Quantitative Literacy in Capstone Design

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One of the desired outcomes of capstone design is the ability to use mathematical arguments such as calculations, modeling, and statistical data analysis to inform design decisions. The VALUE rubric for quantitative literacy was used to assess the work of 24 capstone teams. The goal was to determine if there were particular team or project characteristics that led to high quantitative literacy in the final project. Correlation analysis indicates that high levels of quantitative literacy are associated with more successful projects. In particular, the ability to discuss and present calculations seems to be an indicator of success. The source of project, whether industry, faculty, or student developed, did not have a strong effect on quantitative literacy.

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Introduction

Quantitative literacy (QL) is defined as "the ability to identify, understand, and use quantitative arguments in everyday contexts".[1] QL is not simply the ability to perform mathematical calculations but also to recognize the need for mathematical argument and to use mathematical argument to solve problems and draw conclusions. High degrees of QL tend to be associated with the ability to use and understand statistics in particular, and to be able to integrate numerical with non-numerical information.[2] Because 61% of the highest earners in the labor force are either classified as *competent* or *advanced/superior* in QL, this is clearly a skill that needs to be taught and emphasized.

Various authors have assessed QL on an institutional scale. Specific to capstone, Dym et. al. in their 2005 work mention QL as one of the outcomes that can be promoted and assessed as a part of the capstone design experience[3]. Other works on capstone design have studied mathematical modeling skills, which is a subset of the larger concept of QL.[4,5] Capstone design at its best requires students to take a real-world problem and clearly define it, develop potential solution paths, and use analysis and/or experimentation to validate the chosen solution. Students who can perform robust analysis of their solutions should be able to improve and iterate their solutions and generate better results. Measuring QL can indicate which students are capable of such analysis at the conclusion of their capstone experience.

The VALUE rubrics are a set of validated measures for assessing learning outcomes in a number of key areas.[6] The rubric for quantitative literacy has six levels of assessment for different aspects. *Interpretation* measures the ability of the students to accurately explain information presented in mathematical form. *Representation* measures the ability to display information in the forms of equations, graphs, diagrams and tables. *Calculation* measures the ability to successfully perform and present calculations in response to a problem. *Application/Analysis* measures the ability to draw conclusions and make sound judgements from data, and also to recognize the limitations of analysis. *Assumptions* measures the ability to explicitly describe the assumptions necessary to complete analysis and to provide a rationale for the assumptions made. Finally, *Communication* measures the ability to effectively present quantitative information and use it to support arguments and conclusions. Each of these six aspects is equally weighted on a 1-4 point scale, with 4 being the highest level of achievement.

Capstone in MIE at Northeastern University

Capstone design in the Mechanical and Industrial Engineering (MIE) department at Northeastern University consists of a required two semester sequence. Projects are proposed by faculty members, sourced from industry, or developed by students or student activity groups, with faculty guidance. Students work in 4-5 member teams which are formed at the beginning of the first term, and are encouraged to form their own teams, or at least subgroups, if possible. Teams or subgroups rank all projects from the most to least desirable, and these rankings are used by the instructor to assign a different project to each team, and combine subgroups into teams, if necessary.

The goal of the capstone design course is to consider a real-world problem and produce a functional prototype, to address that problem, by the end of the second term. Each team is assigned a faculty advisor whose role is to mentor the teams and provide feedback on design and analysis. Using a previously developed rubric[7], prototypes are assessed at a point two weeks prior to the end of term on a 10 point scale; 5 points for completeness of the prototype at that point, and 5 points for completeness of verification testing. At the end of term, projects are rated on a scale of 1-10 on how complete the projects are compared to how they were originally scoped by the student teams. By rating the projects at these two separate points, teams who are managing their project well and achieving goals early are distinguished from teams that rush to finish at the last minute.

Written and oral communication is assessed by an engineering instructor who is not involved with any particular group but who has sufficient technical knowledge to provide an educated outside perspective. Three written reports and three oral reports are required during the two-term sequence. Reports are assessed on both the quality and the content of the writing.

Research Questions

The primary research questions to be answered in this study are:

1. What are the characteristics of capstone teams that demonstrate quantitative literacy?
2. Does the source of the project (faculty, industry, or student) influence the quality of quantitative literacy demonstrated by the team?
3. Which aspects of quantitative literacy correlate most to project success?

