2018 ASEE Annual Conference & Exposition
June 24-27, 2018
Salt Palace Convention Center
Salt Lake City, UT
Paper ID #22684

Enhancing Learning by Assessing More than Content Knowledge

Prof. Renee Cole, University of Iowa

Dr. Renée Cole is a Professor of Chemistry at the University of Iowa. Dr. Cole earned a B.A. in chemistry from Hendrix College, and M.S. and Ph.D. degrees in physical chemistry from the University of Oklahoma. Her research focuses on issues related to how students learn chemistry and how that guides the design of instructional materials and teaching strategies as well on efforts related to faculty development and the connection between chemistry education research and the practice of teaching. She is a PI for the Increase the Impact Project, which is developing resources for PIs to improve the propagation of their innovations, as well as a PI for the ELIPSS Project, which is developing resources for STEM instructors to assess professional skills in the classroom. Dr. Cole is also an associate editor for the Journal of Chemical Education.

Prof. Juliette M. Lantz, Drew University
Dr. Suzanne Ruder, Virginia Commonwealth University

Suzanne Ruder, Ph.D., is a Professor of Chemistry at Virginia Commonwealth University in Richmond, Virginia. She has been active in the POGIL project for 15 years, using POGIL in large organic chemistry classes, developing and facilitating faculty workshops, and serving on the POGIL steering committee. Suzanne is PI of the NSF funded project Eliciting and Assessing Process Skills in STEM and has authored two books, "Clickers in Action: Increasing Student Participation in Organic Chemistry" and "Organic Chemistry, A Guided Inquiry".

Gilbert J. Reynders III, University of Iowa

Gil Reynders is pursuing a Ph.D. in chemistry education research at the University of Iowa. Gil earned a B.A. in chemistry from Lake Forest College and an M.S. from the University of Rochester.As part of the ELIPSS (Enhancing Learning by Improving Process Skills in STEM) Project, Gil's research focuses on creating resources to assess student process skills and provide feedback to both students and faculty on the students' process skill development. Gil's other research interests include: organic chemistry students' understanding of reaction mechanisms (i.e. arrow-pushing), the alignment between a course's intended learning outcomes and assessments, and gender-based differences in STEM retention and course performance.

Courtney Stanford, Virginia Commonwealth University

Dr. Courtney Stanford is postdoctoral researcher at the Virginia Commonwealth University and will begin as assistant professor of chemistry at Ball State University in Fall 2018. She earned an M.S. in organic chemistry from the University of Connecticut and a Ph.D. degree in chemistry education from the University of Iowa. Her current research has focused on designing resources to assist in the identification, development, and assessment of workplace skills in STEM classrooms, and investigating the connections between information processing and symbolic representations used in organic chemistry. As part of her graduate work she examined the influences of instructor facilitation and course materials on student argumentation, and the propagation of STEM educational innovations.

Enhancing Learning by Assessing More than Content Knowledge

Abstract: Skills such as communication, teamwork, critical thinking, and problem solving are frequently cited as intended learning outcomes for STEM degree programs. While these skills, sometimes referred to as professional or process skills, are highly valued, they are rarely explicitly assessed in the classroom. Assessment serves two purposes: (1) it provides a measure of achievement, and (2) it facilitates learning. The types of assessment used by an instructor also telegraph to students what is valued in a course. However, in many instances, the lack of alignment between instructional methods and assessment detracts from the added value of engaged student learning environments.

Our NSF funded project, "Enhancing Learning by Improving Process Skills in STEM" focuses on the development of instructor resources that support process (or professional) skill development. These resources are designed to help instructors provide feedback to students and inform the instructor as to the effectiveness of their instructional strategies in supporting the development of these skills in the classroom. Such feedback supports adoption of evidence-based active learning strategies that foster development of student skills in addition to content knowledge. To date, the project has produced rubrics on multiple process skills to assess student written work and classroom interactions and an implementation guide to support optimal use of these resources. Additional resources include a series of professional development workshops used to help instructors develop and assess process skills in their classrooms. The rubrics were created and refined by a multidisciplinary team using a collaborative development approach to ensure validity, reliability, and utility in multiple STEM disciplines. Rubrics were classroom tested in a variety of courses (including both upper and lower level courses) at a broad range of institutions. Data collection from each implementation allowed feedback and other artifacts to be gathered from many faculty in order to create the implementation guide. The initial work of this project generated valuable insights on rubric development and implementation that continues to inform further development of additional rubrics, the implementation guide, and faculty development workshops. For example, it was found that even experienced faculty need to be familiarized with an operationalized view of process skills in their STEM classrooms and provided with opportunities to visualize what process skills look like in student interactions and student written work.

