SELF-EVALUATION AND REFLECTION FOR PROFESSIONAL DEVELOPMENT OF CHEMICAL ENGINEERING STUDENTS

Ashlee N. Ford Versypt
Oklahoma State University • Stillwater, OK 74078

Proficiency in non-technical skills is important for professional success in the modern workforce. While educators can assign students to work in teams or encourage them to be persistent lifelong learners, it is challenging to assess non-technical skills and progress in developing them.[1] Self-perceptions of proficiencies in non-technical skills are limited without clear definitions of such skills and of the metrics for successfully achieving a performance standard. For example, many people may think they are good at communication until they see and hear an exceptional public speaker or encounter conflicting viewpoints in a challenging group project. For defining and assessing a set of 10 non-technical skills relevant to science and engineering fields, a rubric called the self-evaluation rubric (Tables 1 and 2) has been previously developed for undergraduate physics education.[2, 3] Here, I describe use of the rubric in the undergraduate chemical reaction engineering (kinetics) course at Oklahoma State University. Students were assigned a series of *self-reflection assignments* to periodically document their non-technical skill levels using the self-evaluation rubric over the course of one semester and to set goals for developing one or more skills. I, as the course instructor, provided feedback. The assignments held students accountable to report on their progress towards their goals. The self-evaluation rubric provided useful examples of what success in 10 key skills may look like. The purpose of this paper is to share the experiences of using the self-reflection assignments as a means to prepare students to become practicing professionals while also training them in engineering content in a technical course.[4] I conducted an Institutional Review Board-approved classroom research study in 2016 and 2017 that involved surveying the students about their non-technical skill levels and their opinions of the role of the self-reflection assignments on any changes in their skill levels. I reported the results of the first year

TABLE 1
Self-evaluation rubric primary skills.

Primary Skills				
Skill	**Questions to ask yourself**	**Beginning**	**Developing**	**Succeeding**
Persistence	• What do you do when you're frustrated? • Do you independently pursue understanding?	I tend to try one or two things. I give up more easily than I should.	I try to stick with things, but I sometimes feel unsuccessful. Sometimes I seek new approaches to help.	I look for new ways to think about the problem. I find a way to persist when appropriate.
Organization	• Do you keep accurate, thorough, and consistent records of work? • Do you submit materials in a timely manner? • Do you refer to your records to support conclusions?	There are significant gaps in my records, and/or I consistently forget to complete assignments on time.	I don't complete all assignments on time, or I have no record of some of my work/activities. When I neglect to do something, I forget about it because it's too late.	I am timely and thorough with my work and record-keeping. When I've neglected something, I correct my oversight quickly. My records are a valuable resource.
Connections	• Do you try to make connections with new people who might be able to help you in the future? • Do you make use of your connections when you need help?	I tend to go it alone.	I sometimes get help from other people, but only when I really need it. My network of supporters could be better developed.	I have a strong network of people who I go to regularly for help and support.
Self-compassion	• When you're having difficulty with something, how you feel about yourself? • Do you make productive use of failure?	I have trouble with feeling like a failure, and these feelings often make me feel like giving up. I'm my own worst critic.	I am sometimes overly critical of myself. I tend to ignore feelings of failure rather than using them to improve.	I acknowledge my difficulty, but I don't let it define how I feel about myself. I act kindly towards myself and view failure as an opportunity for self-improvement.

Ashlee N. Ford Versypt *is an assistant professor in the School of Chemical Engineering at Oklahoma State University. She earned a B.S. from the University of Oklahoma and an M.S. and a Ph.D. from the University of Illinois at Urbana-Champaign and conducted postdoctoral research at the Massachusetts Institute of Technology, all in chemical engineering. She received the NSF CAREER Award in 2019 and was named as one of AIChE's 35 Under 35 for 2017 in the education category. She currently serves as a Director of the Chemical Engineering Division of ASEE.*

of data in an ASEE conference proceedings paper,[5] and a second year of data has been analyzed and included in this paper. The Assessment section discusses the similarities and differences between the two student cohorts, and the Implementation Tips section is new. The conference paper[5] includes a version of the self-evaluation rubric with introductory and explanatory text suitable for classroom use, expanded details about the responses to the open-ended questions, additional graphical representations of the 2016 data, and the pre- and post-assignment surveys.

