Case Study

The Communication Coefficient Method: A New Faculty Grading Tool Designed to Help Engineering Students Improve Their Technical Communication

—Edward Londner, Matthew Dabkowski, Ian Kloo, and J. D. Caddell

***Abstract*—Introduction:** *Engineering students benefit from understanding the role of technical communication in the professional workplace. This article examines the communication coefficient (CC), a new method for grading student technical communication intended to help students better understand this role. Its goal is to encourage students to treat their communication with the same importance that it has in the professional workplace.* **About the case:** *The core philosophy of the CC method is that audiences perceive technical work more positively when it is communicated well and more negatively when it is not. The method captures this philosophy mathematically: students' grades result from multiplying the points earned for technical content by a number—the coefficient—representing how well they communicated that content.* **Situating the case:** *The CC method is rooted in established principles, such as holistic grading and the separate yet simultaneous consideration of content and communication. It is novel in how it combines these principles into a grading technique.* **Approach:** *The CC method was employed in three undergraduate engineering classes at the United States Military Academy during the spring 2020 semester. Student and instructor feedback were collected to gauge the pros and cons of the method and whether it is worth fielding on a larger scale.* **Discussion:** *The CC method was found to encourage better student communication, although mixed student and instructor opinion suggest that changes to the method and the way that it is messaged are necessary.* **Conclusion:** *The CC method warrants further study and consideration of its usefulness in other departments and institutions.*

Index Terms*—Accreditation Board for Engineering and Technology (ABET), assessment, communication grading methods, evaluation, rubrics, technical communication.*

Writing and speaking are highly valued skills for engineers [1], [2], who must routinely explain complex and high-stakes topics to a wide range of audiences [3]. The importance of these skills has been codified by the Accreditation Board for Engineering and Technology's (ABET's) Engineering Accreditation Commission in its third student outcome, which states that students should graduate with "an ability to communicate effectively with a range of audiences" [4].

Much research has been conducted in pursuit of this outcome, seeking the best ways to prepare engineering undergraduates to communicate technical material [5], [6], [7], [8] and the best ways to assess their ability to do so [9], [10], [11], [12].

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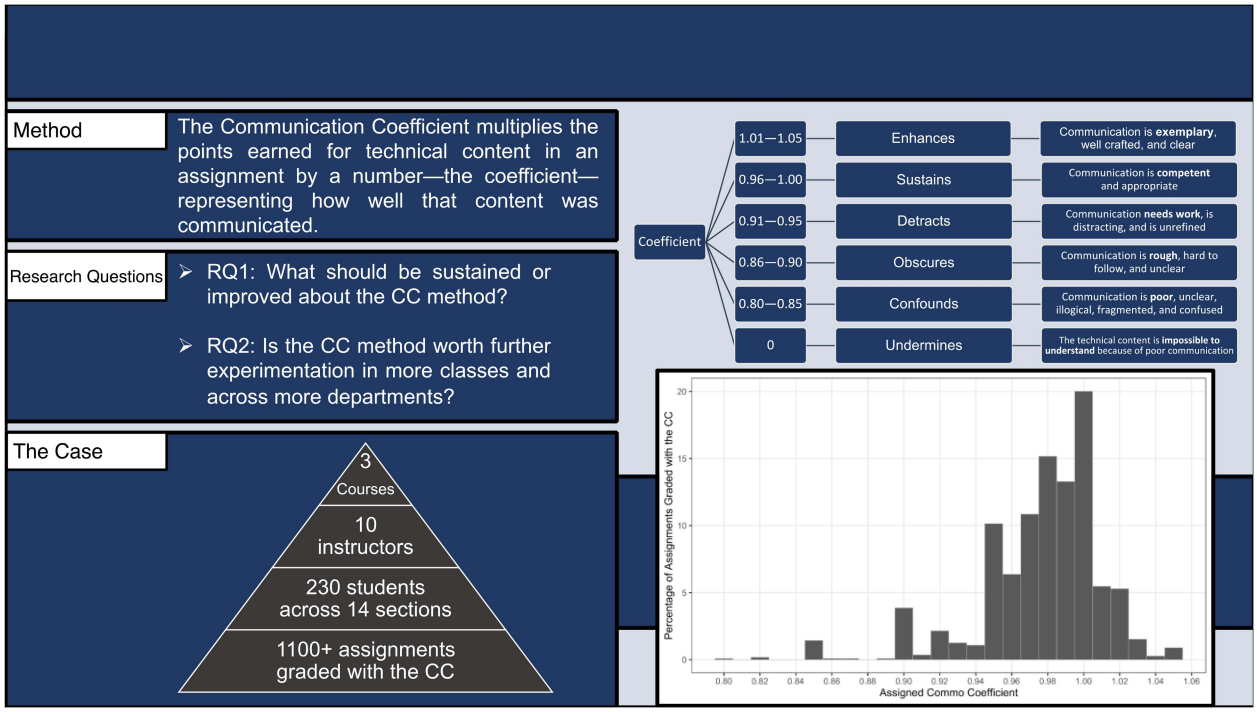
However, research shows that professional institutions remain dissatisfied with the communication ability of recent engineering graduates [13].

