Overview and Comparison of Assessment Tools for Integrative Thinking

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Abstract

Integrative thinking is an essential competency for graduating engineers. Engineering graduates, who are prepared to address significant engineering challenges, e.g., Engineering Grand Challenges, can effectively integrate fragments from multiple disciplines to solve problems. To help students develop integrative thinking skills, engineering programs need to articulate how they will observe, evaluate, and support student development. Universities have recognized the need for students to engage in interdisciplinary projects and develop skills needed to support industry needs. To address that need, they have offered programs ranging from semester-long courses to weekend challenges designed to engage students in multidisciplinary team projects. However, effectiveness of instructional programs intended to support student development with respect to integrative thinking must be evaluated through assessment. While integrative thinking is much discussed in engineering education, evaluation approaches are few and not widely incorporated into engineering curriculum.

The authors have identified four existing approaches for evaluating integrative thinking: (A) Interdisciplinary Writing Assessment Profiles with the following elements: (i) drawing on disciplinary sources, (ii) critical argumentation, (iii) multidisciplinary perspectives, and (iv) interdisciplinary integration; (B) Targeted Assessment Framework with the following elements: (i) purposefulness, (ii) disciplinary grounding, (iii) integration, and (iv) critical awareness; (C) Transdisciplinary Research Quality Framework rubric with the following elements: (i) relevance, (ii) credibility, (iii) legitimacy, (iv) and effectiveness; and (D) Integrative Learning VALUE Rubric with the following elements: (i) connections to experience, (ii) connections to discipline, (iii) transfer, (iv) integrated communication, and (v) reflection and self-assessment. Following descriptions of the four approaches, the authors will offer criteria to compare assessment instruments for integrative thinking to assist other researchers in identifying most appropriate tools for assessing such skills in their curricula or programs.

Keywords: integrative thinking, interdisciplinary understanding, multidisciplinary teams, assessment instrument, quality work

Introduction

Engineering graduates are expected to address complex global challenges (National Academy of Engineering, 2004) which require integrative thinking—the ability to assimilate insights and ideas from multiple perspectives and disciplines. Students with integrative thinking skills and breadth of knowledge across disciplines are referred as “T-Shaped” engineers as they both possess in-depth knowledge within their major (top of T) and breadth of knowledge across majors (body of T) (Rogers and Feuler, 2015). To support the development of integrative thinking, universities, in recent years, have recognized the need for students to engage in projects that cross disciplinary boundaries through programs ranging from semester-long courses to weekend challenges. However, while opportunities to engage in disciplinary-spanning projects exist in most engineering programs, there is limited understanding of their effectiveness in

developing integrative thinking skills. One of the reasons is the lack of assessment and evaluation approaches for integrative thinking.
Engineering departments have incorporated programs intended to develop integrative thinking skills, yet these programs are still lacking in the area needed to address complex global problems. Instead of programs that build integrative thinking, the programs are geared towards interdisciplinary research. One of the barriers that interdisciplinary research is the differences and limited understanding between disciplines, which can make communication difficult (American Society for Engineering Education, 2016). Integrative thinking crosses the line of interdisciplinary research, multidisciplinary research, and transdisciplinary research and focuses on an individual's traits rather than a group, which is the skill that industries are seeking in engineering graduates. While traits of these research types can help build the skills of an interdisciplinary thinker, not all researchers from these fields can be considered integrative thinkers. Rather, the three types of research would greatly benefit if the team members moved towards building their integrative thinking skills.

Although engineering programs assume that their students develop integrative thinking skills through participating in disciplinary-spanning programs, such as undergraduate research, evaluation of student learning with respect to integrative thinking is rarely done, in part because processes and tools for evaluating integrative thinking are few. While studies emphasize the importance of evaluation of integrative thinking (e.g., Laudel and Origgi, 2006; Jacobs and Frickel, 2009; Öberg, G., 2009), only a few have suggested criteria to evaluate traits of integrative thinking (Feller, 2006; Klein, 2006). Self-assessment instruments have been created for students to determine whether their work is interdisciplinary; however, there are few tools and processes to support evaluation of student development with respect to integrative thinking by someone other than the learners. This paper presents a summary of such published tools, all in the form of rubrics.