TABLE 2
Self-evaluation rubric advanced skills.

Advanced Skills Skill	Questions to ask yourself	Beginning	Developing	Succeeding
Courage	• How do you react to uncertainty? • What do you do when you feel overwhelmed? • Do you take intellectual risks?	I don't like to try things unless I'm reasonably certain what the outcome will be.	I take some risks, but I sometimes miss out on some good opportunities.	I make a decision to trust that I'll learn something from each experience, even if I'm unsure at times.
Mental Resourcefulness	• Where do you turn for new ideas? • Do you look for connections between ideas? • Do you apply past experiences to new situations?	When something seems unfamiliar, I often assume it's not useful.	There have been times when I disregarded new ideas before considering them fully. I don't often see connections between what I'm doing and what I've done.	I always try to consider things, even if they seem odd or surprising at first. I often relate new ideas to old ones.
Communication	• Can you clearly convey an idea to someone else using pictures, speech, or demonstrations? • Do you give examples that support your ideas? • Do you seek consistency in ideas?	It seems like others don't understand what I'm trying to say/convey most of the time. Once I try to communicate something, I move on to the next thing.	I can usually convey my ideas, but often others don't seem to understand what I'm trying to communicate. When the message doesn't get across, I might try one other way of communicating.	Communication is a strength of mine. When I'm feeling misunderstood, I search for new ways to convey my point. I look back through my conclusions to make sure they're clear and consistent.
Diligent Skepticism	• How do you evaluate the quality of procedures? • Do you scrutinize sources of information and search for ways to test ideas? • Can you identify problems with procedure that lead to erroneous or incomplete conclusions?	Much of what I believe came from someone else directly. When someone sounds convincing, I trust that they are right.	I should ask more questions about information that I receive and steps that I'm taking. Sometimes I discover that I've been led down a path that I could have avoided with more thought, testing, and questioning.	I ask plenty of questions (to myself and others) and head off problems before they start.
Collaboration	• Are you respectful, supportive, and critical of peers? • Do you share your ideas with others? • Do you consider strategies employed by your peers for study, organization, and investigation?	Sometimes I either don't participate; dominate the work, so that others might not feel like they have a role; or distract others.	I'm great as either a leader or a participant, but not both. I could be more mindful of the needs of others with whom I work. I try to learn from what others are doing.	I am an asset to any team. I know how to lead when appropriate and how to support others when they take the lead. I think pretty much everyone has something to offer me.
Reflection	• Do you consider past experiences when making choices? • Do you reference prior work? • Are your reflections thoughtful and substantive?	Once I complete something, I usually just move on to the next thing, without thinking how it went.	I don't always reflect after each science experience. I don't review my notes during and after a topic of study. I'm not great about considering how things went.	I squeeze every bit of learning from everything that I do by evaluating what happened. My notes are excellent, and I use them often to check on my ideas.

EXPERIENCES

The self-evaluation rubric includes 10 skills classified as basic or advanced (Table 3) and questions for students to ask themselves to rate their proficiency level in each skill as beginning, developing, or succeeding. In the chemical reaction engineering course, self-reflection assignments were assigned four times during the semester for tracking approximately monthly progress. The self-reflection assignments were submitted electronically through the course management system and required a three-part essay. The essay prompt was (1) use the self-evaluation rubric to rank yourself for one or more skills, (2) set a goal and make a plan for improving the selected skill(s), and (3) describe your progress in the selected skill(s) since the previous essay. Electronic feedback was provided in the form of a completion grade (0.3% each) and a brief comment from me, typically one sentence to a few paragraphs in length. An example submission written by me after reading many of these essays over four course offerings for self-reflection assignment 2 typically looks like the following: In assignment 1, I reflected on my organization skills. I was at the beginning stage. I read the instructor's feedback and her advice to use an online calendar that syncs with my cell phone. I followed the advice and have not forgotten any assignments or meetings since then. Now I am working on trying to schedule enough time to get projects and homework done by adding reminders in advance, not just deadlines on the calendar.

TABLE 3
Non-technical professional skills included in the self-evaluation rubric.

