Grading the Capstone Written Design Reports: A Comparison of External Judges and Faculty Scores

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Work In Progress: Grading the Capstone Written Design Reports: a comparison of external judges and faculty scores

Abstract

Capstone projects often require senior engineering students to develop oral and written communications skills. Both reports are sometimes graded by faculty advisors, course coordinators, faculty who are not directly involved with a capstone project (a grading committee) and/or adjunct faculty/advisors. Some programs are known to also use external or industry representatives as external judges. When external judges are used, which may or may not include project sponsors, additional input on oral and written skills, as well as design quality may be evaluated outside of the technical design review process that could be requested. This paper reports on research comparing the capstone project evaluations conducted by external judges and faculty. Faculty and external judges scores were compared using correlation and t-test statistical methods using MiniTab 17. The results indicate external judges gave higher grades. The implications might be that faculty grades are based on academic achievement and external graders are based on project success. These reflect two unique perspectives on the capstone process, which leads to future studies related to what bias affect the scores of faculty and external judges.

Introduction

East Carolina University's Department of Engineering (ECU's DoE) is a general engineering program offering five discipline specific concentrations. ECU's DoE has a two semester long Senior Capstone Design program that spans two distinct courses. The first semester requires students to compete a conceptual level design for an industry sponsored project. The second semester requires students to complete a detailed design and often requires build/test objectives be completed. The sequence of courses is intended for students to not only use skills learned throughout their academia endeavors, but also to require students to go beyond traditional course work and expand their knowledge base by deeper researcher, through consulting with subject matter experts and experiential learning. Most projects are industry sponsored and for a considerable portion of students, the capstone project represents their first interaction with an industry-like environment. At ECU DoE, two sequential project management and design courses are required before students begin the capstone course as part of a spiral curriculum [1]. These courses are designed so that the students can begin thinking about the design process and gain some experience in managing a project before they begin capstone. These courses are intended to prepare them for their Senior Capstone Design Course.

The capstone course sequence is designed to focus on student learning as relates to design and project management [2]. The projects are usually industry based and the projects provided are scoped so that students can perform tasks that involve time, costs, and quality measurements that are typical of projects performed in industry [3]. Each year the Course Coordinator prepares and contacts local industries to sponsor projects. The project proposals are normally open-ended statements that are reviewed and vetted by a capstone committee in order to ensure adequate design content is involved and assessment outcomes related to capstone can be assessed. Student teams are assigned by the course coordinator and reviewed by the capstone committee. The open-ended proposals are purposely presented to students so that the process of defining scope, objectives and constraints will build a sense of project ownership and teamwork within the student teams. A sense of ownership and teaming is thought to increase students' motivation and lead to more robust alternative generation through the reality of engineering design. [4,5].

There are about 40 students that start capstone in the Spring semester and finish in the Fall while about 75 students start capstone in the Fall semester and finish in the Spring. Students are divided into random groups of 3, 4, or 5 member teams based on the number of projects available, the number of students available and the number of faculty advisors available. Each team is assigned a specific project with different companies and occasionally multiple teams will be assigned to a specific project either as competing or complimenting teams based on the engineering disciplines involved and the sponsor's willingness to host more than one team on a project. There is little student input into team members or project assignment. A faculty advisor is assigned to each team, and serves as the team's mentor. Faculty advisors are selected based on their discipline, research interest and availability by the course coordinator with approval from the department chair.

Industry sponsored projects are preferred because of their ability to provide capstone students an opportunity to combine academia learning and industry experience/exposure into an experiential learning intervention. This prepares students in becoming an engineer in industry. This also provides students with exposure to industry practices that can provide clarity to the students understanding of what an engineer does on the job in addition to the design component of engineering work that they learn in classes. Based on research, industry's focus on project success is consistent with the learning outcomes of academia [6].

At the beginning of the course, the students receive a book on the course, guidelines they must follow in the form of a Capstone Success Handbook, and objectives to achieve success on their project [7]. The guidelines provide specific expectation on the formatting of drawings, design notebooks, writing papers, oral presentation, and team meetings. While grading has multiple components, ~60% of the students' final grade is determined by the quality of the written and oral design reports. Grading of these two items is conducted by faculty, faculty advisors, the course coordinator, and external judges. The grades have been reviewed periodically from time to time to validate intra-faculty scoring consistency. External judges scores have only been used for assessment considerations and not part of student grading due to a concern that the correlation of scores between faculty and external judges was non-existent or weak. It was felt that the two groups, despite using a common grading rubric, may apply internal bias in evaluating student performance represented in the written reports. Oral report evaluations had been previously determined to be non-discriminating, i.e., the grades from all judges tended to be the same across all teams due to a larger number of evaluations and therefore did not provide a useful grading component.