Introduction

It is generally recognized that students need to become proficient in skills that help them optimize their education in active learning environments and prepare them to be successful in the workplace. Recent National Research Council (NRC) reports [1, 2] focused on undergraduate education in STEM fields noted that current global challenges require people working in science fields to be skilled in solving problems, reasoning, communication, and collaboration with people in other disciplines. In a similar fashion, the engineering community listed teamwork, communication, and ethics/professionalism as being critical to the modern workplace [3]. These skills, which we call process skills due to the early roots of this project in the Process Oriented Guided Inquiry Learning (POGIL) community [4], are also referred to as transferable skills, professional skills, workplace skills, or soft skills. In STEM fields, a slow paradigm shift towards student-centered learning has begun to extend opportunities to undergraduates to foster learning gains beyond the acquisition of disciplinary content. However, most classroom assessment approaches continue to be solely centered on the students' mastery of content and do not assess student performance in the area of process skills. This is of significant concern because of the strong influence assessment has on students' learning [5-8]. Assessment serves two purposes: (1) it provides a measure of achievement, and (2) it facilitates learning [9]. The types of assessment used by an instructor also telegraph to students what is valued in a course. However, in many instances, the lack of alignment between instructional methods and assessment detracts from the added value of engaged student learning.

The primary goal of the Enhancing Learning by Improving Process Skills in STEM (ELIPSS) Project [10] is the creation and assessment of resources that can be readily adopted by instructors to assess student process skills in a wide range of classrooms across STEM disciplines. A secondary goal is the generation of professional development tools to improve the recognition and assessment of process skills.

Process Skills

Process skills are frequently cited as critical components of a successful workforce. Employers and professional societies note the importance of key skills like teamwork, critical thinking, and problem solving. There are a variety of definitions of process skills in the literature; many are somewhat dependent on the subject area of interest. Teamwork, with respect to both individual and group performance, has been emphasized largely in engineering education [3, 11, 12]. Problem solving and critical thinking are ubiquitously identified as key skills for students in STEM to develop, albeit from a number of different perspectives, as they are crucial to the advancement of STEM disciplines [11-16]. Information processing is not as well defined, with much existing emphasis in STEM relating to students' interpretation of diagrams, graphs, and images as opposed to text. Self-assessment and metacognition are largely identified in the science education literature [17] as being important to the cultivation of effective problem solving strategies, with metacognition greatly dominating existing discourse. Communication skills (both oral and written) are noted as crucial skills by STEM professional societies, and are referred to both in the context of forming arguments based on evidence [16] and sharing results with colleagues [11, 12]. Additionally, the vast majority of these process skills have been explicitly identified as important from kindergarten through tertiary levels of education in the "college and career readiness" and "science and engineering practices" sections of the recently constructed Next Generation Science Standards (NGSS) [18].

Development of rubrics

While the importance of process skills is well documented, mechanisms for instructors to assess these skills and to provide regular feedback to students are not. It is important that the feedback provided to students be focused on improving performance, be understandable, and be clearly linked to the desired learning outcomes [6, 8]. It is also important that assessment strategies are "cost-effective" for instructors in terms of the time and expertise required for implementation [8, 19]. Rubrics have been identified as effective means to help instructors evaluate performance tasks [8, 20, 21], and most faculty and administrators are familiar with employing rubrics for assessment and evaluation.

For this project, two types of rubrics were designed: student interaction rubrics and student product rubrics.

- Student interaction rubrics are intended to be used to assess behaviors and other indicators of process/workplace skills exhibited during group work in active learning classrooms.
- Student product rubrics are intended to be used to evaluate process/workplace skills in written work or other products submitted by students in response to questions, activities, or assignments designed to elicit evidence of these skills in the completed product.

Each rubric has undergone multiple stages of testing and revision; this ensures that the rubrics assess the intended process skills and are also applicable in multiple disciplines and classroom settings. Figure 1 shows the stage of development for each type of rubric for the different process/workplace skills targeted by the project. Both sets of rubrics were built on a foundation of testing to establish validity, reliability, and utility.

