Validating & Implementing Engineering Graduate Attribute Rubrics in a Biosystems Engineering Curriculum

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Abstract— **This study was designed to validate and implement a set of graduate attribute rubrics in the Biosystems Engineering curriculum in the Faculty of Engineering at the University of Manitoba in Canada. One researcher worked individually with ten professors to develop 14 rubrics for 12 courses. Content-related and substantive-related validity were established. Pre and post surveys were conducted to measure professors' understanding of graduate attributes and rubrics, and their perceptions regarding this study. Findings showed that while working with the researcher, some professors were channeled to think deeply about teaching and assessing, often in ways that were new to them. There was evidence of the professors achieving constructive alignment by engaging in reverse curricular design. The use of the rubrics ranged from supporting learning outcomes, to marking students' work, to developing course materials. The professors appreciated the efficiency and effectiveness of receiving individual support to develop these assessment tools, as they cited time as an impediment to designing and using rubrics. Overall, continued individual support in developing assessment tools would be valuable in facilitating the change in practices and beliefs that is required to sustain outcomes-based education and importantly, to effectively support student learning.**

Keywords—assessment rubrics; constructive alignment; validity; faculty support

I. INTRODUCTION

The requirements for accreditation of engineering programs have changed globally. Assessment has grown in importance, and a climate of accountability is prevalent in engineering education [1]. Educational reform is being led by changes in assessment programs because they "determine what teachers actually teach and what students actually learn" [2]. Accreditation boards are moving away from quality assurance models to focusing on assessing and improving the knowledge and abilities of students [3]. It is now the responsibility of accredited engineering institutions to show evidence of their graduating students' outcomes. This requires that accredited institutions use systematic and valid methods for measuring what students learn while in their programs [4][5].

In 2009, the Canadian Engineering Accreditation Board (CEAB) followed this global movement and initiated an outcomes-based approach for engineering curriculum development and assessment [6-8]. Canadian engineering programs are now responsible for developing learning outcomes that can be measured; assessments of students' knowledge, skills and behaviors; and procedures for continual improvement of student learning [9]. The CEAB details 12 attributes necessary for graduating engineers: 1. A Knowledge Base for Engineering; 2. Problem Analysis; 3. Investigation; 4. Use of Engineering Tools; 5. Design; 6. Individual and Teamwork; 7. Communication Skills; 8. Professionalism; 9. Impact of Engineering on Society and the Environment; 10. Ethics and Equity; 11. Economics and Project Management; and 12. Lifelong Learning. These attributes enable today's engineering students to gain the knowledge and skills, and form the attitudes, values and behaviours required to become experts in their fields in the 21st century, which is a global, multifaceted, and rapidly changing world [10-12]. To achieve this, Canadian accredited institutions are faced with the challenge of creating new curricula and implementing new assessment protocols to evaluate their students' graduate attributes competencies [13-15]. Assessment tools supporting outcomes-based assessment need to be created using performance descriptors so that thresholds and targets are established, and outcomes-based assessment is conducted.

Rubrics are an assessment tool for 'qualitative rating of authentic or complex student work,' [16] conducive to outcomes-based assessment [17-26]. They are efficient and fair: an excellent tool for configuring the pedagogy for targeted learning outcomes [27], linked to the promotion of student learning [16]. They are descriptive rather than evaluative, communicating important aspects of performance [16], allowing both the assessor and the learner to match learner performance to the descriptor [27-29] as they are criterion-based [30]. Rubrics are a catalyst for determining a common language and understanding for all stakeholders, including faculty, students, and industry members. Particularly useful when it comes to assessing students' competencies in regard to the graduate attributes, rubrics provide a framework to define graduate attributes with concrete, measurable indicators and performance levels, transparently stating expected outcomes for both the instructor and the learner.

Over the past academic year, members of the Faculty of Engineering at the University of Manitoba, a large research

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university in Canada, developed a set of rubrics for the 12 CEAB graduate attributes [29], intended as a pedagogical assessment tool at both course and program levels. The rubrics were inspired and informed by the VALUE rubrics of the Association of American Colleges and Universities [31]. Academics from the Faculties of Engineering and Education and the Director from the Centre for the Advancement of Teaching and Learning (CATL) at the University of Manitoba, as well as a thrice rotating group of between 20-30 Manitoba Industry members were involved in the process of evaluating and revising both the content and wording of the rubrics. With the development of these rubrics, a number of outcomes-based pedagogical and accreditation goals were accomplished for the engineering faculty. We: 1) Divided the graduate attributes into teachable and measurable learning foci and indicators; 2) Defined competency levels; and 3) Developed a common language for faculty, students, and industry to facilitate our work with the graduate attributes [29].

