

# **AC 2010-765: A PROPOSED DOCTORAL ASSESSMENT PROCEDURE AND RUBRIC FOR SCIENCE AND ENGINEERING**

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**Abstract:** Learning outcomes assessment has been ascendant throughout higher education, but little has been developed at the doctoral level. An assessment procedure for the doctoral studies is proposed that has two parts: (1) an evaluation of publication rates within two years after completion of the degree, and (2) an assessment of the dissertation and the defense using a number of criteria. The criteria were based on a review of the online literature plus additional criteria developed ourselves. Common criteria include originality, advancing of the state of the art, and demonstration of a high degree of mastery. The additional criteria include: demonstration of mastery of the literature; the work has academic or practical utility; the work uses advanced or novel techniques; the work has elements of both theory and experiment. Several other criteria are linked to our institution's mission, including: The work may lead to marketable technology; the candidate demonstrates ability to communicate orally and in writing at a high level. Note that not all these criteria are requirements for success; some are intended to be used to evaluate the program, and not the candidate.

A detailed rubric for the evaluation of the doctoral dissertation and the oral defense was developed. A rubric makes evaluation of the criteria less subjective, and can serve as a guide for both the dissertation committee as well as for the doctoral candidate. The rubric was pilot-tested with several engineering doctoral defenses in engineering programs. The results validated the rubric against concerns that dissertation committees would be reluctant to rate a dissertation that the committee passed with anything less than top scores. The results also were revealing of the actual standards used by doctoral dissertation committees in evaluating the dissertation and defense.

## **Introduction:**

Learning outcomes assessment has become a standard part of higher education. Inspired by quality control approaches used in industry, it began to be required in education by specialized accreditation agencies such as ABET, Inc.<sup>1</sup> and The Association to Advance Collegiate Schools of Business (AACSB)<sup>2</sup>. More recently, similar requirements have been adopted by regional accreditation agencies, such as the Middle States Commission on Higher Education<sup>3</sup>, which has promulgated a requirement that all offerings, including graduate programs, have "program goals that are stated in terms of student learning outcomes." Graduate programs are not required by Middle States to be assessed as strictly as undergraduate programs. Nevertheless, they should have "periodic evaluation of the effectiveness (of its educational offerings) ... and utilization of evaluation results as a basis for improving its student development program and for enabling students to understand their own educational progress."

Little information could be found on assessment of the doctoral education. Some studies focused on assessing the work of the thesis committees<sup>4</sup>. One researcher identified a major disconnect

between the expectations of the thesis committee and that of the Ph.D. candidate as a major problem<sup>5</sup>. Holbrook<sup>6</sup> reported: “there has been scant attention paid to PhD outcomes, particularly the examination of the thesis, the qualities of the research undertaken by PhD students and the effectiveness, usefulness and application of the research training received across disciplines.”

The procedure described in this work has the following objectives: Collect information on the quality of doctoral work done in the institution in order to improve that quality; focus the attention of doctoral thesis advisors and committees as well as the doctoral candidate on the criteria for a quality thesis.

### **Existing Criteria for a Doctoral Dissertation**

A thesis by definition is a manuscript that embodies original work. In this context, what are the characteristics that an excellent Doctoral thesis should have? As an example, The University of New Brunswick<sup>7</sup> uses the following:

*The criteria for satisfying the dissertation requirement of our PhD program are the submission of a dissertation which (1) must demonstrate the candidate's competence to undertake and complete independent research or creative work that (2) is original and/or unique in nature, and (3) the completed work must contribute significantly to knowledge in the candidate's field of study. The contribution must be of sufficient merit to suggest publication in an appropriate scholarly journal or other form. The dissertation must show that the candidate is fully aware of the pertinent published material and the dissertation must be written in a satisfactory literary style, free from typographical and other mechanical errors.*

No criteria are given for the oral presentation except as follows:

*“The purpose of the oral examination is to examine both the content of the dissertation and the candidate's ability to defend it. “*

Holbrook<sup>6</sup> quotes Kouptsov<sup>8</sup> for Ph.D. criteria obtained by a survey of European academics as follows:

*Belarus: '...Must reflect research on a disciplinary or interdisciplinary, theoretical, or applied problem, the results of which will constitute an original contribution to knowledge in the discipline or disciplines concerned. Doctoral research must demonstrate the ability of the candidate to identify a new intellectual problem, to apply research methods and techniques competently and to achieve tangible results and convincing conclusions independently. '*

