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Multidisciplinary Capstone: Academic Preparation and Important Outcomes for Engineering Practice*

CLIFFORD A. WHITFIELD, ROBERT B. RHOADS and JACOB T. ALLENSTEIN
Engineering Education Innovation Center, The Ohio State University, Columbus, OH, USA. E-mail:Whitfield.22@osu.edu, rhoads.2@osu.edu, allenstein.1@osu.edu

The Ohio State University Multidisciplinary Capstone Program provides opportunities for engineering and non-engineering students to participate in an industry-partnered capstone experience through a two-semester course sequence with realistic projects defined by the sponsor and program. The program recently concluded a three-year effort to obtain formalized responses from its industry-partners, program alumni and students who had just finished the multidisciplinary capstone experience. The primary focus was on establishing rankings of the corresponding stakeholder's perspectives to the importance of the program's learning outcomes and relevant accreditation board for engineering and technology criteria, and the program's contribution to the student's preparedness. Key comparisons were made between each of the stakeholders. The results were also compared to the rankings of important knowledge, skills and abilities for all engineering students identified by the Transforming Undergraduate Engineering Education Phase I workshop study; a study conducted by the American Society for Engineering Education in 2013 to develop a strategy for undergraduate engineering education that meets the needs of industry in the 21st century. The data for each survey is provided with key observations and discussions on how the surveys are being used to continuously improve the multidisciplinary capstone program at Ohio State.

Keywords: multidisciplinary capstone; industry needs; industry perspectives; outcomes; assessment; program structure

1. Introduction

Most United States universities are using a capstone design course to culminate an undergraduate engineering program in which student teams create solutions to open-ended, real-world problems [1, 2]. Capstone supports a student's transition from the classroom to the engineering profession [1, 3]. The academic engineering accrediting body (ABET) has identified capstone as a key contributing factor to preparing students for engineering practice through a major project experience. The capstone experience typically has a design or research focus, and is based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints [4]. The primary goals of engineering education should be to develop the student's capabilities to integrate, analyze, innovate, synthesize, and understand contextually [5]. Engineering student team capstone projects are often created to meet learning outcomes that are related to the engineering professional practice [4–7]. These learning outcomes include teamwork, communications, sustainability, and consideration of global/societal design context. Multidisciplinary design capstone is a vehicle to holistically connect intellectual components of engineering to the real world [5, 7].

Collaboration between academe and industry can provide a valuable experience in preparing engineering students to meet learning outcomes and the challenges of the future. To meet these challenges, some argue that engineering education must be realigned and a strategy must be developed to recognize the need to communicate with the public and engineering community stakeholders on the goals of education and the value of success [8]. According to Rick Stephens, retired Sr. VP of Human Resources and Administration from the Boeing Company, "Industry, society, and engineering schools can—and should—collaborate to ensure a sufficient number of such qualified and capable engineers to meet industry and society needs" [9]. To meet the needs of both academe and industry, universities are incorporating multidisciplinary student teams to work on industry related capstone projects. Research has shown that multidisciplinary student teams produce better solutions than single disciplinary teams [1]. Capstone design surveys confirmed the trend to move from departmental (single disciplinary) teams to multidisciplinary teams [10–12]. Even though there is an increased interest to offer multidisciplinary teams, multidisciplinary capstone programs are difficult to create without college wide support and structure to foster this growth [13].

The Ohio State University (OSU) Multidisciplinary Capstone (MDC) Program provides opportunities for engineering and non-engineering students

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to participate in an industry-partnered capstone experience. Beginning in 2007, the Mechanical Engineering department offered industry-sponsored multidisciplinary capstone projects to mechanical and industrial systems engineering students. In 2009, OSU's College of Engineering created a Multidisciplinary Engineering Capstone Program to expand its offering to more students and industry sponsorship. Since 2009, the program has included over 450 students from 20 disciplines and 70 projects from over 50 different companies. Students from all 14 undergraduate engineering programs have participated in the program.

The multidisciplinary capstone program is continually developing and improving its capstone course sequence experience through soliciting feedback from the industry partners and past and present students. The program recently concluded a three-year effort to obtain formalized responses from its industry-partners, program alumni and students who had just finished the multidisciplinary capstone experience. The focus was on the demographics perspectives to importance of and preparedness contributed by capstone to relevant ABET Criteria 3 directed category topics related to the program's learning outcomes [4].

Identifying industry expectations of engineering graduates has been an important factor in modifying engineering curriculum to meet both ABET and industry needs [14]. With support from the National Science Foundation, the American Society of Engineering Education (ASEE) conducted a workshop in 2013 to develop a strategy for undergraduate engineering education that meets the needs of industry in the 21st century [15]. This new strategy was called Transforming Undergraduate Education in Engineering (TUEE). Prior to the TUEE workshop, several industry and academe representatives were surveyed to identify the most important engineering Knowledge, Skills and Abilities (KSAs) for today and the future as well as the perceived preparation of new engineering graduates. The survey questions were created from The Engineer of 2020, ABET accreditation criteria and ASEE conference papers related to the global engineer [4, 8]. At the same time, OSU's MDC Program was conducting a survey of its program alumni to evaluate the MDC Program's effectiveness of preparing them for the engineering profession. The survey was modeled after OSU's College of Engineering's Assessment Committee's survey that included ABET's accreditation criteria and the MDC Program's learning outcomes [16]. In 2013, the MDC Program assessed the current MDC students' perceived preparation prior to taking MDC and contribution to their MDC experience as it related to the ABET accreditation criteria. In 2014, the MDC program assessed its effectiveness in preparing students as observed by the program's past and current industry sponsors.

A literature review of collecting industry perspectives on new graduates and the needs of industry has identified common important themes relevant to capstone. Prior to creating a multidisciplinary senior design course, Colorado School of Mines surveyed companies and government agencies that hire their engineering graduates to identify key industrial needs and concerns [17]. Company representatives indicated that 75 percent of their engineering design teams were multidisciplinary in nature. In addition, the respondents identified six attributes they would like to see in new graduates. These attributes included: technical knowledge, communication skills, ability to work in small teams, ability to self-educate, ability to consider non-technical constraints, and ability to accommodate a multidisciplinary approach to problem-solving. In an ASEE Prism article, industrial managers indicated the importance of a multidisciplinary, team-based approach to solving problems and student recognition of the value to collaborate rather than competing to achieve high-quality, well-designed products or processes [18]. Brigham Young University's survey of industry resulted in similar perspectives [19]. Their respondents identified the need for graduates to have the ability to make effective and concise oral presentations, work in teams and have interdisciplinary interactions.

Assessing capstone learning outcomes through students' perspectives has indicated that a multidisciplinary capstone experience offers advantages over single disciplinary capstones. The University of Arizona has performed multiple assessments comparing students in a single disciplinary course and students in a multidisciplinary course [20–22]. These studies indicated students in the multidisciplinary course were better at identifying needs, understanding the importance of documentation and seeing the big picture of the design process. The US Military Academy noted advantages of multidisciplinary capstone courses compared to single disciplinary courses in student's recognizing the contributions of other disciplines in modeling a real-world engineering project [23].