This Research-to-Practice full track paper describes a pilot study to validate and implement these rubrics in the Biosystems Engineering curriculum. The first author of this paper, who is a PhD candidate with her focus in Engineering Education, worked with 10 individual Biosystems faculty members to anchor each rubric to a Biosystems course performance assessment, and obtain content and substantive validity evidence. Faculty completed pre and post surveys exploring their understanding of graduate attributes and rubrics. Anecdotal findings, described through the Bigg's 'constructive alignment' framework [30] showed evidence of faculty thinking about assessment in new ways, and that faculty engaged in curricular 'backward (i.e., reverse) design' [32]. The use of the rubrics ranged from supporting learning outcomes, to marking students' work, to developing course curriculum. The study highlighted the positive outcomes from engaging in one-on-one interaction with faculty to develop assessment tools, to the challenges inherent in this type of work, and provided a holistic view of how the graduate attributes are positioned in the Biosystems Engineering program. It was determined that faculty was not discussing assessment outside of the study parameters, which is an essential practice in facilitating the climate needed to sustain best practices. Overall, faculty expressed their appreciation for the support afforded by the study, and cited time as an impediment to using rubrics for assessment, which reflects the research [30].

The long-term objective of this project is to share our process to validate and implement attribute rubrics into an engineering curriculum in order to facilitate other programs' adoption/adaption of such measures, ultimately enhancing teaching and improving student learning in engineering education.

II. CONSTRUCTIVE ALIGNMENT IN THE CURRICULUM

John Biggs coined the term *constructive alignment*, an approach to teaching and learning whose roots can be found in the work of Ralph Tyler, considered "the father of teaching objectives" who espoused that "'learning takes place through the active behaviour of the student'" [30]. Constructive alignment in the curriculum signifies that what the student is intended to learn, and how that learning will take place, is identified and communicated *before* teaching occurs. This is characterized as a student-centred approach to learning. Traditionally, higher education is dominated by a teacher-centred approach to education, where the focus is on the content to be 'delivered,' rather than on the knowledge, skills or behaviours that students are meant to demonstrate. The evolution of engineering accreditation requirements to a graduate attributes focus inherently shifts the model of teaching and learning to an outcomes-based approach. Bigg's constructive alignment provides a framework by which instructors can engage in outcomes-based education [30].

The crucial step to achieving constructive alignment is to identify what the learner should be able to *do* with what they are being asked to learn [30]. Biggs describes this as the *intended learning outcome* (ILO), and recommends that this action be defined by a verb. Once the ILO is determined, a learning activity is designed to facilitate students in executing the action that is denoted by the verb (i.e., in *doing* what they are required to demonstrate the targeted ILO). The 'teaching task' is to help students to engage in the defined activity [30]. Once students have learned how to engage in the activity, the teacher performs a summative assessment to determine how competent the student is in performing the required activity in the suitable context. Biggs recommends using a 'public rubric' for assessment – a rubric because it enables a holistic assessment of the entire performance, and because it is a 'criterion-referenced' assessment tool [30]. The 'public' aspect of the rubric is in alignment with the philosophy of outcomes-based education, where both the teacher and the learner are aware, *before* the teaching, learning, and assessment take place, what is required of the learner in order to demonstrate the outcome. Thus, constructive alignment is achieved when both the methods used to teach *and* the assessment tools are aligned with the learning outcomes that are intended [30].

III. BACKGROUND: DEVELOPING THE RUBRICS AND ESTABLISHING VALIDITY

In the process of developing the graduate attribute rubrics for the Faculty of Engineering at the University of Manitoba, a number of steps were followed to establish content-related evidence. Content-related evidence shows whether or not the material within the instrument (i.e., the content of the rubric) is demonstrative of the intended concept to be measured [33] (i.e., the knowledge, skills, behaviours, attitudes, and/or values that comprise the graduate attribute). Content-related evidence 'is important for almost all measures and is based on a logical analysis of the content of the measure' [33]. Therefore, we established content-related evidence by harnessing the expertise of a variety of stakeholders in engineering and in education. We struck a committee whose members demonstrated the expertise representative of the graduate attributes and with best practices in measurement and assessment. We worked closely with the Director of the Centre for Teaching and Learning at the university, and also a member of the Faculty of Education who is an expert in evaluation and

measurement, and a rotating group of between 20-30 Manitoba Industry members, who shared their expertise and provided their insight through three industry forums that were hosted by the Faculty of Engineering between December 2013 – June 2014 [29].