*Bulgaria: '...Should be a scholarly work which makes a contribution to knowledge in the given field and reveals the aptitudes of the candidate for independent research'*

*Czech Republic: '...Must be a scholarly work based upon original research. It should make a contribution to a field of knowledge. It must also demonstrate the abilities of the student to solve a scientific problem. In any case, it must contain new information, irrespective of how it was acquired - in laboratory through experiments, by*

*generalisation of practical experience through measurement, by study of archival materials, or theoretically. This new information should contribute to the development of knowledge as well as to practices, and should be statistically or otherwise objectively documented. The new information should also be compared to the state of knowledge at the input, i.e. the period during which work on the dissertation was begun. It is recommended that the results of the dissertation be at least partly published or otherwise publicised (e.g. at conferences), so that the dissertation can be supported by the scientific and research community, not only by the opinions of the opponents.*

*Denmark: '...capacity to carry out a scientific project involving independent use of the scientific method of the subject thereby furthering research at a level corresponding to the international standard of the PhD within the subject area.'*

*The Netherlands: '...The dissertation must report on original research and present scientific results. It should make an original contribution to knowledge in the field and testify to the candidate's mastery of the methodology'*

*Portugal: '...The thesis is expected to be a scholarly work which contributes to the relevant field of knowledge. It must be a piece of original research which indicates the author's knowledge of research methodology'*

*USA: ...demonstrates the candidate's ability to address a major intellectual problem and arrive at a successful conclusion independently, and at a high level of professional competence...its results constitute an original contribution to knowledge in the field'.*

The characteristics that are common to most of these are (1) a high level of scholarship, (2) originality, and (3) significant contribution to the field of research.

Regardless of the criteria suggested, their application begs the question of how these criteria are to be judged. This is the purpose of a rubric, which can be defined as<sup>9</sup>: “A rubric is a scoring tool that lists the criteria for a piece of work, ... it also articulates gradations of quality for each criterion, from excellent to poor.” In this context, a rubric can be a guide both for the thesis committee as well as for the Ph.D. candidate.

### **Proposed assessment procedure and criteria:**

Two metrics are proposed for assessing the Doctoral work at Stevens Institute of Technology:

1. The percentage of graduates with doctoral degrees who have at least a peer-reviewed journal article of their thesis published within two years of graduation. Impact factors of the journals should be reported.
2. Criteria for evaluation of the thesis by the Thesis Committee, with a rubric.

The first of these amounts to an external evaluation or benchmarking of the thesis. The goal is for 100% of theses to be published in peer-reviewed journal articles. However, this ideal is often not met. The degree to which it is met will be an index of the quality of the program.

Some Ph.D. programs now attempt to require candidates to publish their work before defending the thesis. However, often this is not practical. Furthermore, it puts the responsibility for awarding of the degree on anonymous reviewers, removing it from the institution. A more realistic requirement would be that papers, in a form approved by the thesis advisor, should be *submitted* to a peer-review journal prior to the thesis defense and awarding of the degree.

The proposed metric is summative, that is, it is an after-the-fact measurement of performance, and thus is used to improve the program, not the individual thesis.

For the second metric, we have identified a more detailed set of criteria than those described above. The criteria we propose for the thesis and for the oral defense include:

- The work is original and novel; that is, it uses methods or produces results which are not generally anticipated, or which may not be obvious to others in the field.

Originality should be judged relative to existing work in the same field.

- The work advances the state of the art in the relevant field.

The work should push the boundaries of the field either in a new direction or further along the lines of previous work.

- The state of the art is well-described in the literature survey.

The candidate should show through the literature survey that he/she has mastered the literature on the subject, understands the theory and methodology, is able to critically evaluate the work that has gone before and its relation to the current work.

- The work has academic or practical utility.

In other words, the results of the thesis could be used by others to do useful things that are difficult or impossible without the result, including the production of further advances in the state of the art.

*Academic utility* is defined to mean that the work is likely to be used for further advances in the development of the field, such as experimental results that suggest the need for new theory, or theoretical results that suggest the need for new data. In other words, the result of this work could be to stimulate further research by others.

*Practical utility* means that the work has the potential to be used for the sake of the results themselves, such as the ability to make useful predictions or to design a new process or product.

Other characteristics of Ph.D. work which may be unique to science and engineering (as opposed to, say, humanities theses) are:

- The work uses advanced techniques, or techniques which are new to the field.

Utilization of new techniques can provide new insights not previously accessible.