The paper reviews the MDC Program's structure and learning outcomes, survey methods and respondents and results. This paper presents the results of OSU's MDC Program's surveys to the alumni, current students and industry sponsors. The results from these surveys are then compared to those of surveys conducted with OSU's College of Engineering alumni and TUEE participants. A synopsis of the survey results and a thematic analysis of the open-ended responses are provided for the reader's consideration.

2. Program structure

The multidisciplinary capstone experience is a two-semester course sequence with industry related projects defined by sponsor companies who support the projects financially and with company engineers working directly with the project. Projects include process and equipment design, energy and environmental improvements, and new product development. Students from all 14 undergraduate engineering programs have participated in the program. Programs include: aeronautical and astronautical, aviation, biomedical, chemical, civil, computer science and engineering, electrical and computer, engineering physics, environmental, food, agricultural, and biological, industrial and systems, material science and engineering, mechanical, and welding engineering. Students from other colleges also participate, and have included students from business, psychology, international studies, industrial design, dentistry, speech and hearing, occupational therapy, and food science. Many of the product development projects employ MBA students in the role of project manager.

The students follow a formal design process with design review phases that include problem definition, conceptual design, systems (or preliminary) design, detail design and final design. Each team has a budget that supports travel and prototype development costs. The learning outcomes for the program are provided below with identified corresponding related TUEE Knowledge, Skills and Abilities (KSAs). The identified KSAs are listed with definitions in the Appendix.

Because the multidisciplinary capstone course is one of several options for senior engineering students, instructors can be selective when accepting students. Students are screened through an application process that includes submitting a resume and application letter. Often, personal interviews are the deciding factor to ensure teams are formed with self-directed students. Students are asked to explain their interest in joining the program and to describe the contribution they expect to make to their team. During this process, the coordinators look for students exhibiting professional skills including time management, leadership, teamwork, communication, and initiative.

After the interview, students are placed in one of the three sub-programs that the multidisciplinary capstone program offers. These sub-programs include: Industry-Sponsored Projects, Industry-

Table 1. Multidisciplinary capstone learning outcomes and corresponding KSAs

Learning Outcome	Outcome Definition	Related KSAs
1. Perform professionally	Students individually exhibit integrity, accept responsibility, take initiative, and provide leadership necessary to ensure project success as part of a multi-discipline team.	6, 9, 14, 22, 36, 28
2. Produce quality designs	Students collectively produce designs that meet important authentic performance requirements while satisfying relevant societal and professional constraints.	3, 19, 30, 23, 31, 33, 34
3. Establish team relationships for quality performance	Students establish relationships and implement practices with team members, advisors, and clients that support high performance and continuous improvement.	7, 14, 28, 35
4. Manage project schedule and resources	Students plan, monitor, and manage project schedule, resources, and work assignments to ensure timely and within-budget completion.	12, 13
5. Apply knowledge, research and creativity	Students utilize prior knowledge, independent research, published information, patents, and original ideas in addressing problems and generating solutions.	2, 3, 19, 23, 25, 31
6. Make decisions using broad-based criteria	Students make design decisions based on design requirements, life-cycle considerations, resource availability, sustainability, and associated risks.	10, 11, 20
7. Use contemporary tools	Students demonstrate effective use of contemporary tools for engineering and business analysis, fabrication, testing, and design communication.	16
8. Test and defend design performance	Students collectively test and defend performance of a multi-discipline design with respect to at least one primary design requirement.	16, 19, 25, 34
9. Communicate for project success	Students use formal and informal communications with team members, advisors, and clients to document and facilitate progress and to enhance impact of designs.	1, 28
10. Pursue needed professional development	Students individually assess and pursue personal professional growth in concert with project requirements and personal career goals.	5, 12, 28, 6

Sponsored Product Design Projects, and Social Innovation and Commercialization (SIAC). For industry-sponsored projects, students work with local companies to improve processes, reduce costs, or create new products and markets. The SIAC program has been a collaboration effort between five different colleges at OSU; College of Arts, Humanities, Engineering, Business, Medicine, and local non-profit organizations. The SIAC program designs and commercializes products for people with disabilities with the ensuing revenue helping the non-profit partner become more self-sufficient.

Teams typically consist of three to six students matched to the needs and scope of the project. The clients present an overview of their projects to the class and the students identify and apply to projects that they are interested in. The application process includes the student addressing academic and personal skills in which the project can benefit from in written form, and are submitted to the program instructors for review. They are assigned to a project based on their qualifications and interests, ensuring that each team has the disciplines necessary to match the project need. The company assigns an employee (typically an engineer directly associated with the project) to the team of students to act as a liaison, coach, and subject-matter expert. The program instructors recruit faculty advisors for each project and the advisors are compensated by the program through project funds.

The students and faculty advisor hold a project kick-off meeting at the beginning of the course sequence. This meeting is typically held with industry personnel at their facility providing in-depth discussions of the project scope on-sight. Throughout the project, the teams maintain weekly meetings with their advisor and company liaison and are typically conducted through teleconference or videoconference meetings. At each major design review phase, the teams make a formal presentation to the industry and solicit feedback before proceeding to the next design phase. The presentation is complimented with a formal written document addressing key elements and results of the specific design phase. The final deliverables include a formal final report that contains each major review phase, a complete project notebook with a complete working drawing package if applicable, and a functioning design prototype and test results. The students have the opportunity to present their designs to university personnel, industry and the general community at an annual capstone design showcase that is organized by the multidisciplinary capstone program. The showcase is open to students from other discipline-specific capstone courses. There are on average over 120 teams from various capstone courses presenting at the showcase.

3. Survey methods and results

Three surveys were conducted targeting separate stakeholders for the multidisciplinary capstone program: industry partners, program alumni and students. Each survey included relevant questions to the respective responder for general program assessment, improvement and development. The primary focus was on establishing rankings of the stakeholder's perspectives to the preparedness and importance of the program's learning outcomes and

Table 2. Primary questionnaire categories and corresponding program learning outcomes

Category	Related LOs
1. Design and conduct experiments	2, 8
2. Analyze and interpret data	5, 6, 8
3. Design a system, component or process to meet a design need with realistic constraints	2, 6
4. Function on multidisciplinary team	1, 3, 9
5. Function on a cultural and ethnically diverse environment	3, 9
6. Manage and engineering project	4
7. Identify, formulate and solve engineering problems	5
8. Communicate effectively orally: presentations, meetings, etc.	9
9. Communicate effectively in writing: letters, technical reports, etc.	9
10. Use modern techniques, skills and engineering tools	7
11. Use computing technology	5, 7, 8
12. Recognize the need for and engage in life-long learning	10

corresponding ABET Criteria 3 (a–k) student outcomes [4]. The questionnaire regarding ABET objectives and outcomes was modeled directly from a recent survey conducted by the OSU College of Engineering (COE) Assessment Committee [16]. The COE survey targeted early-career college alumni, and included both college common and program specific learning outcomes. The questionnaire categories that were identified from the COE survey and used within the MDC studies are shown in Table 2. The corresponding related program learning outcomes (LOs) are identified for each category.