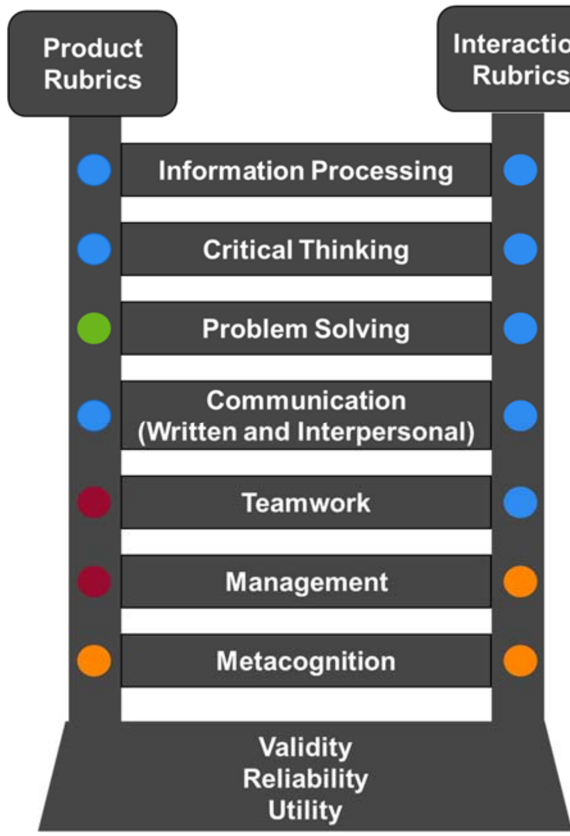

FIGURE 1: Current status of the rubrics for selected process skills. *Note:* The dot color indicates the status of the rubric: **green** - completed and available, **blue** - in revision and available, **orange** - early in development, **red** - not currently planned.

When developing the rubrics, the project team reviewed initial drafts of each rubric to ensure that they were aligned with the literature and operationalized for STEM classrooms. Additional feedback was then solicited from members of the Primary Collaboration Team (PCT), a group of eight faculty members from a variety of institutions and STEM disciplines. The PCT provided varied perspectives on rubric construction and implementation. Once a rubric was revised in response to PCT feedback, it underwent further review by the project team. During this development cycle, students were asked to review the rubrics to determine how well they understood the language in the rubrics as well as their ability to match the rubric descriptors/scores to their group interactions or written work. Depending on the extent of the revision, some rubrics went back to the PCT for further review. This cycle, shown in Figure 2, was repeated until each rubric was deemed ready for classroom testing.

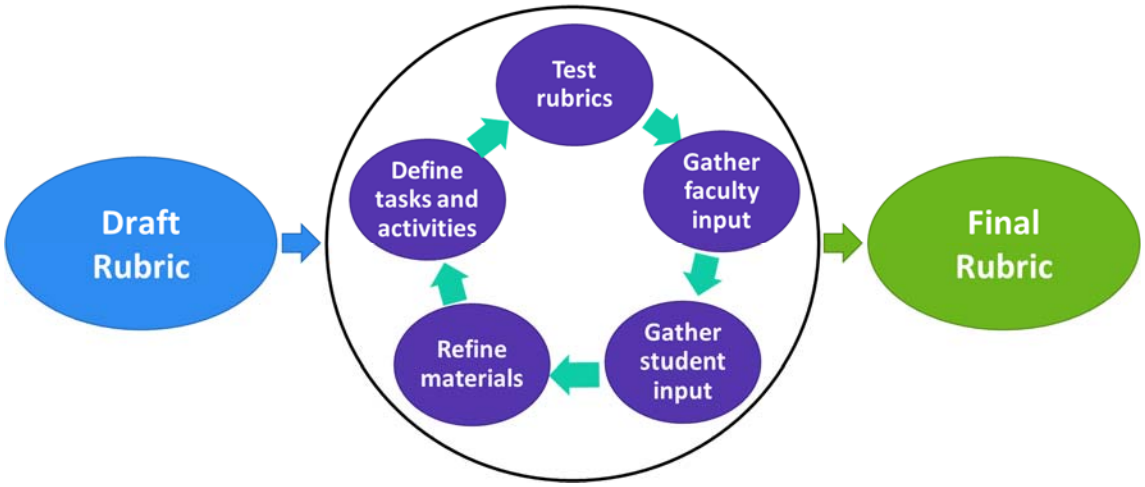

FIGURE 2: Iterative development cycle. Rubrics were continually improved as students and faculty provided feedback to the project team.