- The work has elements of both theory and experiment.  
Theoretical results may be used to suggest experimental design, or the theory itself may be a major outcome of the work.

Experiment may be used to validate new or existing theory, or to probe natural behaviors to suggest the need for new theory or understanding.

In addition, the mission of Stevens Institute has led us to define several additional criteria, which are:

- The work has considered the potential to result in marketable new technology.

When relevant, intellectual property (IP) issues should be addressed in the thesis, and the potential identified.

This criterion arises from Stevens long tradition of enterprise and innovation that started with the Stevens founding family, which has been incorporated into its mission. Stevens has pioneered the concept of *Technogenesis* as the educational frontier, where faculty, students and industry jointly nurture research concepts to commercialization and back to the classroom. It is more than technology transfer, it is part of the Stevens educational experience and creates a climate of innovation and enterprise across the campus.

- The Ph.D. candidate demonstrates the ability to communicate at a high level, both written and orally.

The written thesis presents technical information with adequate detail and clarity, the Ph.D. candidate orally presents the information with clarity, and demonstrates the ability to “think on his/her feet” and respond to verbal inquiries clearly, succinctly and accurately.

Note that not all these criteria are requirements for success; some are intended to be used to evaluate the program, and not the candidate. In particular, not all theses are expected to result in marketable technology.

As stated above, objective implementation of the criteria calls for a rubric. Such a rubric is shown in Table 1. This Table should be made available to the Ph.D. candidate as early as possible, so that the candidate can use it for self-evaluation during the time the research is being conducted. The results from the assessment rubric, however, should be aggregated at various academic levels from the program to the institute as part of the long-range assessment and

evaluation and, ultimately, improvement of its Ph.D. programs offerings. In addition, committee members should provide written comments on any issues noted in the rubric that most need improvement.

The Table is also used by the thesis defense committee when they are reviewing the completed thesis and during the oral defense. The results of their ratings can be used by the committee in its discussions. However, there is no *a priori* minimum rating required for passing the oral defense. That is a judgment of the committee. During the development of this rubric, one faculty reviewer suggested that no one should be awarded a Ph.D. unless they scored at least a 3 in each category. Another said "...I don't think a thesis committee would ever allow a PhD student to graduate if they did not achieve at least all 4s in the present rubric. It is the committee's responsibility to insure that the research is unique and will have an impact on the field so I am not so sure we need all of the ratings." In this work we assess these claims in a pilot test to determine how actual doctoral defense committees rate the theses and oral defenses that they evaluate.

### **Pilot test of proposed rubric:**

Three recently completed Doctoral Dissertations were considered for preliminary benchmarking of the proposed rubric. These were selected based on their schedule and content. Thesis 1 [T-1] is a naval architecture study; thesis 2 [T-2] is an ocean engineering study; and thesis [T-3] is a nanocomposite manufacturing study. It should be noted that the thesis work were performed in programs leading to the Doctor of Philosophy degree that was designed to develop the student's capability to perform research or high-level engineering design. Admission to the programs were made through the departmental graduate admissions committee, based on review of the applicant's scholastic record. A master's degree in which the applicants have demonstrated academic performance to reflect their capability to pursue advanced studies and perform independent research is required for admission to the doctoral programs.

At Stevens, sixty credits of graduate work in an approved program of study beyond the masters degree are required for completion of the doctoral program. Of the 60 credits, 15 to 30 credit hours of course work, as well as 30 to 45 credit hours of dissertation work, are required. Within two years from the time of admission, a student must take a qualifying examination that tests his/her ability to critically analyze the research literature. Upon satisfactory performance in the qualifying examination, and completion of the required course work, the student must take an oral preliminary examination. This examination is primarily intended to evaluate the student's aptitude for advanced research and examine his/her understanding of the subjects associated specifically with the dissertation topics. Upon satisfactory completion of the preliminary examination and all course work, a student will become a doctoral candidate and start his/her dissertation research. Doctoral research work must be based on an original investigation and the results must make a significant, state-of-the-art contribution to the field, and must be worthy of publication in current professional literature. At the completion of the research, a student must defend his/her thesis in a public presentation.