The concern that the evaluations of the external judges and faculty resulted in a research effort led by a senior engineering student and the course coordinator. This paper reports the results of that research. It should be noted that there was no evidence found that a similar initiative had previously been conducted within the capstone community.

Written Report Grading Rubric

The rubric that both faculty and judges are asked to use in evaluating written reports is shown in Appendix I. The grading rubrics are provided to students as part of the Capstone Success Handbook that is a required course pack for students registered capstone. The grading rubrics are supplied to faculty and external judges at the end of each semester along with a copy of the final capstone written report. For all scoring, a score of 1 is a substandard level; 2 is an undergraduate level, underclass engineer level, and moderate writing; 3 is an undergraduate, underclass engineer level, and exceptional; 4 is an undergraduate graduating engineer and that all expectations were met, and 5 is an engineer level with 1-2 years of experience and the expectations are exceeded [7]. There are 5 parts to rubric.

Appendix I, Parts A and B are the rubrics required for evaluating the conceptual design content and design process of the first semester, or Capstone I, written reports and are entitled the Conceptual Design Review (CTDR) Content/Process. Part A of the CTDR is an industry-based approach to design review [8]. Part A was adapted directly from an industry design review procedure. Part B is a process based TDR and was developed from collaboration between capstone academics [9] using extensive reviews of academic and industry literature and reports. Parts A and B represent a combined content and process approach to the TDR for capstone grading. The details within the rubric provide students a guide to expectations for reporting their capstone project's design as well as providing graders a consistent set of criteria to evaluate the quality of the design report.

In addition to the TDR rubrics, a broader assessment of the capstone report is provided by the Final Written Report (FWR), show in Appendix I, Part C. The FWR provides a grading scheme for evaluating the effectiveness of the capstone written report in describing the project, its background, the components of the design process as applied, the alternative reduction process, and the design results. This rubric is intended to provide an evaluation of writing, clarity, formatting, use of illustrations, etc., as a means for evaluating written communication competencies. The FWR is used for evaluating both the conceptual (Capstone 1) and detailed (Capstone 2) design reports.

The Detailed Technical Design Report (DTDR) rubric, Appendix I, Parts D and E is used to evaluate the detailed technical design of the Capstone II detailed written design report. Much like the CTDR rubric, the DTDR Part D, provides for an evaluation of the technical design content, and Part E provides an evaluation of the detailed technical design process. All judges, faculty and industry are asked to complete TDR Parts A-E for the Capstone II detailed written design review. This includes everything that the students have completed throughout both semesters, the final design, drawings, and final conclusion of the project design.

As grades from the TDRs and FWRs have been casually reviewed over the last seven years, there has been a growing concern that there was an inconsistency in evaluations given by industry, or external judges, compared to faculty judges. It was believed that the external judges were more lenient in grading student work samples in the form of capstone written design reports. A research initiative was started that examines the correlation of grades between the two groups for grades given to Capstone I/II students since 2013.

Correlation of Grades

Data has been collected since Spring 2013 on the scoring averages from both faculty and external judges. The data provided in Appendix II is Table 1, shows the mean project scores (percent) received from faculty and external judges, i.e., an average of pooled judges scoring (percent) for each team. Each team mean score reflects from 2-3 faculty evaluations and from 1-3 external judges. The small sample size/per team does not reflect a robust sampling process; it does provide some opportunity for a subjective analysis with very modest statistical basis.

The external judges are normally engineers from the industry. Some are program alumni with anywhere from 6 months to 5 or more years' experience while others might be seasoned engineering veterans with ten or more years of experience in engineering or engineering management. Similarly, faculty judges range from adjunct, tenure track and tenured with a project/industry experience ranging from none to ~30 years. Some faculty means include faculty who had never graded a capstone report previously. The data has not been adjusted for levels of engineering nor capstone grading experience. Teams without both Faculty and external judges scores were excluded from the analysis.