Generally, our committee chose to follow the steps suggested by Gliner, Morgan and Leech (2009) [33] to develop a list of indicators and respective performance levels for each attribute:

1. Define the concept that the investigator (instructor) is attempting to measure.

2. Conduct a literature review to see how this concept is represented in the literature.

3. Generate items that might measure this concept.

4. Reduce the list of items to form the test of measure.

Consequently, the rubrics underwent multiple iterations to ensure that they showed evidence of content-related validity.

The next step was to validate and implement the rubrics in our engineering programs. Therefore, the authors of this paper designed a study to validate and implement the graduate attribute rubrics in the Biosystems Engineering curriculum.

IV. METHODOLOGY

This study, devised to validate and implement the graduate attribute rubrics in the Biosystems Engineering curriculum, was originally designed using a team format and Delphi process. However, it quickly became apparent that having the professors work individually with the researcher was more feasible, as well as more effective in achieving our study goals. Each professor had specific assessment needs for their individual courses that required the design of individualized rubrics, a process that lent itself to working one-on-one with the researcher. Ten professors in the department agreed to participate in the study to establish content-related and substantive-related validity for one rubric, and to implement this rubric into their individual courses. Our ethics board approved the study.

We determined that content-related validity would be reached when the professor and researcher agreed that the indicators chosen represented the specific graduate attribute(s) and the learning outcomes targeted in the course. For example, for the attribute, *Impact of Engineering on Society and the Environment*, we determined whether the four indicators developed by the rubric committee for the Faculty of Engineering represented the skills, knowledge, behaviour, attitudes, and/or values inherent in the attribute in the context of that specific course. We did this by considering the definition of the attribute provided by CEAB, and the learning outcomes of the professor's course. CEAB defines the *Impact* attribute as, 'an ability to consider and analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of sustainable design and development and environmental stewardship.' The four indicators that were devised for this attribute by our rubric committee were:

1. *Considers Diverse Perspectives:* Ability to consider other cultural, disciplinary, and ethical perspectives when investigating the impact of engineering on society and the environment.

2. *Considers Impact:* Ability to consider the impact of engineering interventions (decisions and technology) on society and the environment (historical and/or contemporary).

3. *Solutions for Societal and Environmental Challenges:* Ability to identify solutions to societal and environmental challenges.

4. *Personal and Collective Responsibility:* Ability to recognize the individual and collective responsibility of engineering and its interventions on society and the environment.

The researcher and professor determined whether or not, for the specific course in question, these four indicators effectively defined or 'unpacked' the *Impact* graduate attribute. Using Moskal and Leydens' questions to evaluate the content-related evidence [34], we asked:

1. *Do the evaluation criteria address any extraneous content?*
2. *Do the evaluation criteria of the scoring rubric address all aspects of the intended content?*
3. *Is there any content addressed in the task that should be evaluated through the rubric, but is not?*

Through this process, the researcher and professor established content-related evidence.

Once content-related evidence was established, we focused on determining substantive-related validity. Substantive-related validity ascertains whether the rubric measures the constructs inherent in the performance that we are assessing [27]. For example, consider the rubric *Problem Analysis*, and its indicator *Formulate Strategies for Solving a Problem*. The description of the indicator reads: *Ability to identify strategies for solving problems (brainstorming, research, trial and error)*. We must determine if the verb prompt that is used, i.e., *identify*, is truly what students are doing when they formulate strategies for solving a problem. This can be established in two ways. First, the professor and researcher will come to a consensus about whether or not the verb prompt accurately reflects the performance required to demonstrate this outcome. Then, they will review students' performance assessments to substantiate the consensus. Professors were also able to recall observing situations where students were partaking in performance assessments to establish substantive-related validity.

Interactions between each professor and the research occurred in a preliminary 1 – 1.5 hour meeting, with iterations and the finalized rubric design confirmed via email.