Literature Search

The authors used Google Scholar and Scopus to identify the rubrics and frameworks for evaluating integrative thinking. Their search yielded articles regarding assessment criteria, emergence, and importance of interdisciplinary work and integrative thinking. They included articles that addressed evaluation of integrative thinking, provided criteria that could be used for such evaluation, or provided a framework for evaluation that could be used at a collegiate level. Screening began by title, abstract, and criteria framework. Then, they searched for rubrics in full articles. An initial search yielded several works by Mansilla and her work in interdisciplinary understanding (Mansilla, 2005; Mansilla, 2006; Mansilla and Duraisingh, 2007; Mansilla, Feller, and Gardner, 2006; Mansilla, Duraisingh, Wolfe, and Haynes, 2009). A search for articles that cited Mansilla's work yielded additional papers (Wolfe and Haynes, 2003; Belcher, Rasmussen, Kemshaw, and Zornes, 2016). In the end, the following four instruments were found and are described in detail in the next section:

(1) Interdisciplinary Writing Assessment Profiles,
(2) Targeted Assessment Rubric: An Empirically Grounded Rubric for Interdisciplinary Writing,
(3) Transdisciplinary Research Quality Assessment Framework, and
(4) Integrative Learning VALUE Rubric

Results

This section describes the four rubrics and their major categories and criteria.

Rubric 1: Interdisciplinary Writing Assessment Profiles

Wolfe and Haynes created the Interdisciplinary Writing Assessment Profiles (IWrAP) to assess interdisciplinary thinking through writing assignments (Wolfe and Haynes, 2003b). They created this rubric to address "the difficulty of advising student thesis process and by the lower-than-expected quality of the final products" (Wolfe and Haynes, 2003a). IWrAP developers created the rubric to evaluate writing in undergraduate, interdisciplinary, capstone courses. It focused on two elements: disciplinary and interdisciplinary, that IWrAP developers thought should be present in each paper. The purpose of the rubric is to assess student interdisciplinary work to assist faculty in appropriate curriculum developments. From these two elements, IWrAP developers created four categories:

- Drawing on Disciplinary Sources (disciplinary element),
- Critical Augmentation (disciplinary element),
- Multidisciplinary Perspectives (interdisciplinary element), and
- Interdisciplinary Integration (interdisciplinary element).

Under each category, there is a set of questions for a total of 55 criteria. Each criterion was rated on a scale of 1 (lowest) to 7 (highest) with interpretations provided to guide the ratings. There are positive and negative elements under each criterion and users of the rubric are encouraged to reference a section(s) of the student's work that exemplified the element when giving a score. Drawing on Disciplinary Sources as a category evaluated familiarity with the disciplines being presented in the research. Critical Argumentation evaluated understanding of the topic being presented and its importance to the intended audience. Multidisciplinary Perspectives evaluated the degree to which various disciplines are assembled. Finally, Interdisciplinary Integration evaluated the entire product. IWrAP developers argued all four categories are necessary to evaluate the type of thinking in which they were interested.

Two independent researchers used the inter-rater reliability (IRR) of the instrument by taking a sample of 20 senior research-writing projects which included ten disciplinary-based honors projects and ten interdisciplinary projects. After researchers independently scored each paper, they calculated the IRR as 83%. IWrAP developers evaluated validity using disciplinary and interdisciplinary research papers. While all the scores for the 20 writing projects would be similar for the disciplinary element, the interdisciplinary writing projects would score higher in the interdisciplinary elements, thus showing the validity of the instrument. A limitation in this validity evaluation is the assumption that the reviewers would have had general familiarity with the topics presented in the writing projects.

IWrAP developers desired to improve the quality of the final products of the students, yet the rubric does not offer a summary of the level of quality in a student's work. Users of the rubric assign various scores and offer suggestions of how to improve sections of the writing, but the 55 criteria leave the users to determine on their own what level of quality the final writing product is. As various programs might use this criterion, there is no concise judgment of what is deemed as quality work, which was the developers' intent when making the assessment.