The program study used the COE investigations as ground-work to build the multidisciplinary capstone program investigations. The program focused first on its specific MDC alumni to make direct comparisons to the entire COE alumni population. The promising results of the MDC alumni study lead to the program expanding its investigations to obtain and compare perspectives of its current students and the industry-partners.

The surveys were distributed through an online service to keep the results confidential and to provide real time data analysis. A lead-in statement was provided indicating that all responses were voluntary and would be confidential with no personal identifiers collected. The statement also informed respondents that their responses would benefit the programs future development and its efforts in providing a valuable and positive multidisciplinary capstone experience for the students. The following sub-sections discuss each survey in more depth, starting with the MDC alumni study. For each survey, a Mann-Whitney-Wilcoxon test was conducted independently to determine statistically significant differences ($p < 0.05$) between the contribution of preparedness and importance of the program's learning outcomes and corresponding ABET Criteria 3 (a–k) student outcomes. This test was used due to the related paired sample and population and the data was collected on an interval Likert scale [24, 25]. The criteria that resulted in a statistically significant difference between the contribution of preparedness and importance for each stakeholder will be identified for each survey.

3.1 Program-alumni survey

In 2012–2013, MDC sent out a survey to approximately 370 program alumni. The survey covered first-year (2012) through fifth-year (2008) alumni, who had completed the multidisciplinary capstone course sequence. There were three main sections of the survey: a general questionnaire to determine the demographics with respect to their professional careers, the rankings of the ABET categories and the learning outcomes of the program and their impact on their early careers, and the extent to which the capstone experience helped with interviewing and obtaining their first job.

Table 3. Multidisciplinary capstone alumni general questionnaire results

What year did you take multidisciplinary capstone?

2007-2008 (5th year alum)	2008-2009 (4th year alum)	2009-2010 (3rd year alum)	2010-2011 (2nd year alum)
23%	36%	32%	3%

What is your current employment status?

Employed full-time	Employed part-time	Graduate/professional student	Unemployed, seeking employment	Other (please specify)
74%	5%	20%	2%	0%

Did you have any non-engineering students on your team?

Yes	No
33%	67%

* Percentages may not equal 100% due to rounding errors.

The general demographics questions had the respondents indicate their current professional status, and whether they had non-engineers on their respective capstone team. Of the 370 surveys sent out, the MDC program received a response rate of 17.8% (n = 66). Table 3 shows the demographics of the program alumni who completed the survey.

The majority of the alumni responses were from third to fifth year alumni, with the majority (74%) employed full-time. The remainder indicated that they were pursuing graduate school (20%), employed part-time (5%), or indicating that they were unemployed and seeking employment (2%). Of the alumni respondents, 33% had a capstone experience that included a non-engineering major on their team.

The primary focus of the survey was on the learning outcomes of the program and their impacts on recent graduates' careers. The questionnaire followed a similar process and structure as the COE Outcomes Assessment Committee's survey and included the COE's common outcomes previously discussed. The respondents were asked to rank, using a Likert scale, how important and how prepared they were when considering the ABET categories identified in Table 2. The specific lead-

Table 4. Multidisciplinary capstone alumni survey results

	Rate the following based on the importance to your career			Rate the following based on the contribution to your preparation resulting from your capstone experience		
Category	**Extremely Important, Very Important**	**Important**	**Somewhat Important, Unimportant**	**Extremely Helpful, Very Helpful**	**Helpful**	**Somewhat Helpful, No Contribution**
Design and conduct experiments	42%	20%	38%	41%	24%	35%
Analyze and interpret data*	73%	23%	5%	38%	35%	27%
Design a system, component or process to meet a desired need with realistic constraints	68%	20%	12%	70%	21%	9%
Function in a multidisciplinary team	79%	12%	9%	76%	8%	17%
Function in a cultural and ethnically diverse environment*	62%	27%	11%	52%	14%	35%
Manage an engineering project	74%	20%	6%	73%	23%	5%
Identify, formulate, and solve engineering problems	71%	17%	12%	77%	15%	8%
Communicate effectively orally: presentation, meetings, etc.	86%	12%	2%	82%	12%	6%
Communicate effectively in writing: letters, technical reports, etc.	79%	17%	5%	76%	20%	5%
Use modern techniques, skills, and modern engineering tools*	62%	23%	15%	47%	35%	18%
Use computing technology*	77%	12%	11%	53%	27%	20%
Recognize the need for and engage in life-long learning*	77%	15%	8%	42%	39%	18%

* Criteria with statistically significant differences.
** Percentages may not equal 100% due to rounding errors.

in questions to the alumni were: rate the following based on the importance to your career and rate the following based on the contribution to your preparation resulting from your capstone experience. Table 4 show the results of the alumni's perspectives on the importance to their career and the contributions to their preparation resulting from their capstone experience to the categories defined in Table 2.

The following criteria have a statistically significant difference between the alumni's perception of the importance to and the contribution of their capstone experience in the preparedness: analyze and interpret data; function in a cultural and ethnically diverse environment; use modern techniques, skills, and modern engineering tools; use computing technology; and recognize the need for and engage in life-long learning. For each criterion, the alumni indicated a higher percentage regarding importance to their early professional career than the contribution to their preparedness from the multidisciplinary capstone experience.

These results were initially compared to the COE Outcomes Assessment Committee study that was conducted in 2012 with a target audience of second (2010) and third (2009) year college alumni. Of the 1,376 surveys sent out, the COE received a response rate of 22.9% (n = 315). The results were divided into two categories that correspond to the general analysis conducted by the COE's Outcome Assessment Committee. The categories include topics that the Committee identified and determined that the COE reached a balance between the importance and preparation, and topics for continued or further consideration in program development across COE [16].

The COE's Outcome Assessment Committee identified four topics the college appeared to have reached a balance between the importance and preparation. The results indicated that a "balance" topic was one in which the difference between the preparation and importance rating (based on the Likert 1–5 rating) is on the order of ±0.30 [16]. Three of the four topics corresponded to questions asked by the MDC survey, of which two can be directly related to the learning outcomes of the program, and the third a supplementary topic of the program. The three topics identified by the Assessment Committee include: ability to design and conduct experiments, ability to identify and solve engineering problems, and ability to function in culturally and ethnically diverse environments. The MDC survey results demonstrated that the program is also balanced with respect to the first two topics; details are provided in Table 5.

The COE Outcome Assessment Committee identified seven topics that the college recognized room for continued development. Following suit with the balanced topics, the results indicated that a topic for "continued development" was one in which the difference between the preparation and importance rating was greater than ±0.30 [16]. Six of the seven topics corresponded to questions asked by the MDC survey, of which four can be directly related to the learning outcomes, and the other two are supplementary topics of the program. The six topics identified by the COE include: ability to function on multi-disciplinary teams, ability to communicate effectively in writing: letters, technical reports, etc., ability to communicate effectively orally through informal and prepared talks, ability to manage an engineering project, ability to analyze and interpret data, and ability to use computing technology. The first four topics listed have direct correspondence to the MDC program learning outcomes, and the MDC survey results show that the topics are "balanced" by the program using the COE committee's definition; details are provided in Table 6.