Shown below in Figure 1 is the correlation between the Faculty and External Judges. Correlation values were calculated in MiniTab 17. To test the regression of the data the α value was set to 0.01. After running the test, the p-value received from the test was 0.136. The results indicated no significant correlation because the p-value is greater than α. This would support the concern that there is a difference between faculty and external judge scores.

A paired t-test was used to compare if faculty or external judges are more lenient. The paired t-test α value was set at 0.01 yielding a p-value 0.014 for the analysis and no significant correlation between faculty and external judges. Based on a team-by-team comparison, the data shows that external judges score ~15% higher than faculty.

Conclusion

The research results show a significant difference in capstone written report evaluation based on correlation and means testing. This would imply that the capstone constituency may want to use caution when using grades that could have a source bias. However, if used consistently across all teams in a given grading sequence there is no reason to suspect that grades could be adversely inflated or deflated by using grades only from faculty, only from external judges or a combination. It could be inferred that any grading bias would be consistently applied across all teams and all semesters. Still, based on the data available and the statistical results, faculty and external judges scores are not corellated.

Limitations and Future work

The research, as conducted, does not reflect a rigorous statistical approach. The data was collected in the past only as a means for assigning scores to the work of student teams and not for the purpose of research. A more rigorous approach would require the solicitation for capstone constituents who also collect capstone written reports evaluations from faculty and external judges. However, adjustments would have to be considered based on the diversity of grading schemes and rubrics.

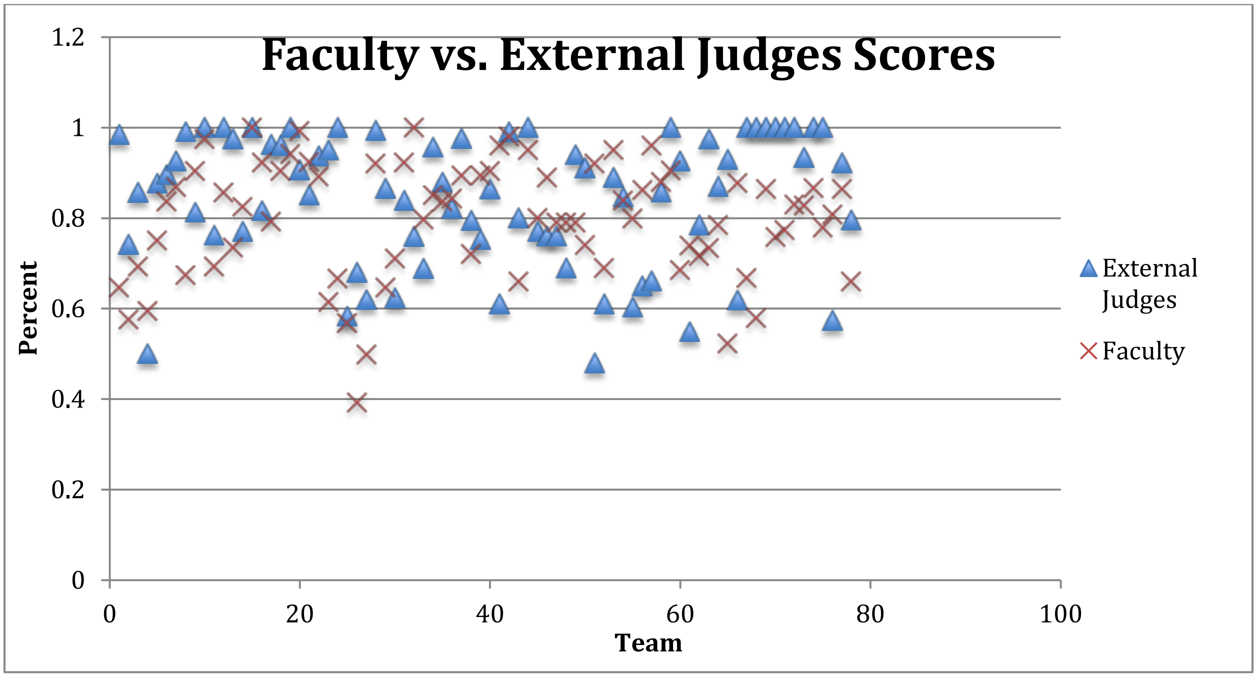

Figure 1: Correlation between Faculty and External Judges

Additionally, this initial research did not consider grader bias. For instance, are faculty biased by their perception of level of effort required to complete the project and inflate technical design review evaluations because of their perception? Are external judges motivated by sympathies for students to be lenient in evaluating the design technical content? Both faculty and external judges sometimes will grade a Capstone I report as well as the same teams' Capstone II report. Does familiarity with the previous semester's results, and carry-over perceptions of level of effort affect Capstone II scores? Additionally, there has been no consideration of grading experience, i.e., the experience, in number of years, of either faculty or external judges in grading capstone reports. It might be possible to survey both groups to determine if leniency bias or experience bias exists and how those biases might impact grading. Since faculty advisors grade not only their teams' reports (some faculty advisors may have as many as five teams assigned during a semester and these will be a mixture of Capstone I and II teams), but other teams as well, is there a comparison of teams inherent in the grading or is the grading completely objective.