Basic skills	Advanced skills
Persistence	Courage
Organization	Mental resourcefulness
Connections	Communication
Self-compassion	Diligent skepticism
	Collaboration
	Reflection

I developed the self-reflection assignments during my first time to teach the course in spring 2015. I observed that students seemed to become more confident in their non-technical skills and that I was able to connect with many students

on a personal level through the assignments. I designed a classroom research study to assess the outcomes of the assignments. The spring 2016 class had 82 students, and the spring 2017 class had 66 students. No control group has been used for comparison.

IMPLEMENTATION TIPS

For other instructors interested in adopting the self-evaluation rubric and self-reflection assignments, it is recommended to introduce the self-evaluation rubric at the beginning of a semester and have 3 – 4 self-reflection assignments during the term spaced 4 – 6 weeks apart. Using online submissions through the course management system makes it straightforward for the instructor to provide feedback to the students from a master list of common feedback that can then be customized as appropriate without rewriting all comments every time, as would be the case for paper-based submissions. For the latter assignments, feedback can be provided in aggregate to the whole class either verbally or electronically by simply providing some tips on key themes or acknowledging good progress by all. The key skills that most of my junior level students have focused on are self-compassion, collaboration, communication, connections, and organization (both file and time management). Even if the self-assessment assignments are not adopted by others, students need help in developing these professional skills. I recommend providing resources to aid students' development in these key skills. For self-compassion, a portion of one lecture is dedicated to defining and discussing the imposter syndrome,[6] to reassure students that they are not alone in struggling with self-compassion, and to share tips for developing new habits.[7] Collaboration, communication, and connections are clustered as team-related skills. I dedicate the third of four self-reflection assignments to team-related skills. The third assignment is after the first of the Unit Operations Laboratory team projects and before the team project in the chemical reaction engineering class. Each student is required to open a pdf version of a published teamwork handbook[8] through the course management system before he/she can submit his/her essay and to include reflection on a team-related skill. The handbook provides good information about what to do during team meetings, styles of contributions to teams, and conflict resolution. The handbook is highly recommended for use in any team context and is student friendly. For improving the skill of organization, I suggest use of online calendars or cell phone reminders and hole-punched course materials stored in binders or digital versions of course materials stored electronically for each course.

METHODS

The methods for the classroom research study have been previously described in detail.[5] Briefly, I administered anonymous, optional surveys at the beginning and end of the semester via Google forms to assess the self-reflection assignments. Self-reflection assignment submissions from the course were not used as part of this research study. Data were analyzed in aggregate form for each semester (spring 2016 and 2017). The Likert-scale (1 – 5) questions in the post-assignment survey are summarized and labeled as Q1 – Q7 in Table 4. My hypothesis was

- *self-reflection assignments positively impact student progression toward higher levels of non-technical skills,*
- *skills that students focus on actively will improve during the semester with some level of attribution to the self-reflection assignments,*
- *skills that students are simply made aware of through the exercises and do not actively reflect on in course assignments will also improve during the semester with some level of attribution to the self-reflection assignments.*

ASSESSMENT RESULTS

The first part of each survey asked students to rank their proficiencies for each skill on the self-evaluation rubric (Table 5). The original intention for the study was to anonymously track changes in individuals over a semester through the use of keyword identifiers set by the survey respondents. However, in both years the numbers of perfect matches between the pre- and post-surveys were very small, likely due to different students taking the two surveys and/or some students forgetting their identifiers despite the unique personal formula for the identifier being provided in both surveys. Therefore, the data reported are the percentages of respondents who evaluated themselves at each proficiency level in the two surveys for each cohort. The changes between the pre- and post-surveys are summarized in Table 6. Many students reflected on

TABLE 4
Likert-scale questions in Part 2 of the post-assignment survey[5]. Reproduced with permission of ASEE, copyright 2017.