Additional details and discussions with respect to the program's direct comparison to the COE as a whole can be viewed in Whitfield et al. [26].

The program alumni survey also asked questions

Table 5. COE balanced topic list

Topic	COE			MDC		
	Imp.	Prep.	Diff.	Imp.	Prep.	Diff.
Ability to design and conduct experiments	3.36	3.22	-0.14	2.96	3.00	0.04
Ability to identify and solve engineering problems	4.03	3.73	-0.30	3.79	3.88	0.09
Ability to function in culturally and ethnically diverse environments	3.62	3.68	0.06	3.50	2.58	-0.92

Table 6. COE topics list for continued development

Topic	COE			MDC		
	Imp.	Prep.	Diff.	Imp.	Prep.	Diff.
Ability to function on multi-disciplinary team	4.17	3.62	-0.55	4.00	4.08	0.08
Ability to communicate effectively in writing: letters, technical reports, etc.	4.25	3.67	-0.58	4.08	3.75	-0.33
Ability to communicate effectively orally through informal and prepared talks	4.42	3.58	-0.84	4.33	4.13	-0.20
Ability to manage an engineering project	3.85	3.27	-0.58	3.92	3.79	-0.13
Ability to analyze and interpret data	4.39	3.75	-0.64	3.96	2.96	-1.00
Ability to use computing technology	4.42	3.77	-0.65	4.17	3.21	-0.96

Table 7. Multidisciplinary capstone alumni survey outcomes

Did the capstone experience help with...	Strongly Agree, Agree	Neutral	Strongly Disagree, Disagree	N/A
Having a successful interview	64%	9%	5%	23%
Obtaining your first job after graduation	52%	12%	6%	30%
Transition into your fist job assignment	58%	15%	6%	21%

* Percentages may not equal 100% due to rounding errors.

regarding whether the capstone experience helped with various stages of obtaining their first job, and if they would recommend the multidisciplinary capstone experience to up-coming students. Table 7 shows the alumni's responses to these specific questions.

The majority of the respondents indicated that the multidisciplinary capstone experience helped with interviewing for, obtaining and transitioning into their professional careers. The respondents that marked not applicable are, most likely the individuals pursuing advanced degrees and the small percentage (2%) still seeking employment. Ninety-five percent of the program alumni indicated that they would recommend MDC to underclassmen.

3.2 *Industry-partner survey*

The MDC program has long standing industry partners. A survey was distributed to 20 of the program's most recent industry sponsors to identify their specific reasons for getting involved with MDC, and their perspectives of the importance to and preparation from a multidisciplinary capstone experience on the program's learning outcomes and ABET criteria. The industry partners were selected based on the diversity of the companies and their involvement with the capstone program. The surveyed population covered the span of industry types that partnered with the capstone program. The response rate for the survey was 50%, with nine respondents fully completing survey ($n = 9$). Table 8 shows the demographics and responses to general questions regarding their capstone involvement.

The industry-partner responses include companies that had been involved with the program varying from one to over four years. 89 percent of the partners indicated that the purpose of getting involved with the multidisciplinary capstone experience was to educate students. The majority of them also indicated that there were multiple direct industry benefits for being involved. The benefits included solving a current company problem (78%) and identifying potential new employers (67%). One partner specifically indicated that involvement with MDC students provided an avenue to investigate new technologies and applications. From this demographics analysis, the program concluded that the industry's represented within the survey data provided a well-rounded industry demographics of the types of companies that are involved with the multidisciplinary capstone experience.

Sixty-seven percent of the industry-partners indicated that they had three or more employees involved throughout the capstone experience, with majority (89%) spending between two and five hours a week involved with the program and the capstone students. This level of involvement is an indicator that the program places high expectations on the industry-partners when getting involved with the multidisciplinary capstone program.

The specific lead-in questions to the industry-partners for the ABET criteria identified above were: rate the following based on the importance to an engineer's early professional career ($\leq$ 5 years), and rate the following based on the importance to the contributions of the capstone program. Table 9 shows the results of the industry-partners responses.

An interesting observation from Table 9 is that the majority of the industry-partners indicated that each category was very important for both questions and in regard to every category, except one: the importance to manage a project during an engineer's early career. This category received a lesser importance rating.

3.3 *Program-student survey*

The 2013–2014 class demographics for the MDC course sequence included 105 students from 11 of 14 engineering programs and 23 non-engineering students. The non-engineers included students from various colleges pursuing an engineering science

Table 8. Multidisciplinary capstone industry-partner general questionnaire results

How many years has your company been involved with the capstone program?

1 year	2 years	3 years	4+ years
22%	22%	11%	44%

What is your company's purpose for getting involved with the capstone program? (Select all that apply)

Educating students	Solving a current company problem	Identifying potential employees	Promoting company's opportunities to students	Identifying potential future research opportunities	Other+
89%	78%	67%	78%	22%	11%

+If you selected "Other", please specify (Optional):
Text Response: Investigating new technology and applications

How many people are directly involved in supporting the capstone project at your company?

1 people	2 people	3 people	4+ people
11%	22%	33%	33%

How many hours per week on average do you spend working with students related to capstone (i.e. meetings, emails, presentations, student facility visits, etc)?

0-2 hours	2-5 hours	6-10 hours	10+ hours
11%	89%	0%	0%

* Percentages may not equal 100% due to rounding errors.

minor, Masters of Business Administration (MBA) students, and several students from industrial design.

The student survey focused primarily on the program's learning outcomes and the ABET criteria. The specific lead-in questions to the current students were: rate the following based on your academic preparation prior to starting capstone, and rate the following based on the importance to your capstone experience. The survey was distributed at the end of the course sequence, with a response rate of 35% (n = 37). Students from eight of the 14 engineering programs and two non-engineering students responded to the survey. Table 10 includes the students' perspectives to academic preparation and importance to their multidisciplinary capstone experience for the defined categories.

The following criteria have a statistically significant difference between the student's perception of their preparation prior to their capstone experience and the importance to their capstone experience: design and conduct experiments; analyze and interpret data; function on a multidisciplinary team; manage an engineering project; and communicate effectively orally. For each criterion, the students indicated a higher percentage in the importance to their multidisciplinary capstone experience than the level of their academic preparedness prior to starting capstone.

4. Comparisons of survey results

Observations from each survey are discussed with comparisons to related KSAs. First consider the industry-partner's perspectives, and their views on the categories importance to an engineer's early professional career (< 5 years) from Table 9.