V. FINDINGS

In the end, 10 professors participated in this study, 14 individual rubrics were developed for 12 courses, and at least one rubric was developed for each of the 12 CEAB graduate attributes for courses in the Biosystems Engineering

curriculum. Professors used indicators from more than one attribute, designing individual rubrics to meet their assessment needs for their courses. Overall, six of the professors involved in the study appeared to gain new understandings and appreciation for the use of rubrics in the design and execution of program curriculum, and ideally these new understandings will be applied in the future development and execution of program curricula. Eight of the professors used the newly designed rubrics in their courses in some capacity during the year of the study; only two professors did not confirm whether the rubrics were used. Eight of the professors stated that they would continue to use the rubrics the following year, either as developed, or re-designed, or in some cases, for the first time. In all cases, the use of the rubrics ranged from supporting learning outcomes, to marking students' work, to developing course curriculum.

There were a number of general findings that emerged from this study, including positive outcomes that were characterized as: *New Pedagogical Understandings, Appreciation of Individual Support*, and *Continued Use of Rubrics*. There were also some challenges.

A. Positive Outcomes

There were a number of positive outcomes that emerged from this study, characterized as: *New Pedagogical Understandings, Appreciation of Individual Support*, and *Continued Use of Rubrics*.

1) New Pedagogical Understandings: There was evidence of six of the professors coming to new pedagogical understandings, which can ultimately lead to improvements and best practices in teaching and assessing:

- *I am beginning to understand the necessity of preplanning a course using specific objectives in mind to achieve the demonstrable desired outcomes in the students' skillset.*

This comment was reflective of several comments made in the post survey that exemplified critical evidence of emerging understandings of best practice in assessment: specifically, the concept of designing course content, including teaching and assessment materials, with the learning outcomes in mind. This comment speaks to the importance of professors understanding the concept of reverse design in curriculum development in order to effectively teach and assess targeted competencies in students [32].

Additionally, there was evidence of professors making pedagogical improvements, such as how assignments were structured; how assignments were communicated to students; and the reevaluation of intended learning outcomes, course materials, teaching strategies, and assessment tools and processes to achieve the constructive alignment in their curriculum [30].

- *...the work associated with developing rubrics makes you think deeply about the purpose of the assignment. Thinking back on my teaching, I now recognize there are situations when I prepared a project or assignment without giving in-depth consideration to how it would be evaluated and exactly what I would be looking for in the assignment/project. When you develop a rubric, you must think about the evaluation up front. I believe the use of rubrics allows more consistency from year to year in terms of evaluating the desired course objectives.*

Six professors made statements reflective of the development of new pedagogical understandings, underscoring the importance of this study in the development of assessment tools facilitated by one-on-one interaction.

2) Appreciation of Individual Support: There was evidence that professors appreciated the individual support in customizing and using the rubrics in their courses.

- *Yes, it was helpful in modify[ing] existing assignments to better meet course outcomes and CEAB indicators.* [The researcher] *gave specific examples of how to change my questions to match the indicators, which helped me see how to make the connection and where the link was missing.*

Nine of the professors stated that time was an impediment to developing and using new assessment practices, such as the rubrics, and expressed that they would appreciate continued support.

3) Continued Use of Rubrics: Some professors committed to the continued use of rubrics in their courses. This commitment appears to be divided between professors who were intrinsically motivated and confident that the use of rubrics supports best practice in assessment, and professors who appeared extrinsically motivated by other factors, such as accreditation demands and processes.

B. Challenges

There was evidence that although the rubrics were designed for their individual courses, not all the professors implemented the rubrics. There was indication of some professors struggling with the concept of rubrics and with using rubrics in their courses. These struggles were found in the amount of time perceived by professors as needed to create and use rubrics in their courses; the perception of inflated student marks; and in the structure of the rubric itself. There was evidence that more work is needed to support professors in customizing, implementing, and using rubrics, for example, training TAs to use rubrics in their courses. Finally, there was no indication that professors were discussing assessment or the use of rubrics with other professors in the department outside of the work that was conducted between the researcher and individual professors.

