conservation.	Process optimization / energy conservation meets desired objectives.	Process optimization / energy conservation meets or exceeds desired objectives.	
Process Control Scheme/Controllers (2)	Erroneous design of process control scheme.	Some deficiencies in the design of the process control scheme.	Process control scheme meets desired objectives.	Process control scheme meets or exceeds desired objectives.	
Process Safety and Design Concerns (2)	Little or no understanding of process safety and design concerns.	Some understanding of process safety and design concerns.	Overall sound understanding of process safety and design concerns.	Clear and thorough understanding of process safety and design concerns.	
Process Environmental Considerations / Sustainability / Green Energy Tech (2)	Little or no understanding of process environmental considerations / sustainability / green energy technologies.	Some understanding of process environmental considerations / sustainability / green energy technologies.	Overall sound understanding of process environmental considerations / sustainability / green energy technologies.	Clear and thorough understanding or process environmental considerations / sustainability / green energy technologies.	
Process Economics (3)	Erroneous economic conclusions based on proposed design.	Some deficiencies in economic conclusions.	Sound conclusions reached based on economic evaluation.	Insightful, supported economic conclusions and recommendations.	
Team Participation (2)	Not all team members participated in the presentation / explanations / questions.	Most team members participated but without evidence of adherence to teamwork.	Participation of all team members, but with little evidence of teamwork.	Participation by all team members with evidence of advanced teamwork.	
Presentation Format (10 min) (3)	Not within time limit, ineffective use of visual aids, little use of correct technical language.	Not within time limit, ineffective use of visual aids, little use of correct technical language.	Within time limit, ineffective use of visual aids, appropriate technical language.	Within time limit, effective use of visual aids, appropriate technical language.	
Questions and Answers (5 min) (3)	Serious deficiencies in understanding and answering questions.	Some understanding of questions and answers.	Effective understanding of questions and answers, but only by some team members.	Effective understanding and answering of questions by all team members.	
POINTS	**0–50**	**51-69**	**70–84**	**85–99**	