The first observation made from Table 9 is that all categories were ranked by the majority of the industry-partners as very important except for one, Category 6 Manage an engineering project. This category was the only criteria that resulted in a statistically significant difference between the industry partner's perception of the importance to and the contribution of their capstone experience in their preparedness. The industry partners placed more significance with the importance to the contribution of developing project management skills

Table 9. Multidisciplinary capstone industry-partner survey results

	Rate the following based on the importance to an engineer's early professional career (≤ 5 years)			Rate the following based on the importance to the contributions of the capstone program		
	Extremely Important, Very Important	Important	Somewhat Important, Unimportant	Extremely Important, Very Important	Important	Somewhat Important, Unimportant
Design and conduct experiments	67%	33%	0%	89%	11%	0%
Analyze and interpret data	100%	0%	0%	56%	44%	0%
Design a system, component or process to meet a desired need with realistic constraints	100%	0%	0%	89%	11%	0%
Function in a multidisciplinary team	89%	11%	0%	89%	11%	0%
Function in a cultural and ethnically diverse environment	67%	33%	0%	56%	33%	11%
Manage an engineering project*	11%	67%	22%	56%	44%	0%
Identify, formulate, and solve engineering problems	67%	33%	0%	78%	22%	0%
Communicate effectively orally: presentation, meetings, etc.	89%	11%	0%	89%	11%	0%
Communicate effectively in writing: letters, technical reports, etc.	89%	11%	0%	78%	22%	0%
Use modern techniques, skills, and modern engineering tools	78%	22%	0%	78%	22%	0%
Use computing technology	56%	44%	0%	67%	22%	11%
Recognize the need for and engage in life-long learning	89%	11%	0%	78%	22%	0%

* Criteria with statistically significant differences.
** Percentages may not equal 100% due to rounding errors.

during the capstone experience than they do with respect to the engineer's early professional career. This may be an indication that the industry-partners recognize that the responsibilities for developing project management skills is shared between academia and industry and that this skill will be further developed during their professional career. This hypothesis is supported by the results from a TUEE high priority KSA, KSA 13 Project management (skill). Forty-six percent of the TUEE respondents indicated that the responsibility was shared between academia and industry, 29 percent on industry, 21 percent on academia, and four percent indicated it was solely on the student.

With respect to project management from the students and alumni directly, Table 11 provides the perspectives of the current students' views on their ability prior to starting capstone and the alumni's view of the contribution of the multidisciplinary capstone experience to developing this skill. The corresponding views from TUEE with the current ability of engineering education as a whole are also included.

This category is related to an MDC learning

Table 10. Multidisciplinary capstone students survey results (2013–2014)

Category	Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the importance to your capstone experience		
	Extremely prepared Very prepared	Prepared	Somewhat prepared, Not prepared	Extremely Important, Very Important	Important	Somewhat Important, Not Important
Design and conduct experiments*	51%	41%	8%	86%	11%	3%
Analyze and interpret data*	68%	24%	8%	89%	5%	5%
Design a system, component or process to meet a desired need with realistic constraints	62%	32%	5%	81%	14%	5%
Function in a multidisciplinary team*	70%	19%	11%	78%	19%	3%
Function in a cultural and ethnically diverse environment	57%	19%	24%	54%	32%	14%
Manage an engineering project*	62%	27%	11%	84%	16%	0%
Identify, formulate, and solve engineering problems	73%	16%	11%	81%	14%	5%
Communicate effectively orally: presentation, meetings, etc.*	81%	14%	5%	95%	5%	0%
Communicate effectively in writing: letters, technical reports, etc.	73%	16%	11%	89%	8%	3%
Use modern techniques, skills, and modern engineering tools	76%	19%	5%	84%	16%	0%
Use computing technology	76%	16%	8%	84%	14%	3%
Recognize the need for and engage in life-long learning	65%	24%	11%	62%	30%	8%

* Criteria with statistically significant differences.
** Percentages may not equal 100% due to rounding errors.

outcome, and the program places significance to the development of project management skills throughout the course sequence. This is most likely the reason for the alumni indicating that the experience was extremely helpful for developing this skill, and better prepared once completing capstone. The data supports that the current level of emphasis on project management and the alumni's perspectives from the program, positively impacts their preparation when entering into the work force. This structure to capstone would support the TUEE population perspectives for increasing the current ability of engineering education to produce graduates with the skills to manage projects, and ultimately increase the percentage of respondents in the very good, good column.

Returning back to Table 9, the only categories in which all (100%) industry-partners that completed the survey indicated that were very important were: Category 2 Analyze and interpret data, and Category 3 Design a system, component or process to meet a desired need with realistic constraints.

With respect to Category 2, the most related KSA is KSA 20 Data interpretation and visualization (ability). TUEE indicated that 72 percent of the respondents recognized it as the sole responsibility

Table 11. Category 6 Manage an engineering project comparisons

Current Students			Program Alumni			TUEE		
Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the contribution to your preparation resulting from your capstone experience			Current ability of engineering education to produce graduates (Stages of product development)		
Extremely prepared Very prepared	prepared	Somewhat prepared, Not prepared	Extremely Helpful, Very Helpful	Helpful	Somewhat Helpful, No Contribution	Very Good, Good	Fair	Poor, Very Poor
62%	32%	5%	70%	21%	9%	20%	53%	27%

* Percentages may not equal 100% due to rounding errors.

Table 12. Category 3 Design a system, component or process

Current Students			Program Alumni			TUEE		
Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the contribution to your preparation resulting from your capstone experience			Current ability of engineering education to produce graduates (Stages of product development)		
Extremely prepared Very prepared	prepared	Somewhat prepared, Not prepared	Extremely Helpful, Very Helpful	Helpful	Somewhat Helpful, No Contribution	Very Good, Good	Fair	Poor, Very Poor
62%	32%	5%	70%	21%	9%	20%	53%	27%

* Percentages may not equal 100% due to rounding errors.

of academia, 22 percent was a combination between academia and industry, and the remainder was government. TUEE further indicates that this ability is fundamental for engineering, and that development of this ability should be incorporated in all applicable courses, rather than a stand-alone course such as a single statistics course.

There was a statistically significant difference between the alumni's perception of the importance to and the contribution of their capstone experience in the preparedness to analyze and interpret data. The alumni indicated a higher percentage in the importance to their early professional career than the contribution of their preparedness from the multidisciplinary capstone experience. Furthermore, it is of interest to note that this category also resulted in a statistically significant difference between the current student's perception of their preparation prior to their capstone experience and the importance to their capstone experience. The students indicated a higher percentage in the importance to their multidisciplinary capstone experience than the contribution of their academic preparedness prior to starting capstone.

To date, MDC viewed data analysis as an already established ability by the students prior to starting multidisciplinary capstone and did not place emphasis within the program's learning outcomes. The current course sequence structure does not have direct learning modules focused on data analysis. However, all survey responses indicate that this as a very important ability for early career engineers, and that the multidisciplinary capstone experience, like all capstone experiences, would be an applicable course in which to further emphasize this ability. The program is currently putting in place learning modules and time dedicated to furthering the development of the student's ability to analyze and interpret data.