Understanding rubric based criteria for grading capstone final reports is certainly plausible. Objectively applying that understanding can be challenging in a growing student project team environment.

Bibliography

1. Venters, C., Reis, J., Griffin, O. H., & Dixon, G. (2015). A Spiral Curriculum in Design and Project Management. Paper presented at the 45th Annual Frontiers in Education Conference, El Paso, TX

2. Dixon, G. (2012, June), *Experiencing Capstone Design Problem Statements* Paper presented at 2012 ASEE Annual Conference, San Antonio, Texas. https://peer.asee.org/21367
3. Charyton, Christine, Richard J. Jagacinski, John A. Merrill, William Clifton and Samantha DeDios, Assessing Creativity Specific to Engineering with the Revised Creative Engineering Design Assessment, *Journal of Engineering Education*, 100(4), 2011, pp. 778-799.
4. Bannerot, Richard, An Exercise In Problem Definition In An Early Design Course, *2003 American Society for Engineering Education Annual Conference Proceedings*, Nashville, 2003.
5. Conrad, James, Daniel Hoch, Peter Schmidt, Nabila (Nan) BouSaba, William Heybruck, Deborah Sharer, Assessing Senior Design Project Deliverables, *2009 American Society of Engineering Education Annual Conference & Exposition*, Austin, 2009.
6. Green, Matthew, Thomas Hellmuth, Roger Gonzalez, Stephen Ayers, Paul Leiffer, Effectively Implementing The Interdisciplinary Senior Design Experience: A Case Study And Conclusions, *2007 American Society of Engineering Education Annual Conference Proceedings*, Honolulu, 2007.
7. Dixon, G. (2015, June), *Capstone and Faculty Mentors/Advisors/Coaches* Paper presented at 2015 ASEE Annual Conference and Exposition, Seattle, Washington. 10.18260/p.23662
8. Dixon, G. (2014, June), *Technical Design Reviews in Capstone* Paper presented at 2014 ASEE Annual Conference, Indianapolis, Indiana. https://peer.asee.org/23111)
9. (Dixon, Gene and Denny Davis, (2015), "Design Reviews for Capstone Courses, *The International Journal of Engineering Education, v21n6B, p1832-1844.)*

Appendix I: Capstone Written Report Grading Rubrics

Evaluation Range (all rubrics): 1, Substandard; 2, Undergrad, underclass engineer, moderate; 3, Undergrad, underclass engineer, exceptional; 4, Undergrad graduating engineer (expectations met); 5, Engineer (1-2 yrs experience, expectations exceeded); N/A, not applicable

Part A: Conceptual Design Review

Eval.	Dsgn Phase	Review Criteria
	Prob Descrip.	Does the problem statement adequately represent a broad description of the project context and is free of solution "hints"?
	Prob Descrip.	Does the problem definition adequately transition from the broad problem statement into a project focus?
	Prob Descrip.	Were design inputs correctly and completely identified? By appropriate means?
	Prob Descrip.	Are assumptions adequately documented and reasonable?
	Prob Descrip.	Have codes and regulations been properly recognized?
	Prob Descrip.	Were design constraints correctly and completely identified? By appropriate means?
	Prob Descrip.	Were design objectives correctly and completely identified? By appropriate means?
	Prob Descrip.	Is the design plan comprehensive and well-conceived?
	EDS	Do the engineering design specifications ensure the design will meet requirements?
	Ideation	Are the alternatives reasonable and comprehensive?
	Parametric Dsgn	Are necessary design inputs for interfacing equipment, facilities, utilities and/or organizations specified?
	Parametric Dsgn	Have suitable materials, parts, processes, and inspection and testing criteria been specified?
	Dsgn Analysis	Appropriate design methods and computer programs used?
	Dsgn Decisions	Were design inputs correctly incorporated into the product/service design and design process?
	Dsgn Decisions	Have engineering judgments been identified, technically justified, and supported?
	Dsgn Decisions	Is the alternative reduction process leading to a recommended design appropriate and used properly?
	Dsgn Decisions	Is the design (output) reasonable compared to the design inputs?
	Dsgn Decisions	If testing of mockups have been completed, have appropriate scaling laws been established, analyzed and verified?
	T&E Feasibility	Were the technical and economic criteria employed for trade-off analysis appropriate and adequate?