Rubric 2: Targeted Assessment Rubric: An Empirically Grounded Rubric for Interdisciplinary Writing

Mansilla and Duraisingh pointed out two limitations of the IWrAP: "(a) disciplinary reasoning was assessed solely by examining students' use of sources, and (b) the multiple criteria proved too unwieldly for the rubric to be viable" (Mansilla and Duraisingh, 2007). To address these limitations, they developed a framework for another rubric. Based on the proposed framework, Mansilla and Duraisingh teamed with Wolfe and Haynes to develop a rubric for measuring the *quality* of student work through interdisciplinary writing namely, The Targeted Assessment Rubric (Mansilla, Duraisingh, Wolfe, and Haynes, 2009). Researchers ask a series of 10 questions categorized into four categories that should be included in student interdisciplinary writing:

- Purposefulness,
- Disciplinary Grounding,
- Integration, and
- Critical Awareness.

Each category includes core guiding questions and descriptors used to determine the *quality* of student interdisciplinary writing in four distinct levels: naïve, novice, apprentice, and master. Purposefulness evaluated presentation of the interdisciplinary problem and if it clearly explained the problem to the audience. The Disciplinary Grounding category is used to assess accuracy of disciplinary knowledge and methods to approach the problem. Once the student has defined the problem and identified appropriate disciplinary resources for solving it, the next step would be to solve it through integration. Integration evaluates how well several disciplinary models have been integrated to solve the problem. Finally, in Critical Awareness, the student's work is assessed for demonstration of their understanding of each discipline and its contributions and limitations in solving an interdisciplinary problem. In each of the four categories for interdisciplinary understanding, authors define what each level means for the writer and what can be done to further improve their integrative thinking.

Developers evaluated reliability using inter-rater reliability (IRR). Forty essays were randomly taken from a sample of eighty four and graded by two independent researchers for an overall IRR of 83.5%. The rubric was also tested for validity through four 4x1 ANOVAs for each category and similar to Rubric 1, it was applied to disciplinary and interdisciplinary reports. Interdisciplinary students are expected to score higher each passing year as they continue to gain experience and develop skills with each level. While the rubric was created to test interdisciplinary writing, developers suggest that, with a few adjustments, the rubric can also be applied to other forms of student work. This rubric allows the scorers to compare the quality of work from different year levels and gives guidelines on how a student can improve their work.

Rubric 3: Transdisciplinary Research (TDR) Quality Assessment Framework

The Transdisciplinary Research (TDR) Quality Assessment Framework was developed by Blecher, Rasmussen, Kemshaw, and Zornes to define and measure projects of transdisciplinary research. Transdisciplinary research is problem-oriented and interdisciplinary as it crosses disciplines to address societal needs. Researchers developed this framework from a systematic review of current transdisciplinary research to answer the following question: “What are the appropriate principles, criteria, and indicators for defining and assessing research quality in TDR?” (Blecher, Rasmussen, Kemshaw, and Zornes, 2015). It should be noted that as transdisciplinary research is still an emerging field, a majority of the methods are theoretical and there is still unpublished work in this area.

The Transdisciplinary Research (TDR) Quality Assessment Framework is based on the following four categories:

- Relevance,
- Credibility,
- Legitimacy, and
- Effectiveness.

The developers used Relevance category as researchers must determine whether or not their work is significant and how the work being produced will address a current problem. After the relevance of a problem is addressed, the developers suggested the category of Credibility to set a standard that the data and methods being used are robust. While the two primary categories are expected to be in any research project, developers proposed that a trait of transdisciplinary research is the Legitimacy of the research. Transdisciplinary research focuses on societal problems. Therefore, the research process must take into account the ethical and social factors of the problem. Finally, the last category suggested by the developers in the framework is Effectiveness. As Legitimacy focused on the fairness and ethical aspect of the project in regards to societal needs, Effectiveness of transdisciplinary will determine how the research will make a positive change in its context.

Unlike Rubrics 1 and 2, this paper only presents a framework and a prototype rubric. The value in the proposed Transdisciplinary Quality framework is that it can be used to determine whether or not the selected project is meeting its research goal. While the researchers tested the framework on a set of masters’ theses, reliability or validity tests were not reported. While the framework provides a standard, it also presents a limitation of not setting the objectives or characteristics of TDR work. The framework presented in this paper can be used as a starting point for those wishing to develop a transdisciplinary research quality rubric.