Question Number	Question
Q1	I believe that the self-reflection assignments resulted in positive changes in my proficiency level(s) for at least one of the skills that I actively worked on during the semester.
Q2	I believe that the self-reflection assignments resulted in positive changes in my proficiency level(s) for at least one of the skills that I DID NOT actively work on during the semester.
Q3	I believe that completing the self-reflection assignments was the most significant factor influencing changes in my proficiency level(s) for at least one of the skills listed in the self-evaluation rubric by the end of the semester.
Q4	I believe that WITHOUT the self-reflection assignments I would have made the same changes in my proficiency level(s) for at least one of the skills that I actively worked on during the semester.
Q5	I believe that developing professional, nontechnical skills is a valuable experience in an engineering course.
Q6	I believe that the completing the self-reflection assignments was a positive experience in the chemical reaction engineering course.
Q7	I recommend using the self-reflection assignments in this course or other engineering courses for developing professional, nontechnical skills.

their progress in organization in at least one self-reflection assignment, and large percentages of respondents ranked themselves as succeeding in organization in both surveys. For the basic non-technical skills in 2016, higher percentages of students ranked themselves at the succeeding level after the self-reflection assignments (positive values for column %S in Table 6), and the percentages of the beginning and developing levels decreased (negatives values for columns %B and %D in Table 6). The exception in 2016 was self-compassion for which the number and percentage of students at the developing level increased appreciably by the end of the semester. In 2017, the trends for all of the basic skills except organization were for increasing percentages of students at the developing levels. This is likely due in part that only 13 of the Survey 2 respondents were matched to respondents of Survey 1 through a unique private code. Additionally, the 2017 Survey 1 succeeding levels were relatively high and more optimistic than those in 2016, which did not leave much room for improvement and more opportunities for the effects of being made aware of deficiencies through academic challenges of the semester.

TABLE 5
Percentage of total survey respondents who evaluated themselves at proficiency levels of beginning (B), developing (D), and succeeding (S) for the non-technical skills. "Before" denotes the pre-assignment survey, while "After" denotes the post-assignment survey. Data for 2016 and 2017 cohorts are presented with the number of respondents indicated in parentheses.

Skills	Before						After					
	2016 (46 Respondents)			2017 (24 Respondents)			2016 (31 Respondents)			2017 (26 Respondents)		
	%B	%D	%S	%B	%D	%S	%B	%D	%S	%B	%D	%S
Persistence	8.7	45.7	45.7	4.2	25.0	70.8	3.2	38.7	58.1	0.0	57.7	42.3
Organization	6.5	43.5	50.0	4.2	45.8	50.0	0.0	16.1	83.9	7.7	26.9	65.4
Connections	10.9	56.5	32.6	16.7	54.2	29.2	3.2	29.0	67.8	7.7	65.4	26.9
Self-compassion	19.6	47.8	32.6	8.3	41.7	50.0	9.7	58.1	32.3	23.1	61.5	15.4
Courage	4.3	60.9	34.8	25.0	33.3	41.7	3.2	45.2	51.6	19.2	23.1	57.7
Mental resourcefulness	0.0	41.3	58.7	16.6	41.7	41.7	0.0	22.6	77.4	7.7	38.5	53.8
Communication	2.2	54.3	43.5	12.5	37.5	50.0	3.2	32.3	64.5	11.5	61.5	26.9
Diligent skepticism	6.5	56.5	37.0	8.3	58.4	33.3	0.0	54.8	45.2	15.4	46.2	38.5
Collaboration	2.2	45.7	52.1	4.2	29.1	66.7	6.4	35.5	58.1	7.7	46.2	46.2
Reflection	10.9	58.7	30.4	8.3	54.2	37.5	3.2	64.5	32.3	15.4	34.6	50.0

Communication and collaboration among the advanced non-technical skills had larger numbers of respondents at the beginning level at the end of the semester as compared to at the start of the semester in both years. In 2016 the succeeding levels increased over time, while in 2017 the succeeding levels dropped for these two skills. This may be an example of a phenomenon where self-assessments are artificially inflated when one has trouble recognizing their own incompetence and that improving in competence helps with recognition of limitations of abilities.[9] One possible explanation is that some students may have had experiences such as Unit Operations Laboratory course group projects that revealed deficiencies in these skills. Because of this transformational concurrent course, I do not claim that the self-reflection assignments are independently responsible for transitions in communication and collaboration skills. The other advanced non-technical skills increased in succeeding levels by the end of the semester. More than 50% of the respondents in both years rated themselves at the succeeding level for the advanced skill of mental resourcefulness, which is related to lifelong learning.