Part B: Conceptual Design Review Process

Context	**Levels of Evidence**	**Eval. (1-5, N/A)**
Ability to contextualize the concept	• Need for design solution is understood in context • Concept meets needs and justifies further development • Concept promises important benefits desired by others	
Adequacy of searching for existing ideas	• Effective methods are used to find relevant design concepts • Concepts identified provide value and diversity • Search results identify areas with difficult design challenges	
Adequacy of new idea generation	• Idea generation focused on difficult design challenges • Individual and group idea generation are used • Methods are used well and provide valuable ideas	
Adequacy of concept evaluation	• Evaluation process is defined and followed consistently • Importance of requirements drives selection of components • Selected components are validated	
Adequacy of concept synthesis	• Synthesis process considers subsystem relationships • Cost, performance, simplicity, system integration achieved • System concept is validated	
Understanding of concept function	• Function of selected concept is explained well • Required function is proven feasible (e.g., prototyping) • Concerns about function are identified	
Understanding of concept reliability	• Robustness of selected concept is explained well • Required robustness is proven practical (e.g., analysis) • Concerns about robustness are identified	
Understanding of concept finances	• Financial soundness of concept is explained well • Required financial attributes are predicted (e.g., models) • Concerns about financial attributes are identified	
Understanding of concept social impact	• Safety and social impacts of concept are explained well • Impacts are defended relative to regulation, standards, etc. • Concerns about safety/social impacts are identified	
Adequacy of concept risk assessment	• Greatest risks with the concept are explained • Greatest opportunities with the concept are explained • Plans forward address risk/opportunity analysis	

Part C: Final Written Report (FWR) Evaluation

	Evaluation, 1-5, N/A
Executive Summary and key words	
Introduction to problem	
Economic motivation in introduction	
Problem statement	
Solution description	
Thoroughness of analysis	
Soundness of arguments supporting solution	
Clarity of technical presentation	
Use of an appropriate decision method	
Creativity of design	
Summary and conclusions (follow from body of report?)	
Economic analysis	
Recommendations to sponsor (plausible and defensible?)	
Progress for the semester	
Response to draft critique	
Organization of report	
Clarity of writing	
Grammar and sentence construction	
Use of correct engineering units	
Effectiveness of photos, figures, tables	
Quality of preparation of visual aids	
All design documents/files have been submitted/included.	

Part D: Detailed Design Review

Evaluation	Criteria
	Does the design conform to regulatory and other code requirements?
	Has adequate design testing been established?
	Has the design been analyzed for unique material/physical properties?
	Does the design adequately address unique materials requirement for (harsh) operating environments?
	Has the design been verified for compliance with the facilities hazards?
	Is the design compatible with interfacing equipment, systems, facilities, controls and personnel?
	Considering the operating environment, does the design provide adequate accessibility for maintenance, inspection, removal or replacement?
	Is sufficient detail provided to clarify construction, installation, and/or inspection methods and requirements?
	Has the design included provisions to perform tests required to verify performance requirements and calculated values?
	Does the design represent waste minimization and sustainable materials utilization?
	Have all the necessary drawings for equipment and facilities operation been identified, modified and/or created?
	Does the design provide adequate provision for equipment lock-out/isolation?
	Has the design impacted existing procedures (operations, maintenance, engineering, support, etc.) and the necessary change requests been initiated/recommended?
	Has a bill of materials been developed that will support spare parts inventory?
	Has the use of hazardous chemical, local exhaust systems, bio-hazards, noise hazards, etc. been minimized or controlled in a way that protects operations, maintenance, engineering, support, etc.)?
	Does the design address fire protection/life safety requirements as necessary?