Methods

The VALUE rubric for quantitative literature was used to assess the final reports for 24 Mechanical Engineering capstone teams from Fall 2017.[6] Multiple readers were used and results compared to ensure inter-rater reliability. The scores for each individual rubric criterion as well as the total quantitative literature score (Total QL) were tabulated and examined for correlations with various team factors and project outcomes. Team factors included number of team members, advisor, project source (faculty vs. industry vs. student), and team formation (student formed vs. instructor formed). Project source was rated on an ordinal scale where increasing value indicated increasing student involvement in project scoping and development. In this scale Faculty sponsored projects were given a value of 1, Industry sponsored projects 2, and Student sponsored projects 3. Team formation was similarly ranked based on increasing student involvement where 0 indicates completely faculty formed teams and 1 indicates completely student formed teams. Outcomes included prototype grade and writing grade. Correlations between these factors were examined using the Pearson Product-Moment Correlation Coefficient implemented with the Excel correlation analysis. Single factor ANOVA was also used to determine whether significant differences existed between groups.

Results

A total of 24 project teams were examined for the study. Ten projects were proposed by faculty members, eleven were industry sponsored projects, and three were student developed. The projects included a range of topics, such as industrial redesign, development of small consumer goods, student competition team projects, and laboratory equipment for research and teaching labs. Nine of the teams were formed by the capstone instructor, while the remainder were student formed.

Table 1 shows the results of the Pearson's Correlation analysis. As stated, each individual area of the QL rubric was treated individually, as was the Total QL score. Total QL was most highly correlated with abilities in Application, Assumption, and Calculation. Abilities in Assumption and Application were also highly correlated. Total QL was moderately correlated with Representation, Interpretation, and Communication abilities, as well as Prototype Score and Writing Grade. Prototype score was also moderately correlated with Communication, Application, Assumption, and Calculation abilities. Prototype score was less highly correlated with Sponsor type, writing grade, and Interpretation ability.

Table 1: Pearson's Correlation Coefficients for Paired Factors

Paired Factors	**Pearson's R (R^2)**	**P-value ($\alpha = 0.05$)**
Total QL/Application	0.89	0.00
Total QL/Assumption	0.84	0.00
Total QL/Calculation	0.81	0.00
Assumption/Application	0.71	0.00
Total QL/Representation	0.66	0.00
Application/Calculation	0.66	0.00
Total QL/Interpretation	0.65	0.00
Total QL/Prototype Score	0.62	0.00
Assumption/Calculation	0.62	0.001
Application/Interpretation	0.60	0.002
Calculation/Writing Grade	0.59	0.002
Application/Representation	0.56	0.004
Total QL/Communication	0.55	0.005

Communication/Prototype Score	0.54	0.006
Application/Prototype Score	0.53	0.008
Assumption/Prototype Score	0.52	0.01
Assumption/Writing Grade	0.49	0.02
Calculation/Prototype Score	0.48	0.02
Calculation/Representation	0.47	0.02
Sponsor/Prototype Score	0.45	0.03
Total QL/Writing Grade	0.44	0.03
Writing Grade/Prototype Score	0.43	0.05
Sponsor/Application	0.43	0.04
Representation/Interpretation	0.43	0.03
Interpretation/Prototype Score	0.43	0.04
Assumption/Interpretation	0.42	0.04
Communication/Assumptions	0.40	0.05
Calculation/Interpretation	0.40	0.05

Table 2 below shows the Pearson's Correlation results that are particularly focused on the technical communication aspect of the projects. Each individual report grade was considered separately, as was the total writing grade. These grades were compared to the total QL score along with individual aspects of the QL score. The prototype score and final completeness score were also examined in comparison to the various reports.

Table 2: Paired Factors for Writing Details

Paired Factors	Pearson's R	P-value
Report 1/Writing Grade	0.70	0.00
Report 3/Writing Grade	0.67	0.00
Report 3/Assumptions	0.63	0.001
Report 2/Writing Grade	0.60	0.002
Final Completeness/ Communication	0.60	0.002
Report 1/Prototype Scoring	0.53	0.008
Final Completeness/ Calculation	0.52	0.009
Report 3/Application	0.51	0.01
Report 3/Total QL	0.50	0.01
Report 3/Calculation	0.46	0.02
Final Completeness/Total QL	0.44	0.03
Final Completeness/Writing Grade	0.42	0.04
Report 1/Calculation	0.40	0.05
Report 3/Sponsor	0.40	0.05

Two-tailed t-tests were used to compare projects that were student formed vs. those formed by the instructor based on their prototype score, total QL, and writing score. There were no significant differences based on type of team formation at $\alpha = 0.05$.