Rubric 4: Integrative Learning VALUE Rubric

While the focus of this paper is to evaluate assessment tools for integrative thinking, the authors also included an instrument developed for integrative learning in general. The Integrative Learning VALUE (Valid Assessment of Learning in Undergraduate Education) Rubric is 1 of 16 assessments developed by a team of faculty experts across American universities as a means of measuring student learning (VALUE, 2009). The purpose of this rubric is to measure the performance level of a student as they complete their undergraduate education, both in student life and academia. Unlike the other rubrics which are meant to evaluate student products (e.g. writing), the Integrative Learning VALUE rubric measures a student’s performance, but does not suggest a specific product for evaluation. However, the rubric offers a means for students to improve on integrative thinking by suggesting how a student learns throughout the years in their school program.

The Integrative Learning VALUE Rubric is based on the following five categories:

- Connections to Experience,
- Connections to Discipline,
- Transfer,
- Integrated Communication, and
- Reflection and Self-Assessment.

Under each category, there are five levels of integrative learning: benchmark (1), milestones (2 and 3), and capstone (4). In the Connections to Experience category, the students at the benchmark level are able to identify and perceive life experiences outside the classroom and academic knowledge while at the capstone level they demonstrate ability for synthesizing and deeper understanding of the information. The second category the developers used is Connections to Discipline in which a student first can present examples of the various disciplines but in the capstone, is able to draw conclusions from the learned facts and examples. In the Transfer category, at the benchmark level students are able to transfer a set of basic skills from one problem to another. As students reach the capstone level, they will be able to adapt and apply the skills they have learned from their life experiences to address complex issues. In Integrated Communications, at the benchmark level students are able to produce an appropriate means of communication and at the capstone level they should have enhanced the language for their intended audience. The final category in the rubric that the developers chose was Reflection and Self-Assessment in which the student achieves the benchmark level by describing their strengths and weaknesses and in their capstone can have vision of themselves moving towards a goal from what they have learned. The VALUE Rubrics have been approved by the Voluntary System of Accountability (VSA) and are currently being used in schools throughout the United States.

Discussion

The Texas A&M University AggiE_Challenge projects have undergraduate engineering students working on semester-long projects in interdisciplinary teams to address Grand Challenges for Engineering. One of the expected outcomes of this collaboration are to support experiential learning, yet as students continue multiple semesters with the same project or take their skills to the work force, the students would gain much more if the programs supported the student's integrated learning. One of the main outcomes that we would like to measure in our students is the ability to understand the integration of other disciplines, outside of their own, to solve a problem. For this reason, authors have created the following criteria to measure the outcomes of the participants within the AggiE_Challenge:

1. Purposeful Argumentation
2. Credibility in Disciplines
3. Multidisciplinary Connections
4. Integration of Knowledge and Skills

The fours rubrics evaluated offer different approaches to assessing the traits of integrative thinking. Table 1 summarizes the categories within each rubric and identifies common rubric elements. Table 1 also presents the authors' synthesis of the four approaches to present a fifth set of categories. The authors present brief rationales for each of the four categories in the following subsections. These suggested criteria are synthesized from the rubrics evaluated in this paper.

<table>
<tr><th>Rubric 1</th><th>Rubric 2</th><th>Rubric 3</th><th>Rubric 4</th><th>Authors’ Criteria</th></tr>
<tr><td>Drawing on Disciplinary Sources</td><td>Grounded in Disciplines</td><td>Credibility</td><td>Connections to Disciplines</td><td>Credibility in Disciplines</td></tr>
<tr><td rowspan="2">Critical Argumentation</td><td rowspan="2">Purposefulness</td><td>Relevance</td><td>Reflection and Self-Assessment</td><td rowspan="2">Purposeful Argumentation</td></tr>
<tr><td>Effectiveness</td><td>Integrated Communications</td></tr>
<tr><td>Multidisciplinary Perspectives</td><td>Critical Awareness</td><td></td><td>Connections to Discipline</td><td>Multidisciplinary Connections</td></tr>
<tr><td rowspan="2">Interdisciplinary Integration</td><td rowspan="2">Integration</td><td rowspan="2">Legitimacy</td><td>Connections to Experience</td><td rowspan="2">Integration of Knowledge and Skill</td></tr>
<tr><td>Transfer</td></tr>
</table>