TABLE 6
Change in percentage of total survey respondents who evaluated themselves at proficiency levels of beginning (B), developing (D), and succeeding (S) for the non-technical skills. Data for 2016 and 2017 cohorts are presented with the number of respondents indicated in parentheses.

Skills	Change = After - Before					
	2016 (46 Respondents)			2017 (24 Respondents)		
	%B	%D	%S	%B	%D	%S
Persistence	-5.5	-7.0	12.4	4.2	32.7	-28.5
Organization	-6.5	-27.4	33.9	-3.5	-18.9	15.4
Connections	-7.7	-27.5	35.2	9.0	11.2	-2.3
Self-compassion	-9.9	10.3	-0.3	-14.8	19.8	-34.6
Courage	-1.1	-15.7	16.8	5.8	-10.2	16.0
Mental resourcefulness	0.0	-18.7	18.7	8.9	-3.2	12.1
Communication	1.0	-22.0	21.0	1.0	24.0	-23.1
Diligent skepticism	-6.5	-1.7	8.2	-7.1	-12.2	5.2
Collaboration	4.2	-10.2	6.0	-3.5	17.1	-20.5
Reflection	-7.7	5.8	1.9	-7.1	-19.6	12.5

The most prevalent skills that student reflected on in their assignments were self-compassion, organization, connections, and communication. In both years, at least 50% of the survey respondents identified connections as one of the skills they most needed to improve upon. In 2016, self-compassion was identified as the predominant skill for students to address. The least frequently addressed skills in the assignments were courage, diligent skepticism, and reflection.

In comparing between the two years, the 2017 initial percentages of students rating themselves in the succeeding category was both higher than the initial percentages for 2016 and higher than the final percentages for 2017. Of the 26 Survey 2 respondents, only 13 could be matched to the initial respondents, indicating that perhaps the sample in 2017 is skewed by different individuals taking the surveys compared to the 22 matched respondents out of the 31 who completed Survey 2 in 2016. The collective responses from Survey 2 for the Likert-scale and open-ended questions were also analyzed. The summary of responses to the Likert-scale questions is presented in Figure 1 for 2016 and Figure 2 for 2017. Collectively, the open-ended responses to Q1 – Q4 indicated that students felt the intervention of the self-reflection assignments positively impacted their skill development, even if the assignments were not the primary contributor to

that development. Several students mentioned the awareness of the skills and the rubric as being positive for bringing their attention to certain areas that could be improved.[5] Student opinions on the value of development of non-technical skills were higher than expected and show that student interest in this area is strong. Overall the responses in 2017 were less positive or more neutral than in 2016. The strong positive response to the final question "I recommend using the self-reflection assignments in this course or other engineering courses for developing professional, nontechnical skills" in 2016 strongly suggested that the self-reflection assignments guided by the self-evaluation rubric should indeed be adopted in other engineering contexts. The responses were less enthusiatic in 2017 but still a majority of responses were postive or neutral.

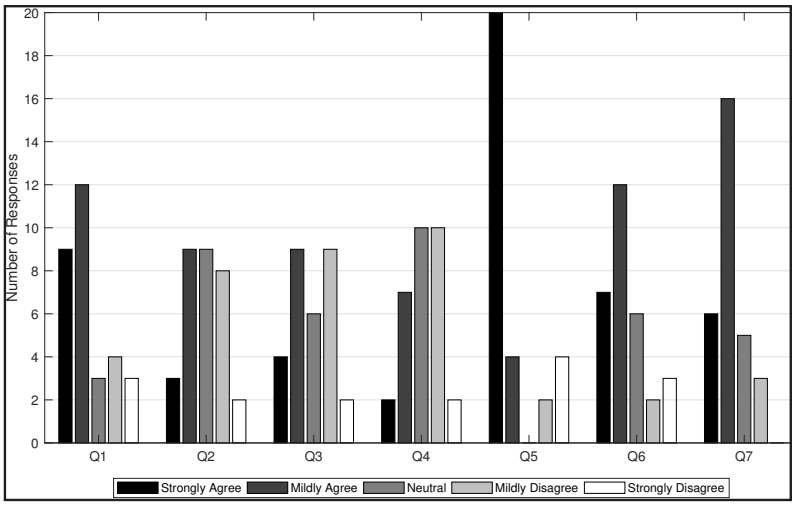

Figure 1. *Likert-scale question responses on the post-assignment survey in 2016.[5] Reproduced with permission of ASEE, copyright 2017.*