The project team, the PCT, and four additional instructors were involved in classroom testing of both the student interaction and the student product rubrics. The PCT provided examples of content-specific behaviors and questions for their various disciplines and active learning classrooms. Additionally, they provided feedback to improve the usability of the rubrics and increase adoption by faculty in a variety of disciplines and using a diverse set of active learning instructional approaches. Thus far, classroom testing has taken place for six interaction rubrics (Information Processing, Critical Thinking, Problem Solving, Interpersonal Communication, Management, and Teamwork) and five student product rubrics (Information Processing, Critical Thinking, Problem Solving, Written Communication, and Metacognition). These rubrics were tested in a range of STEM classrooms at fourteen different institutions to establish validity and utility. Information about these different implementations is summarized in Table 1. Each rubric was tested in at least three disciplines and at three different institutions.

TABLE 1: Summary of instructional contexts in which rubrics have been tested.

Discipline	Course Level	Institution Type	Class Size	Pedagogy
Biology/Health Sciences	Introductory, Intermediate, Advanced	RU, CU	M, L, XL	Case Study, Lecture, Lab, Peer Instruction, POGIL, Other
Chemistry	Introductory, Intermediate, Advanced	RU, PUI	S, M, L, XL	Case Study, Lecture, Lab, PBL, Peer Instruction, PLTL, POGIL
Computer Science	Introductory	CU	S, M	POGIL
Integrated Science	Advanced	PUI	S	Case Study, Lecture, POGIL
Kinesiology	Advanced	RU	M	Case Study, Flipped, POGIL

Materials Engineering	Advanced	PUI	M	Case Study, Flipped, Other
Mathematics	Introductory, Advanced	PUI	S, M	Lecture, PBL, POGIL
Statistics	Introductory	PUI	M	Flipped

Institution Type: RU = Research University, CU = Comprehensive University, PUI = Primarily Undergraduate Institution
Class Size: S = <25 students, M = 25-50 students, L = 51-150 students, XL = > 150 students
Pedagogy: PBL = Problem Based Learning, PLTL = Peer Led Team Learning, POGIL = Process Oriented Guided Inquiry Learning

Following the process shown in the development cycle (Figure 2), the project team gained insights on the validity and utility of the rubrics generated. For example, a combined effort between the project team and the PCT resulted in language selection that was specific enough to operationalize the process skill definitions and rubric descriptors, but expansive enough that it could be easily interpreted and applicable across STEM disciplines. Furthermore, through many detailed discussions with the PCT before and during classroom implementation, the appearance and structure of the rubrics were optimized in order to be used efficiently as an assessment tool in classrooms.

We have established that each rubric can distinguish among different levels of evidence for the targeted process skills, and that each category of the rubric assesses different aspects of the skill. Figure 3 illustrates the use of the problem solving rubric to assess student laboratory reports in an analytical chemistry laboratory course. The results indicate that each category measures a range of student achievement and that the distribution of rubric scores is different for each category.

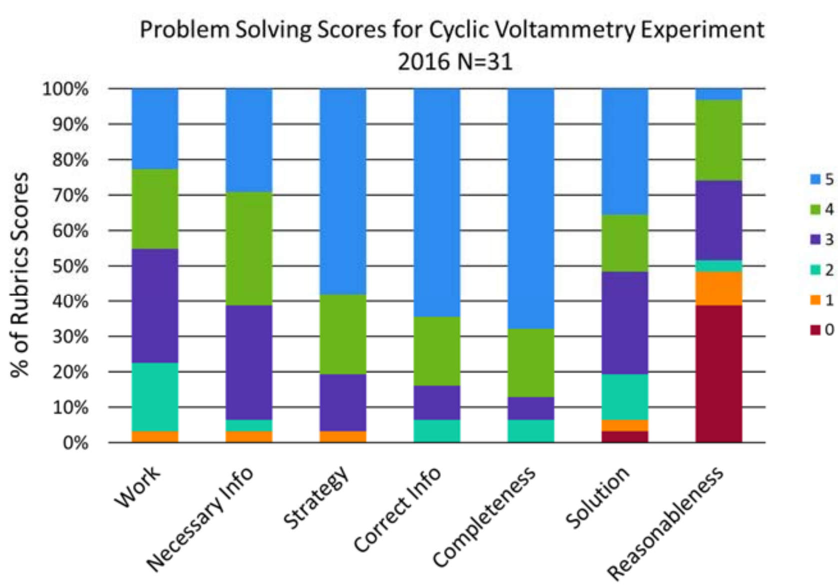

FIGURE 3: Summary of analysis of student laboratory reports using the problem solving rubric.