For Category 3, the most related KSA is KSA 34 Understanding of design (knowledge). Fifty-six percent of TUEE respondents placed the responsibility on academia, 13 percent indicated it was on industry, six percent on the student and 25 percent of the respondents recognized it as a combination between academia and industry. TUEE agreed that design is a debatably ambiguous concept, and further recognize that design can mean a lot of different things depending on the industry [15]. It is further recognized that industry's input in the teaching of design is important. This is supported by the industry-partners' perspectives on the importance to the contribution of the multidisciplinary capstone experience in Table 9, where 89 percent of the respondents indicated that the development of this knowledge during capstone is very important.

Table 12 provides the perspectives of the current students' views on their knowledge of design prior to starting the multidisciplinary course sequence, the alumni's view of the contribution of the multidisciplinary capstone experience in developing an understanding of design, and the corresponding views from the TUEE respondents on the current ability of engineering education as a whole.

This category is also a program learning outcome and MDC places emphasis on design throughout the multidisciplinary capstone experience. The data supports that the current level of emphasis on design and the alumni's perspectives from the program positively impacts their preparation when entering into the work force. This structure to capstone would also support the TUEE population perspectives for increasing the current ability of engineering education to produce graduates with the design skills, and ultimately increase the percentage of respondents in the very good column.

Three other categories of interest are Category 4 Function on a multidisciplinary team and Categories 8 and 9 Communicate effectively orally and in writing, respectively. These categories have direct relationships to high priority KSAs, as well as with MDC learning outcomes. With respect to the ability to function on multidisciplinary teams, 33 percent of the TUEE respondents placed sole responsibility on academia. The next highest group (26%) recognized it as the responsibility of the combined student, academia and industry. In order to foster the development of multidisciplinary teamwork, TUEE indicated that academia should identify opportunities for students from multiple engineering disciplines to work together, and with faculty mentors and points-of-contacts in industry and the community to address common issues. This is evident by multidisciplinary capstone in Table 13.

TUEE also indicated that multidisciplinary teamwork should be embedded throughout academia as part of authentic design experiences. The current students' survey results above show that 70 percent of the students indicated that they were very prepared prior to starting capstone. One contributing factor to this is that OSU offers a first-year fundamental of engineering course sequences that culminates in semester long multidisciplinary hands-on design experiences. The First-year Engineering Program is part of the COE's Engineering Education Innovation Center and has close ties with MDC faculty, providing the opportunity to incorporate important capstone design elements, like functioning on multidisciplinary teams, early in the student's academic career.

Table 13. Category 4 Function in a multidisciplinary team comparisons

Current Students			Program Alumni			TUEE		
Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the contribution to your preparation resulting from your capstone experience			Current ability of engineering education to produce graduates		
Extremely prepared Very prepared	prepared	Somewhat prepared, Not prepared	Extremely Helpful, Very Helpful	Helpful	Somewhat Helpful, No Contribution	Very Good, Good	Fair	Poor, Very Poor
70%	19%	11%	76%	8%	17%	45%	41%	14%

* Percentages may not equal 100% due to rounding errors.

Table 14. Categories 8 and 9 Communicate effectively orally and in writing comparisons

Communicate effective orally

Current Students			Program Alumni			TUEE		
Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the contribution to your preparation resulting from your capstone experience			Current ability of engineering education to produce graduates		
Extremely prepared Very prepared	prepared	Somewhat prepared, Not prepared	Extremely Helpful, Very Helpful	Helpful	Somewhat Helpful, No Contribution	Very Good, Good	Fair	Poor, Very Poor
81%	14%	5%	82%	12%	6%	31%	45%	24%

Communicate effectively in writing

Current Students			Program Alumni			TUEE		
Rate the following based on your academic preparation prior to starting capstone			Rate the following based on the contribution to your preparation resulting from your capstone experience			Current ability of engineering education to produce graduates		
Extremely prepared Very prepared	prepared	Somewhat prepared, Not prepared	Extremely Helpful, Very Helpful	Helpful	Somewhat Helpful, No Contribution	Very Good, Good	Fair	Poor, Very Poor
73%	16%	11%	76%	20%	5%	31%	45%	24%

* Percentages may not equal 100% due to rounding errors.

Table 15. Open-ended responses

Alumni open-ended selected responses (n=43) **How could we improve the multidisciplinary capstone experience?**	**Related LOs**
1. Making sure that there is an understanding of what the role of the advisors will be (faculty that are assisting the team). Our faculty advisors were often difficult to get a hold of (which was an issue when their clearance etc. was required) and were pretty unaware of exactly what we were doing with our project. The advisors tended to be more of a hindrance on our project than help. I believe they may not have been fully aware of how they were supposed to help us and what their role was.	3
2. The experience should be better advertised throughout the engineering programs. Every engineering student should have to complete this course. It provides invaluable experience that directly relates to today's industries.	4
3. More planning involved with the partner companies to ensure a logical timeline and scope for the group project. The project cannot be too open ended or the team will struggle too much, but I also know the importance of allowing for creativity in the process. It is a delicate balance that I'm sure you will refine in the near future. Teaching and learning is hardly a perfect science, especially when you are trying to prepare students for a field of employment that is very diverse.	2, 4
4. Learning to work with a large diverse team is essential in corporate America. The capstone experience could better prepare students for this challenge if they increase the size and complexity of the capstone teams.	1, 3
5. I know that in years after mine, every group had at least one non-engineering student, which was a good improvement. I assume cultural differences were addressed in later years as well, since one of the questions addresses this issue. I am living in Germany and work in an very multinational environment, but with English as the business language. Therefore, I would only suggest that a lecture on cultural and ethical differences be added to the course (and to stress speaking slowly while presenting to non-native English speakers!).	1, 2, 3
6. We need to make sure the industry partner is fully engaged and accountable for success. A lot of time and money can be spent on a program, and it would be nice to see the industry partner crack the whip a little bit. Ultimately, it may open the student's eyes to what the real world is like and again, expose them to failure. Sometimes I think college students have an oblivious outlook and forget that one day they will be working for a "boss" until retirement. Let's just say not all bosses are perfect and you probably won't always agree with him/her, but you'll need to learn to deliver results.	1, 3
7. If I had to pick one thing to improve, it would be the project options and companies. Some groups were stuck with very difficult projects that could not be completed in time. Maybe this is okay if there was an associated lesson to go with it, but for my group it was just a stressor.	1, 4
8. More diversity in the type of projects offered	N/A
9. Stronger repercussions for people who don't do their part and SERIOUSLY consider who you have as advisors for the program.	1, 3
10. More refinement of the program. Better industry contacts, more organized class work, more structure to the topics taught. Great concept overall but just needs some tweaks	3, 4
11. Require more rigorous computer work or statistics for data analysis. Make project emphasis on data collection and analysis. I think employers really want to see what students can do in their companies. I don't think entering employees will be asked to lead teams to work from the ground up on projects but they will be asked to jump in on assignments and help analyze and/or gather data.	1
12. Include more components of "how to" communicate in the working environment, including body language training and "ways to leave your mark" when trying to influence company culture.	1, 9
13. Maintain involvement with social causes.	6
Industry open-ended responses (n=4) **How can we improve the multidisciplinary capstone program in preparing students for their professional career?**	**Related LOs**
1. Open their mind and provide more opportunities on industry experience	N/A
2. None at this time	N/A
3. More frequent communication with the team seemed to improve results.	1, 9
4. I went through a co-op work program and senior project that provided nearly 2 years of work experience. I am a big advocate of these types of work experience/projects for students. It helps provide focus to the type of career path a student may want for their professional career. If there was an introductory course for students early in their curriculum that would provide some of the foundation for this later Capstone project, I think that could be very helpful.	N/A
(n=5) **How can we improve multidisciplinary capstone program experience for partners?**	**Related LOs**
1. The students are enrolled in this program for the education and experience. If the sponsors choose not to engage the students with challenging, meaningful projects, then the sponsors are not gaining all they	1, 10