VI. DISCUSSION

Working individually with professors to design rubrics for their specific assessment needs was very constructive because in addition to designing 14 individual rubrics for 12 courses, these discussions led many of the professors to think deeply about teaching and assessing, and in many cases, to think about assessment in new ways. There was evidence that six of the professors engaged in a 'reverse design' approach, where the rubrics were developed with the targeted learning outcomes and course materials in mind, and course materials were

revised to align with the learning outcomes and the rubrics. Although this seems like a logical way to approach designing assessment tools, several professors who engaged in reverse design during the study expressed surprise and satisfaction by the logic and ease of this process. The researcher's experience, anecdotally, is that this process actually requires a shift in the way educators think about assessment. Once the shift happens, developing curricular tools becomes easier, and the developed tools embody sound assessment practices that support student learning and lead to curricular alignment. In the end, the shift in perception is perhaps more important than the physical work with the rubrics; but it was through the facilitation of individual rubric design that this understanding was achieved. This change can be flagged as a critical improvement in teaching practices, and evidence of continual improvement in support of accreditation efforts.

There were also findings that lend themselves to program improvement. One area that was flagged for improvement was the further development and use of rubrics for the CEAB graduate attribute, *Individual and Teamwork*. All of the 12 CEAB graduate attributes were targeted in Biosystems courses during this study. However, *Individual and Teamwork* was not as broadly represented. Only one indicator was assessed in one course using the rubrics during the 2015-2016 academic year, with plans for one other indicator being assessed in two courses during the 2016-2017 academic year. In both of these cases, the indicators were housed within rubrics that emphasized other graduate attributes. *Individual and Teamwork* is an attribute that has received much attention in engineering education research: working in teams is considered one of the most important competencies for new engineers as they enter the field [10][35]. Although the skills and knowledge necessary to competently demonstrate this attribute are wholly required of students in the Biosystems curriculum, the attribute needs to be directly assessed more comprehensively.

Finally, there was no indication that professors were discussing assessment or the use of the rubrics with other professors in the department while this study was being conducted. Perhaps this shouldn't be surprising, as changing assessment practices is not an easy feat: it requires dedication and a change in culture, and change takes time and determination. As Biggs writes [30]:

> CA [constructive alignment] provides a framework for adjusting teaching and assessment to address the attainment of those outcomes and the standards reached. Research indicates that CA is effective in this but it initially requires time and effort in designing teaching and assessment and, as a systems approach, it is important that supporting institutional policies and procedures are in place.

Institutional support is essential in facilitating the change and fostering the climate needed for the adoption and sustainability of outcomes-based pedagogical practices. Culture is manifested and demonstrated through communications. Creating a culture that supports pedagogical discussions demonstrates to all stakeholders that best pedagogical practices are valued.

VII. CONCLUSIONS

The study was designed to validate and implement the graduate attribute rubrics developed for the Faculty of Engineering at the University of Manitoba into the Biosystems Engineering curriculum. One researcher worked independently with 10 professors to design rubrics for the professors' individual courses. Taking this individual approach enabled the researcher to work with each professor's specific assessment needs and establish content-related and substantive-related validity for each rubric. By the end of the study, 14 individual rubrics were developed for 12 courses in the Biosystems Engineering curriculum, and many of the professors were thinking deeply about teaching and assessing in new ways. There was evidence of professors constructively aligning curriculum, by designing assessment tools that were explicitly connected to the targeted learning outcomes and course activities. Some professors were surprised and pleased by the logic and apparent ease of this process. Using reverse design is essential in best assessment practices and in developing outcomes-based assessment tools, and it cannot be assumed that all educators are aware or have experience with this practice.

Globally, it appeared that professors who were already open to the use of rubrics in support of the move to outcomes-based assessment, developed and used the rubrics in their courses, and plan to continue to develop and use rubrics in their future courses. On the other hand, professors who were already reticent about the use of rubrics and the change in accreditation requirements to outcomes-based assessment practices designed the rubrics for their courses were less apt to implement the rubrics fully or follow-through with their rubric use and plans for future use in their courses. This is not surprising, as adopting new pedagogies and changing assessment practices take time, and nine of the professors cited time as an impediment to using rubrics. Further to the notion of the difficulty of achieving change, there was no indication that professors were discussing assessment or the use of rubrics with other professors in the department while this study was being conducted. Overall, continued individual support in outcomes-based assessment practices for instructors ensured by institutional policy and procedures would be valuable in facilitating the cultural change in assessment beliefs and practices that is required to sustain them, and importantly, to effectively support student learning.

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