From analysis of classroom implementation and discussions with implementers, the general types of classroom questions, prompts and activities that lent themselves to the assessment of process skills became evident. These experiences allowed us to strategize implementation techniques for large and small classes, and to discuss ways in which instructors could deliver rubric feedback to their students for maximum effectiveness. It was also evident that classroom videos of student interactions are crucial for validating rubrics, training new users, and providing online resources in support of propagation.

Preparing faculty to implement rubrics
A series of workshop modules were designed to provide participant-centered professional development on assessing process skills, including the use of the rubrics. The goals of the workshop are to introduce instructors to the concept of eliciting and assessing process skills and enable them to use the rubrics along with the implementation guide developed by the project.

Workshops generally begin with an introductory module designed to help participants explore process skills before employing the rubrics. The components of the Introduction to Process Skills module allow participants to: (a) explore different process skills, (b) determine how to elicit process skills with various classroom facilitation strategies, and (c) discover how to observe different process skills during group work. Participants explore the process skill definitions and then reflect on ways they can elicit these skills in their own classes. In order to model an active learning classroom where process skills could be observed, an introductory sample assignment was developed on a topic that was accessible to all participants. Participants complete the activity in groups and then reflect on the process skills that were employed while working on the activity.

In the remaining modules, participants explore the rubrics to familiarize them with the general structure, then use two different rubrics to assess students in an authentic context. In the module 'Student Interaction Rubrics.' participants examine the interaction rubrics, watch a video of students working on a classroom activity, then use the rubrics to assess student interactions. In the module 'Student Product Rubrics,' participants explore two different product rubrics and then use the rubrics to assess authentic student written work. This modular workshop plan provides a flexible format that can be combined to fit different venues and time slots. A fourth module on identifying or designing appropriate tasks for assessing process skills is planned.

The feedback from instructors who participated in the initial Student Interaction Rubrics workshops indicated that, while valuable, the workshop was somewhat overwhelming to those who did not have much experience with process skills. One strength that was identified was the opportunity to watch videos of students working through activities and applying the rubrics to those students' interactions. In contrast, the initial Student Product Rubrics workshop appeared to be a better entry module, in part because using a rubric to assess student written work is more familiar to instructors than observing and assessing group interactions. We are collecting classroom activities, student data, and videos of student interactions that feature broadly applicable STEM topics to be used for general STEM audiences, as well as focused topics that align with particular disciplines. These may be inserted into the workshop modules to customize the components of the workshops for a particular audience.

Conclusions

As part of ongoing efforts to assess and improve process skills of undergraduate STEM students, rubrics were developed that can measure these skills in student group interactions and in student written products. The development cycle, involving multiple iterations of feedback from both students and faculty in a variety of STEM disciplines, led to optimization of both rubric design and instructional usage strategies. For example, our faculty collaborators noted that students pay greater attention to the rubrics over the course of a semester if the instructor begins discussing process skills at the very start of the semester when setting expectations for the students. Faculty found that focusing on assessing one process skill at a time allowed them to score student work faster and that some rubrics are best used earlier in a semester. For instance, using the interpersonal communication and teamwork rubrics early in the semester can lead to stronger and more effective group interactions, which allow teams to further develop other skills as the semester progresses.

Based on feedback we received from surveys of our faculty development workshop, we discovered that it is highly effective for workshop participants to play the role of learners. In this manner, participants experience the development of process skills through a classroom activity and experience how various process skills become evident in their own interactions and written answers to activities. Reflecting on the process skills used while completing an activity was key to becoming familiar with the process skills and how to elicit and assess these process skills in student interactions in an active learning classroom. The experience also directly illuminates the purpose and impact of instructional feedback on process skills. Since the assessment of these types of skills are unfamiliar to most faculty, we found it most effective to link assessment and feedback on process skills to existing faculty expertise in evaluating and providing feedback to students regarding content knowledge.