Table 15. (*cont.*)

	could from this project. The Capstone program provides all of the tools and resources needed to help these students succeed.	
2.	Provide certain undergraduate student information such as their interestings and education background to sponsors	N/A
3.	The topic presentation at the beginning of the Fall semester could be done online through WebEx. All sponsors can present remotely and reduce the need of travel or presenting by faculty.	N/A
4.	None at this time	N/A
5.	Before entering the OSU Capstone program, have students gain some co-op work experience and/or a Capstone type project earlier in their curriculum to help better prepare them for this experience with a company. They will have a better set of tools and more grounded expectations which would probably deliver higher level results to company	1

	Student open-ended selected responses (n=21) **How could we improve the multidisciplinary capstone experience?**	**Related LOs**
1.	Make sure students on the team actually do work, or can contribute	1, 3
2.	finding sponsors who are all passionate about teaching students	N/A
3.	I think that our capstone project was truly hindered by our OSU advisor. Having a different advisor may have changed the experience, but I don't think any team member was satisfied with the experience.	3
4.	Incorporate more concepts from the curriculum in the project. my project used no mechanical engineering concepts and was therefore a bad summary of my five years studying Mechanical Engineering.	5
5.	I would have professors who run labs at OSU be setup prior to the start of a project to help the project teams. We spent about 2 months floundering to obtain help from the professors who were supposed to be helping us. When we were able to meet with them, they were for the most part unhelpful and would drag their feet for weeks. It seems hard when our project does not seem as importance to them as it is to us.	3
6.	Allowing you to choose at least one or two members of your team would be nice.	3
7.	I don't have any suggestions. My capstone experience was extremely beneficial and I greatly enjoyed it.	N/A
8.	Do not let non-engineering majors participate. engineering minors should have their own capstone projects that are less technical. These students do not have the appropriate background for a highly technical design process.	3, 5
9.	Better Define the project Scope	4
10.	It was great already	N/A
11.	Some parts of the project weren't necessarily setup for certain projects as far as format goes	4

The final comparison made looks at the TUEE study directly, and what they have identified as one of the highest priority KSA. TUEE has identified that good communication skills should be a priority for engineering education. The majority of the respondents (50%) indicated that it is the responsibility of the student's parents and academia. However, their open-ended responses suggested that the students themselves and industry, along with the parents and academia, were jointly responsible for developing communication skills.

Communication skills were broken into effective oral and writing communications for the MDC surveys. The industry-partners also recognized this as an important skill for an engineer's early career with 89 percent respondents listing it as very important. However, there was a slightly less rating to the importance to the contribution of the multidisciplinary capstone experience with respect to writing skills. Table 4 also indicates that the alumni gave slightly more value to the importance to their career in oral communication skills (86% very important) compared to writing communication skills (79% very important).

Table 14 provides the perspectives of the current students' views on their communication skills prior to starting a multidisciplinary experience, the alumni's view of the contribution of the multidisciplinary capstone experience in developing these skills, and the corresponding views from TUEE on the current ability of engineering education as a whole. The table shows both oral and writing communication separately.

With respect to communications, the only criterion to result in a statistically significant difference between the current student's perception of their preparation prior to their capstone experience and the importance to their capstone experience was with effective oral communications. The students indicated a higher percentage in the importance to their multidisciplinary capstone experience than the contribution of their academic preparedness prior to starting capstone.

Communication skills are also emphasized throughout the multidisciplinary capstone experience. The data supports that the current level of emphasis on both written and oral communications and the alumni's perspectives from the program

Table 16. Thematic analysis to open-ended responses

33%	**6%**	**30%**	**12%**	**6%**	**3%**	**0%**	**0%**	**6%**	**3%**
LO 1	LO 2	LO 3	LO 4	LO 5	LO 6	LO 7	LO 8	LO 9	LO 10

positively impacts their preparation. This structure to capstone would also support the TUEE population perspectives for increasing the current ability of engineering education to produce graduates with the improved communication skills, and ultimately increase the percentage of respondents in the very good column.

5. Open-ended responses

Each survey provided the opportunity to respond to open-ended questions with respect to the multidisciplinary capstone experience. The MDC alumni and current students were asked how the program could improve the experience, and the industry-partners were asked to identify ways for the program to improve its student preparation for the professional careers and improve the experience for the industry partners.

Selected responses to the open-ended questions are provided in Table 15 for all three surveys, along with identified related learning outcomes.

The responses that were not provided for the program alumni and current students both addressed that it would be beneficial to interact with the industry-partners earlier within their capstone experience. MDC also recognized this as a benefit, and has made the corresponding adjustments to its course sequence and organizational structure to provide the earliest possible interaction with the industry personnel.

A thematic analysis was conducted on the open-ended responses using the program's related learning outcomes as the identified themes. Table 16 shows the occurrence of the theme throughout the three stake-holders responses.

Two related program learning outcomes stand out as themes discussed by the industry, alumni and current students: LO1 Perform professionally and LO3 Establish team relationships for quality performance. There are several common characteristics among the comments that are related to LO1 and LO3 that are specifically relevant to the future development of the multidisciplinary capstone program. The lessons learned from the common characteristics include: ensuring engaged industry personnel throughout the entire project cycle, maintain consistent project work-load among all projects regardless of project-specific complexity, maintain a clear understanding of the roles and responsibilities of the faculty advisor and individual students, and establish stronger repercussions for individual student's failure to perform. Other noteworthy comments shared by the alumni and industry-partners, with respect to LO1 and LO3, include encourage fostering co-op experience prior to Capstone, and provide prior academic activities and curriculum that support capstone experiences.

6. Conclusions

The Multidisciplinary Capstone Program at The Ohio State University recently concluded a three-year effort to obtain formalized responses from its industry-partners, program alumni and students who had just finished the multidisciplinary capstone experience. The primary focus was on establishing rankings of the corresponding stakeholder's perspectives to the preparedness and importance of the program's learning outcomes related to relevant accreditation board for engineering and technology criteria, criteria 3 (a–k). The results were also compared to the rankings of important knowledge, skills and abilities for all engineering students identified by the Transforming Undergraduate Engineering Education (TUEE) Phase I workshop study; a study conducted by the American Society for Engineering Education in 2013 to develop a strategy for undergraduate engineering education that meets the needs of industry in the 21st century.