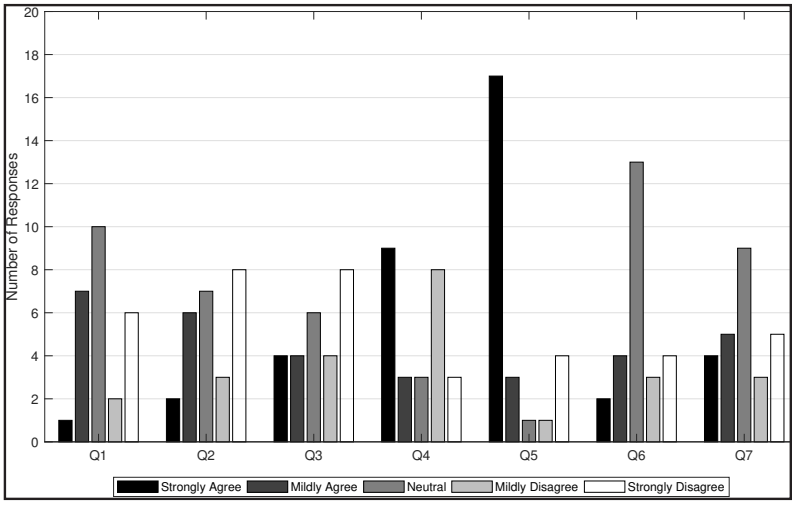

Figure 2. *Likert-scale question responses on the post-assignment survey in 2017.*

SUMMARY

Self-reflection assignments coupled with the self-evaluation rubric were described and assessed as a means for supporting students in developing non-technical skills while taking a chemical engineering core undergraduate course. The skills are transferable to a wide array of career paths often explored by graduates of chemical engineering undergraduate programs. Tips are also provided for instructors to help students' professional development in the five key skills of self-compassion, organization, collaboration, communication, and connections.

ACKNOWLEDGEMENTS

I am thankful to have been given the opportunity to present these results as a poster at the 2017 ASEE Chemical Engineering Summer School and for the invitation to submit this manuscript. Additionally, I would like to acknowledge the Oklahoma State University Institutional Review Board for helpful suggestions for designing and conducting this classroom research project.

REFERENCES

1. Shuman LJ, Besterfield-Sacre M and McGourty J (2005) The ABET "professional skills"-- Can they be taught? Can they be assessed? *J. Eng. Ed.* 94(1):41-55.
2. Dounas-Frazer D (2012) Measuring growth, part 1: Origin of the self-evaluation rubrics. *The Compass Project* http://www.berkeleycompassproject.org/measuring-growth-part-1-origin-of-the-self-evaluation-rubrics/ accessed March 27, 2019.
3. Dounas-Frazer DR and Reinholz DL (2015) Attending to lifelong learning skills through guided reflection in a physics class. *Am. J. Physics* 83(10):881-891.
4. Ponton MK, Horine Edmister J, Ukeiley LS and Seiner JM (2001) Understanding the role of self-efficacy in engineering education. *J. Eng. Ed.* 90(2): 247-251.
5. Ford Versypt AN (2017) Self-reflection assignments for evaluating non-technical skills and setting goals for professional development. *Proceedings ASEE Annual Conference*, available at https://peer.asee.org/28819
6. Young V (2011) *The Secret Thoughts of Successful Women: Why Capable People Suffer from the Imposter Syndrome and How to Thrive in Spite of It*. Crown Business, New York.
7. Duhigg C (2012) *The Power of Habit: Why We Do What We Do in Life and Business*. Random House, New York.
8. Kennedy FA and Nilson LB (2008) *Successful Stategies for Teams: Team Member Handbook*. Clemson University Office of Teaching Effectiveness and Innovation, https://facultyinnovate.utexas.edu/sites/default/files/TeamworkHandbook-KennedyandNilson.pdf, accessed March 27, 2019.
9. Kruger J and Dunning D (1999) Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *J. Personality Social Psych.* 77(6):1121-1134. ❐