Single factor ANOVA was used to compare groups that had faculty vs. industry vs. student proposed projects based on their prototype score, total QL, and writing score. No significant difference in the total QL or the writing score was found based on the source of the project at $\alpha = 0.05$. However, the difference in prototype scores between the three groups was nearly significant at $P = 0.08$. Student and industry sponsored groups had higher average prototype scores than the faculty sponsored groups. The average prototype score for faculty sponsored groups was 5.4, while the average prototype scores for industry and student sponsored groups were 7.1 and 8.0 respectively.

Single factor ANOVA was also used to compare groups based on advisor. No significant difference was found in prototype score, total QL, or writing grade based on who advised the team at $\alpha = 0.05$.

Discussion

Total QL is most highly positively correlated with the subskills of Application, Assumption and Calculation, although naturally the other subskills were also positively correlated. Previous work by one of the authors[8] has indicated that the ability to present and explain calculations in particular is often associated with higher level behaviors and more sophisticated outcomes. High prototype scores as well as high final project completeness were also positively correlated with Total QL. QL was also strongly associated with certain aspects of the communications grade; total QL was positively correlated, although more moderately, with the total writing grade. In particular, high grades on the final report were positively correlated with Total QL. Groups with high degrees of quantitative literacy seem to be able to pull together the quantitative information from the entire project in a well written, concise, and mathematically correct written presentation.

Groups with the top 5 highest QL scores were a mixture of faculty and student formed teams, and included both faculty and industry sponsored groups. Groups with the 5 lowest QL scores were also a mixture of faculty and industry sponsored projects and faculty and student formed teams. The average prototype scores for the lowest 5 teams was 4.6/10, whereas the average for the highest 5 teams was 7.8/10. Although these differences were not statistically significant, the P value was close to significance (P=0.8). This seems to indicate that higher quantitative literacy leads to more robust analysis and better prototypes in the end. The higher QL groups did have a higher average writing score (91.2/100) than the lower QL groups (84.4/100) but the difference was not significant.

The 2005 Capstone Design Survey indicated that 71% of projects nationwide are industry-sponsored.[9] This may be because they are more likely to be relevant, real-world problems and require students to interact with outside clients. However, the source of the project does not seem to strongly influence the QL that is demonstrated by the team. Teams can demonstrate high levels of QL on any type of project, from the design of small consumer goods to the redesign of an established product line. The only place where the project source seemed to have any effect was in the grades for the final report. There was a positive correlation (0.40) between the grades on report 3 and having a project where the students were more heavily involved in the project formation. These industry or student sponsored projects seemed to have more buy-in from the teams, and thus may have led to more in-depth and thorough analysis.

Conclusions

Robust quantitative literacy is possible from teams with a variety of characteristics such as type of team formation and type of project. Project source does not have a significant effect on the total QL score. This is encouraging, since new programs often struggle to attract and properly scope industry sponsored projects. While industry sponsored projects are nice to have, they do not seem to convey any particular advantage when it comes to quantitative skills. Industry sponsored projects are desirable, but not necessary for a good capstone experience.

The various aspects of quantitative literacy do not seem to correlate equally with project success. In particular, the ability to apply and clearly discuss calculations is correlated highly with project success. Being able to perform calculations competently is not enough. Students need to be able to describe what they calculated, how it was done, and why it is important to the work in question. This points to a need to give students the opportunity to practice and receive feedback on this skill throughout the curriculum. This is also an opportunity in and of itself; if communicated effectively to core faculty, this point may provide them direct guidance in how to improve course delivery. Note that although there was positive correlation between QL and the other forms of intelligence described in this paper, an open and interesting question remains as to the causality between these attributes.

Future work will expand this analysis to additional capstone teams. In addition, the curriculum will be examined to determine where additional practice in discussing, rather than just performing, calculations can be inserted.

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