The multidisciplinary capstone program that is described in detail is a two-semester course sequence with realistic projects defined by industry partners who support the projects financially and with company personnel. Students from all 14 undergraduate engineering programs have participated in the program along with students from various other Colleges that included students pursuing an engineering science minor, MBA students, and students from industrial design. The program was established in 2007 and currently has over 450 alumni.

Using a Likert scale, the industry-partners were asked to rank the relevant criteria based on the importance to an engineer's early professional career ($\leq$ 5 years) and based on the importance to the contributions of the capstone program; the alumni were asked to rank based on the importance to their career and based on the contribution to their preparation resulting from their capstone experience; and the current students were asked to rank based on their academic preparation prior to starting capstone and based on the importance to their capstone experience. The results from each survey were provided, including identifying criteria with statistically significant differences between the two corresponding questions for each stakeholder. Comparisons of the survey results were made and correlated to the TUEE workshop study results on the rankings of important knowledge, skills and abilities. Additionally, open-ended questions were asked of each stakeholder to comment on ways to improve the multidisciplinary capstone experience, and a thematic analysis of the responses was conducted using the program's related learning outcomes as the identified themes.

The industry-partners indicated that each category was very important for both questions, except one: the importance to manage a project during an engineer's early career. This is the only criteria that resulted in a statistically significant difference. The industry partners placed more significance with the importance to the contribution of developing project management skills during the capstone experience than they do with respect to the engineer's early professional career. This may indicate that the responsibility for developing this skill is shared between academia and industry, a hypothesis that is supported by TUEE results. Another key observation made with respect to the industry surveys is that all (100%) partners indicated that the ability to analyze and interpret data (category 2) and design a system, component or process to meet a desired need (category 3) was ranked extremely important. For category 2 there was a statistically significant difference between the alumni's perception indicating a higher percentage in the importance to their early professional career than the contribution of their preparedness from the multidisciplinary capstone experience. A significant difference was also recorded for the students' survey showing a higher percentage in the importance to their multidisciplinary capstone experience than the contribution of their academic preparedness prior to starting capstone. TUEE indicates that the development of the ability to analyze and interpret data should be incorporated in all applicable courses, rather than a stand-alone course. However, all survey responses indicate that this as a very important ability, and capstone would be an applicable course in which to further emphasize this ability. The program is currently putting in place learning modules and time dedicated to furthering the development of the student's ability to analyze and interpret data.

Additional key observations made and lessons learned were developed from alumni's responses compared to a similar criteria-based survey sent by the College of Engineering Outcomes (COE) Assessment Committee to alumni from all 14 engineering programs. The COE's Outcome Assessment Committee identified four topics the COE appeared to have reached a balance between the importance and preparation, and seven topics the COE recognized room for continued development. Of the seven topics, the multidisciplinary capstone program alumni indicated that five categories were balanced using the predetermined COE definition, and two categories were recognized as room for improvement. The two topics for improvement were ability to analyze and interpret data and ability to use computing technology.

The program is continually improving its multidisciplinary capstone experience from evidence-based assessment, including on-going analysis of the survey results within this manuscript. The program's future assessment plans include distributing a similar survey to its capstone project faculty advisors. The program uses faculty from across the college in various engineering programs and their input with regard to the important criteria would be very beneficial to the continuous improvement of the multidisciplinary capstone experience. A significant evidence-based consideration for all capstone programs that have similar learning outcomes is that by all indication the development of key "shared" skills such as project management is important, but should not be focused at the level that impedes providing structured learning experiences for the development of important engineering abilities such as analyzing and interpreting data. A well-rounded balance between developing important knowledge and skills unique to capstone while providing opportunities to further emphasize important fundamental engineering abilities is the underlying message taken away from the survey results from the stakeholders, and is the basis for continuously developing the multidisciplinary capstone program at Ohio State.

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Appendix

The following includes the identified related TUEE Knowledge, Skills and Abilities to the Multidisciplinary Capstone Program learning outcomes [15].

1. Good communication skills (*skill*)
2. Physical Sciences and engineering science fundamentals (*knowledge*)
3. Ability to identify, formulate, and solve engineering problems (*skill*)
4. Curiosity and persistent desire for continuous learning (*ability*)
5. Self-drive and motivation (*ability*)
6. Cultural awareness in the broad sense: nationality, ethnicity, linguistic, gender, sexual orientation (*knowledge*)
7. High ethical standards, integrity, and global, social, intellectual, and technical responsibility (*ability*)
8. Critical thinking (*skill*)
9. Willingness to take calculated risk (*ability*)
10. Ability to prioritize efficiently (*skill*)
11. Project management: supervising, planning, scheduling, budgeting, etc. (*skill*)
12. Teamwork skills and ability to function on multidisciplinary teams (*ability*)
13. Ability to use new technology and modern engineering tool necessary for engineering practice (*skill*)
14. Applied knowledge of engineering core sciences and implementation skills to apply them in the real world (*skill*)
15. Data integration and visualization (*skill*)
16. Leadership (*skill*)
17. Creativity (*ability*)
18. Emotional intelligence (*ability*)

19. Good personal and professional judgment (*ability*)
20. Flexibility and the ability to adapt to rapid change (*ability*)
21. Ability to deal with ambiguity and complexity (*skill*)
22. Technical intuition/metacognition (*ability*)
23. Understanding of design (*knowledge*)
24. Conflict resolution (*knowledge*)

Clifford A. Whitfield currently functions as an Assistant Professor of Practice for the Mechanical and Aerospace Engineering Department and Engineering Education Innovation Center at The Ohio State University, and senior engineer for Whitfield Aerospace LLC. He received his doctorate in aeronautical and astronautical engineering, and teaches aerospace engineering courses, and teaches and advises capstone design teams for the Multidisciplinary Capstone Program. He is an engineering practitioner in the areas of aerospace systems design and test engineering, with a background that includes unmanned and manned aircraft and aircraft component design and testing, jet engine test cell facility design and testing, and curriculum development and education research focused on design.

Robert B. Rhoads currently functions as the Multidisciplinary Capstone Program Coordinator for the Engineering Education Innovation Center at The Ohio State University. He has a Bachelor of Science in Mechanical Engineering from Ohio State University and Masters in Business Administration from Regis University. Prior to his involvement as the program coordinator, he had over 12 years of experience in industry with roles that varied from process engineering to sales engineering to design engineering. He has also functioned as an engineering technology faculty for three years at Zane State College in Zanesville, Ohio, where he developed and taught courses that included CAD, solid modeling, statics, strength of materials, machine design, and statistical process control. He is currently active in curriculum development and education research focused on design.

Jacob T. Allenstein currently functions as a Teaching Research Associate for the Multidisciplinary Capstone Program in the Engineering Education Innovation Center at The Ohio State University, and as a Graduate Research Associate at the Aeronautical and Astronautical Research Laboratories. He received his Bachelor and Masters of Science in Aeronautical and Astronautical Engineering at Ohio State, and is currently pursuing his doctorate in aerospace engineering. His background includes experimental fluid dynamics in the areas of jet engine test cell facility design and testing, and curriculum development and laboratory oversight for first-year and capstone courses and education research focused on design.