Table 1: Rubric Category Synthesis

First Category: Credibility in the Disciplines

Credibility in Disciplines is similar to the other categories in that the student’s discipline or the disciplines being used are explained within the project. Students must be grounded in their disciplines to integrate fragments from each. Grounded, meaning, that the students are able to effectively use their knowledge of the presented disciplines and can use the expertise to make meaningful contributions to the problem being addressed. The level in which a student is credible in the various disciplines should increase as they continue to work on the project which is a mix of the Rubric 2 and Rubric 4 discipline categories. As the AggiE_Challenge students often work on their given projects for multiple semesters, this category would measure the level of understanding how their own discipline and the others used help address the project.

Second Category: Purposeful Argumentation

Purposeful Argumentation is where a student can show how a project has impact to society through the challenge being addresses, the project goals, objectives, and findings. Each of the evaluated rubrics placed strong emphasis of being able to convince the intended audience that the project is significant to society. Once a student is grounded in individual disciplines, the next step would be to use their expertise to solve meaningful problems. Being able to solve a problem is an important skill, but the student also has to convince the intended audience that the problem being solved is important. A student can use prior experience and knowledge of his engineering discipline to build clarity of how addressing an issue will make a positive impact to the community.

Third Category: Multidisciplinary Connections

Multidisciplinary Connections is where the student provides justification for the various disciplines used by explaining how the project could not be supported without the listed majors or how use of multiple disciplines would benefit the project. Integrative thinkers may be strong in making Multidisciplinary Connections and have the ability to integrate their knowledge and skill, but it does not mean that other students do not possess these skills. This category is only presented in three of the four evaluated rubrics, yet global problems require students to use Multidisciplinary Connections to know which disciplines can address certain aspects of a problem. A student must then makes connections regarding experience and knowledge of disciplines to begin to form a solution to the problem being addressed.

Fourth Category: Integration of Knowledge and Skills

It is crucial that the student then take the effective solution and demonstrate its use to the community. Though many solutions may be offered for a problem, it is truly the end-users who the student must convince that their work is valuable. Each of the evaluated rubrics has the final category as a way to summarize the project, yet the emphasis of learning is only present in the fourth rubric. Integration of Knowledge and Skills should demonstrate the level of what the student learned from the project and what future implications can be made in addition to successfully using the various disciplines. Many engineering capstone projects or programs like the AggiE_Challenge do not end with the completion of the school year. Projects that have true impact to society will continue after the school year is over by either continuation from other students or the student being hired on by a company that found the skills of the student useful. For this reason, the level of knowledge and skills of the student should be measured so that engineering programs or the individuals themselves can know that the curriculum is producing integrative thinkers.

Conclusion

Evaluation of integrative thinking is important as the NAE and ASEE have gathered employer information and found that a majority of engineering graduates are underdeveloped for the type of jobs that society needs (Rogers, P., & Freuler R.J., 2015). Employers are having to retrain the graduates to communicate well, problem solve, and adapt to various environments which are skills that the graduate is expected to have learned at the universities. Integrative thinking skills enable students to adapt to various environments and be comfortable working in a field outside of their own expertise. This paper identified and reviewed articles that offer rubrics and frameworks to measure interdisciplinary and transdisciplinary research and the levels of integrative learning. As universities seek to fill the demand of companies seeking engineers who are integrative thinkers, the rubrics presented in this paper have been summarized into criteria as a framework to offer programs a means to evaluate their students' work with regards to integrative learning. While the criteria provides a framework to measures traits that employers find valuable in the student, this framework needs further development and testing so that it can be presented in engineering curriculums. Overall, this work contributes to the research in developing additional evaluation tools for interdisciplinary work to support a variety of programs offered at universities and proposes that the engineering curriculum shift their focus to further developing integrative thinkers rather than the emerging interdisciplinary research. Existence of such tools will provide universities the means to further improve their programs and better prepare students with the skills needed to solve complex engineering problems when joining industry.

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