**Table 1. Stevens Institute Engineering PhD Thesis and Defense Assessment Rubric**

<b>CRITERIA</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Originality and novelty</b>	The work completely lacks originality	Repeats work of others with only minor changes	Work has not been done before, but is an obvious extension of previous work	Work incrementally improves on previous approaches	Work is cleverly designed and/or represents a significantly new direction or approach
<b>Advances the State of the Art</b>	No advance is evident	Results are obvious or easily anticipated	Incrementally advanced the knowledge or methodology in the field	Results can be expected to have a modest impact	Produced a significant result that is likely to have a major impact
<b>Literature survey</b>	Lacking	Cursory	Extensive but either not complete or not critical	Complete and concise, but not adequately critical	Comprehensive and critical
<b>Possesses Practical and/or Academic Utility (Potential Impact)</b>	Work is unlikely to be useful to others	Work has a low likelihood to be used by others	Work has some likelihood to be used by others	Work is reasonably likely to be used by others	Work has strong potential for use by others either in applications or in further research
<b>Uses new or advanced techniques</b>	Uses only primitive methods	Uses only simple and long-established methods and techniques	Uses standard methods commonly known in the field	Uses the most advanced established methods	Uses leading-edge methods not applied before in this field
<b>Has elements of theory</b>	Does not involve any theoretical development or predictions	Incorporates standard theory in the field	Incrementally advances theory currently used in the field	Significantly extends existing theory in the field	Involves theory that represents a break with the state-of-the-art
<b>Has elements of experiment</b>	There is no data collection or usage	Few data are collected or relies on data from others	Data collection is a minor part of this work	Data collection is a major part of this work	Employs sophisticated and novel experimental methods

<b>CRITERIA</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Technogenesis Potential for Intellectual Property (IP)</b>	No IP issues recognized or addressed	Some recognition of IP issues	IP issues considered but there is limited IP potential	Significant consideration of IP issues and demonstrated IP potential	Well defined IP context and strong IP potential
<b>Written presentation (Thesis)</b>	Missing significant details or very difficult to read	Disorganized or lacking in some details	All details are present, but requires some effort by reader	All details are present, organization is adequate	Comprehensive, elegantly and clearly written
<b>Oral presentation (Defense)</b>	Poor quality visuals or inarticulate presentation	Some visuals need improvement or presentation is not confident	All visuals adequate and presentation is confident	Significant effort evident in visuals, and presentation is confident	High production quality and articulate presentation
<b>Responsiveness to questioning</b>	“Freezes up” or generally unable to adequately handle questioning	Often isn’t able to respond to questions, or requires prompting	Makes satisfactory responses on his/her own to most questions	Clearly understands the issues raised and always makes satisfactory responses	Articulate and thorough, demonstrates complete mastery of the topic



The following are some of the common features of the theses.

- 1) The doctoral thesis dissertation was successfully defended and considered to be acceptable by the committee.
- 2) The thesis committee included one external member from Stevens who was a full-time regular (tenure track) faculty from another academic program whose research interest was closely aligned with the thesis topic.
- 3) The thesis committee also included one full-time regular (tenure track) faculty from another Institution or an R & D professional from a neighboring federal research laboratory, whose research interest was closely aligned with the thesis topic and who also assisted the thesis advisor in providing advising and guidance to a portion of the research.
- 4) Manuscripts involving a part of the thesis research have been submitted for publication in peer reviewed journals with relatively high impact factors in their field and found acceptable for publication (subject to satisfactory address of the reviewers' comments and suggestions).
- 5) The thesis committee had no prior knowledge of the rubric-based evaluation approach for the assessment of doctoral dissertation.

In addition to the content and approach between the three theses, there were also certain dissimilarities between the development and presentation techniques involved. The following summary based on the construction of the rubric is used to highlight these dissimilarities.

- 1) *Originality and novelty*: T-1 was considered by most of the committee to be “Work incrementally improves on previous approaches”, while T-2 and T-3 were rated as “Work is cleverly designed and/or represents a significantly new direction or approach”. A major reason being that there were several similar studies that T-1 was built upon; while T-2 involved a heretofore novel data acquisition system and real-time data analysis, and T-3 involved an innovative nanocomposite manufacturing technology.
- 2) *Advances the State of the Art*: T-1 was considered to be “Incrementally advanced the knowledge or methodology in the field” while T-2 and T-3 were rated as “Results can be expected to have a modest impact” to “Produced a significant result that is likely to have a major impact”. This difference was due to the innovative and clever processing approach used in T-3 and the level of sophisticated data acquisition and statistical analysis used in T-2 in comparison to a more mundane approach, data reduction and analysis employed in T-1.
- 3) *Literature survey*: T-1, T-2 and T-3 were rated as “Extensive but either not complete or not critical” or “Complete and concise, but not adequately critical.”
- 4) *Possesses Practical and/or Academic Utility (Potential Impact)*: T-1 was considered to be “Work has some likelihood to be used by others” to “Work is reasonably likely to be used by others” while T-2 and T-3 were rated as “Work is reasonably likely to be used by others” to “Work has strong potential for use by others either in applications or in further research”. This difference was again based on the novel data collection and analysis used in T-2 and innovative manufacturing technique used in T-3 .
- 5) *Uses new or advanced techniques*: T-1 was rated by all as “Uses standard methods commonly known in the field” while T-2 and T-3 were rated as “Uses the most advanced established methods” to “Uses leading-edge methods not applied before in this field” due to the novel system and relatively sophisticated real-time data analysis.