Future work will focus on describing best practices for using the rubrics for assessment in a variety of classroom settings, including large-enrollment courses, and encouraging students to use the rubrics for meaningful self- and peer-assessment. Additionally, while the current rubrics can be used to accurately assess student performance, additional rubrics and strategies are being developed that will provide more guidance to students to further their process skill development and improve performance.

References

[1] National Research Council, *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*. National Academies Press, 2012.

[2] S. R. Singer, N. R. Nielsen, and H. A. Schweingruber, "Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering." Washington D.C.: The National Academies Press, 2012.

[3] ABET Engineering Accreditation Commission, "Criteria for accrediting engineering programs," Baltimore, MD, 2012.

[4] R. S. Moog and J. N. Spencer, *Process oriented guided inquiry learning (POGIL)*. ACS Publications, 2008.

[5] D. Boud and N. Falchikov, "Introduction: Assessment for the longer term," in *Rethinking Assessment in Higher Education*. New York: Routledge, 2007, pp. 3-13.

[6] F. Dochy, M. Segers, D. Gijbels, and K. Struyven, "Assessment engineering: Breaking down barriers between teaching and learning, and assessment," in *Rethinking Assessment in Higher Education*, D. Boud and N. Falchikov, Eds. New York: Routledge, 2007, pp. 87-100.

[7] C. Fuentealba, "The Role of Assessment in the Student Learning Process," *Journal of Veterinary Medical Education,* vol. 38, no. 2, pp. 157-162, 2011.

[8] R. Smit and T. Birri, "Assuring the quality of standards-oriented classroom assessment with rubrics for complex competencies," *Studies in Educational Evaluation,* vol. 43, pp. 5-13, 2014.

[9] J. Biggs, "Constructive alignment in university teaching," *HERDSA Review of Higher Education,* vol. 1, no. 1, pp. 5-22, 2014.

[10] *Enhancing Learning by Improving Process Skills in STEM*. Available: http://www.elipss.com [Accessed April 2018]

[11] A. Mohan, D. Merle, C. Jackson, J. Lannin, and S. S. Nair, "Professional Skills in the Engineering Curriculum," *IEEE T. Educ.,* vol. 53, pp. 562-571, 2010.

[12] L. J. Shuman, M. Besterfield-Sacre, and J. McGourty, "The ABET "Professional Skills"-Can They Be Taught? Can They Be Assessed?," *J. Eng. Educ.,* vol. 94, pp. 41-55, 2005.

[13] H. L. Petcovic, A. Stokes, and J. L. Caulkins, "Geoscientists' perceptions of the value of undergraduate field education," *GSA Today,* vol. 24, pp. 4-10, 2014.

[14] *American Institute of Biological Sciences Education Programs*. Available: http://www.aibs.org/education/ [Accessed April 2018]

[15] S. Musante. *Creating a Community of Educators to Improve Biology Student Learning*. Available: http://www.aibs.org/eye-on-education/eye_on_education_2005_04.html [Accessed April 2018]

[16] H. K. Boo, "Students' understandings of chemical bonds and the energetics of chemical reactions,"*Journal of Research in Science Teaching,* vol. 35, pp. 569-581, 1998.

[17] A. Zohar and S. Barzilai, "A review of research on metacognition in science education: current and future directions," *Studies in Science Education,* vol. 49, pp. 121-169, 2013.

[18] *The Next Generation Science Standards*. Available: http://www.nextgenscience.org/next-generation-science-standards [Accessed April 2018]

[19] L. Suskie, "Understanding the nature and purpose of assessment," in *Designing Better Engineering Education Through Assessment: A Practical Resource for Faculty and Department Chairs on Using Assessment and ABET Criteria to Improve Student Learning*. Sterling, VA: Stylus, LLC, 2008, pp. 3-19.

[20] S. M. Brookhart and F. Chen, "The quality and effectiveness of descriptive rubrics," *Educational Review,* pp. 1-26, 2014.
[21] B. M. Moskal and J. A. Leydens, "Scoring rubric development: validity and reliability," *Pract. Assess., Res. Eval.,* vol. 7, pp. 1-11, 2000.