Part E: Detailed Design Review Process

Context	Levels of Evidence	Eval. (1-5, N/A)
Ability to abstract the solution	• Needs of stakeholders are understood in context • Solution fits needs, promises desired performance • Solution benefits justify implementation and user testing	
Adequacy of requirements validation	• Requirements have been reviewed and revised over time • Requirements have been validated with key stakeholders • Requirements align with industry standards	
Appropriate focus of detail design effort	• Design risks and benefits have been assessed • Time was prioritized where maximum gain was expected • Design effort was invested for effective use of time	
Adequacy of solution evaluation	• Engineering analysis was used to prove design adequacy • Formal testing was used to prove design adequacy • Evaluation results are interpreted correctly	
Proof solution has desired functionality	• Important functions are tested to prove performance • Functional performance meets critical requirements • Areas of functional weakness are identified	
Proof solution gives desired financial value	• Important financial performances are tested • Financial performance meets critical requirements • Areas of financial weakness are identified	
Proof solution is safe and responsible	• Issues of solution responsibility are tested • Solution is found safe and meets societal expectations • Concerns about ethics and responsibility are identified	
Adequacy of solution validation	• Solution is tested in the hands of intended users • Solution meets needs and applications of intended users • Areas of concern about solution validity are identified	
Adequacy of solution risk assessment	• Risks encountered in detail design were mitigated • Risks for solution implementation are identified • Actions for risk mitigation are described	

Appendix II: Mean Percent Grade Scores per Team for Faculty and External Judges

	Faculty	**External Judge**	**Class**
Team 1	65%	98%	Spring 2014 (4010)
Team 2	58%	74%	
Team 3	69%	86%	
Team 4	60%	50%	
Team 5	75%	88%	
Team 6	84%	90%	Fall 2015 (4010)
Team 7	87%	93%	
Team 8	67%	99%	
Team 9	90%	81%	
Team 10	98%	100%	
Team 11	69%	76%	
Team 12	86%	129%	
Team 13	73%	98%	
Team 14	89%		
Team 15	82%	77%	
Team 16	100%	100%	
Team 17	92%	82%	
Team 18	79%	96%	
Team 19	90%	96%	
Team 20	94%	100%	
Team 21	99%	91%	
Team 22	92%	85%	
Team 23	89%	94%	
Team 24	63%		Spring 2015 (4010)
Team 25	61%	95%	
Team 26	67%	100%	
Team 27	57%	58%	
Team 28	74%		
Team 29	39%	68%	
Team 30	82%		
Team 31	50%	62%	
Team 32	92%	99%	Spring 2013 (4010)
Team 33	65%	86%	
Team 34	71%	62%	
Team 35	92%	84%	

Team 36	102%	76%	
Team 37	80%	69%	
Team 38	74%		
Team 39	85%	96%	
Team 40	84%	88%	
Team 41	91%		
Team 42	84%	82%	
Team 43	89%	98%	
Team 44	84%		
Team 45	72%	79%	
Team 46	89%	75%	
Team 47	90%	86%	
Team 48	96%	61%	Spring 2015 (4010)
Team 49	98%	99%	
Team 50	66%	80%	
Team 51	95%	100%	
Team 52	80%	77%	
Team 53	89%	76%	
Team 54	79%	76%	
Team 55	79%	69%	
Team 56	79%	94%	
Team 57	74%	91%	
Team 58	87%		
Team 59	92%	48%	
Team 60	69%	61%	
Team 61	95%	89%	
Team 62	95%		Spring 2014 (4020)
Team 63	84%	85%	
Team 64	85%		
Team 65	77%		
Team 66	80%	60%	
Team 67	86%	65%	
Team 68	92%		
Team 69	96%	66%	
Team 70	86%		
Team 71	83%		
Team 72	78%		
Team 73	88%	86%	
Team 74	67%		
Team 75	91%	106%	

Team 76	94%		
Team 77	85%		
Team 78	69%	93%	Fall 2015 (4020)
Team 79	74%	55%	
Team 80	72%	78%	
Team 81	73%	97%	
Team 82	78%	87%	
Team 83	52%	93%	
Team 84	88%	62%	
Team 85	67%	100%	
Team 86	58%	100%	Spring 2015 (4020)
Team 87	86%	100%	
Team 88	76%	100%	
Team 89	77%	100%	
Team 90	83%	100%	
Team 91	89%		
Team 92	83%	93%	
Team 93	87%	100%	
Team 94	78%	100%	
Team 95	78%		
Team 96	81%	57%	
Team 97	73%		
Team 98	86%	92%	
Team 99	66%	80%	