- 6) *Has elements of theory*: T-1 and T-3 were rated as “Incorporates standard theory in the field” while T-2 was rated to be “Significantly extends existing theory in the field”. This was based on the extensive use enhancements to the computational approach that is used by the practitioners of the art.
- 7) *Has elements of experiment*: T-1 was rated as “Data collection is a major part of this work” while T-2 and T-3 were rated to be “Data collection is a major part of this work” to be “Employs sophisticated and novel experimental methods”

The results were quite encouraging from the point of validating the concepts behind the rubric:

- 1) The members of the doctoral committees did not rank all items in the rubric with a 3 or 4; thus validating the objectivity of its construction.
- 2) The doctoral thesis advisors for all did not uniformly award a 3 or 4 for all items; another validation measure for the construction of the rubric.
- 3) Although the Technogenesis® segment of the rubric was not included in the version used by the two committees, all theses were ranked at 2 to 3 from the point of IP development.
- 4) Similarly, the rubric on the communications involving “written” “oral” and “responsiveness” was not used uniformly by all members of the committee. However, based on the authors perspective, T-1 is to be rated as 2 while T-2 and T-3 can be easily rated as 3.

## Summary

As can be seen, the topic of the thesis and the tools available for the investigators had a major impact on the outcome and the rubric ratings. Thus, the role of the advisor, the resources available and the techniques and tools that are considered to be the “state of the art” will contribute to the outcomes assessment within the context of this rubric construction.

From a long term point of view, it is quite possible that T-1 may have as much impact as T-2 or T-3 once the novelty of the manufacturing process, data acquisition and the methodology becomes standardized. It is even possible that T-1 will have a long term impact on the design of marine-craft, while the approach and the methodology used in T-2 or T-3 may be eclipsed by enhancements to the state-of-the-art even in near term. The doctoral degree is not considered a terminal degree; rather it is the starting point for academic and scholarly research, in which the sustained contributions and the scholarship of the doctoral degree recipients play a crucial role. Lacking a crystal ball, the academic vision and foresight of the thesis advisor is also seen to play an important role in the long term impact of the thesis.

From the authors’ perspective, the use of a rubric is to be considered essential for evaluating the outcomes of all doctoral theses. The authors plan to use the rubric for a variety of additional doctoral theses to validate and refine the approach.

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### **Author Biographies:**

Prof. Vaccari is an environmental engineer whose research interests include biological treatment processes and system modeling. He has co-authored a textbook titled, “Environmental Biology for Engineers and Scientists.” He serves as Director of Assessment at Stevens, is the Director of the Department of Civil, Environmental and Ocean Engineering. He has eight years of service as a program evaluator in environmental engineering for EAC of ABET, Inc., was a member of ABET’s Technical Accreditation Committee for two years, and is currently a member of the ABET Board of Directors. He is also Chair of the American Academy of Environmental Engineers (AAEE) Education Committee. A licensed Professional Engineer in the State of New Jersey, Dr. Vaccari also holds the bachelors, masters, and doctorate degrees in Environmental Science, and a Master of Science in Chemical Engineering all from Rutgers University.

Prof. Siva Thangam is a mechanical engineer whose research interests include turbulence modeling of separated flows, aero-elastic flows in turbine cascades, and biomedical systems. He was visiting scientist and consultant at ICASE, NASA Langley Research Center from 1990-1998; during 1993-2005, he was the director of the New Jersey Space Grant Consortium, a NASA-funded educational, research and outreach enterprise. He is a Professor of Mechanical Engineering and the Dean of Academic Administration at Stevens. He is responsible for coordinating Academic Assessment at Stevens. He serves as a program evaluator in mechanical engineering for EAC of ABET, Inc. Dr. Thangam received his doctoral degree in mechanical and aerospace engineering from Rutgers University.