Differences between the classroom environment and professional workplace contribute to this situation [14], [15]. For example, Paretti describes how students can develop poor expectations of professional communication because they tailor their work to satisfy their instructors, who are primarily concerned with gauging their students' learning, and not to satisfy fellow engineers or supervisors, who are primarily concerned with making project decisions [5]. In earlier work, Dannels describes how students often revert to this "classroom" mode of communication even when encouraged to communicate as if they were in a professional setting [16].

These studies make the limitations of teaching communication in the classroom clear. They also highlight the value of giving students realistic expectations of communicating as professional engineers, despite these limitations. The more realistic these expectations, the better prepared students will be to communicate professionally [17], [18], [19].



The communication coefficient (CC) is a new method for evaluating and grading classroom models of *technical communication:* the communication of technical material in reports, briefings, and other settings that professional engineers routinely engage in. The CC method is designed to prepare engineering students to communicate technical material as professionals. It does this by exposing students to three key aspects of professional engineering communication, referred to in this article as *philosophies*:

1. **Philosophy 1:** The way that we communicate affects how others perceive our work. They perceive our work as more valid and useful when we communicate it well and less so when we communicate it poorly.
2. **Philosophy 2:** Individuals judge communication quality based on a host of personal factors, including their experiences, preferences, technical background, linguistic background, and membership in professional groups.
3. **Philosophy 3:** Communication matters during all interpersonal interactions, to varying degrees.

Later in this article, we describe the role that these philosophies play in the CC method, along with our justifications for them based on the literature and our professional experience.

By incorporating these aspects of professional engineering into the classroom, the CC method attempts to create a culture of accountability around student writing and speaking: one that motivates students to improve their communication skills by showing them the importance that these skills have in the professional workplace. By emphasizing the importance of communication and providing a mechanism to improve it, students' communication skills should improve and their confidence using them should increase [20].

In this article, we describe the CC method and a study conducted on it in the Department of Systems Engineering at the United States Military Academy (USMA) during the spring semester of 2020. The goal of the study was to answer the following research questions:

RQ1. What should be sustained or improved about the CC method?
RQ2. Is the CC method worth further experimentation in more classes and across more departments?

This article addresses these questions such that engineering department faculty and administrators can determine the CC method's usefulness to their own programs. It is outlined as follows: in About the Case, we describe the academic setting, mechanics, and philosophical underpinnings of the method, along with its theoretical advantages over traditional grading methods; in Situating the Case, we show that although the CC method is new, it is based on established, accepted principles of

Practitioner Takeaway

- The Communication Coefficient method aligns how technical communication is graded with its effects and importance in the professional workplace. Its goal is to encourage better student communication.
- The core principle of the method is that the way we communicate our work affects how audiences judge the quality of that work. The method captures this principle mathematically by scaling points earned for technical content up or down based on how well that content is communicated.
- A one-semester study of the method revealed that it can encourage better student communication when it is used fairly, transparently, and consistently by instructors.

education; in Methods and Approach, we describe the methodology, sample sizes, and instruments of our study; in Results and Discussion, we show that the CC method can be effective under the "right circumstances," which we discuss, and we describe student and faculty attitudes toward the method; and in the Conclusion, we offer perspectives on future work.

About the Case

USMA, commonly referred to as West Point, is the United States Army's federal service academy. USMA's Academic Program is divided into 13 departments, ranging from English and Philosophy to Physics and Nuclear Engineering. Students—known as cadets—receive a liberal arts education built around a core curriculum of 24 courses and required instruction in mathematics, science, and engineering. This includes nonengineering majors, who take a sequence of three engineering classes within a chosen discipline covering fundamentals, methodologies, and principles of design.

USMA's faculty is a blend of military and civilian instructors and professors occupying temporary and permanent assignments. Class sizes are small, typically capped at 18 students, daily attendance is logged, and struggling students receive additional instruction. There are no teaching assistants, and faculty members are encouraged to interact with students outside the classroom.

Students attend several writing-heavy classes in their early semesters, and USMA maintains the West Point Writing Program, which is responsible for setting, assessing, and supporting student writing standards. That said, there is no specific course at USMA dedicated to technical writing or presenting. Individual departments determine how much to emphasize this material in their curricula, leading to a variety of approaches across the academy. This diversity of approaches was a motivation for developing the CC method, which could serve as a unifying approach.

Communication Coefficient Method At the heart of the CC Method is the relationship between *technical content* and *communication:*

1. *Technical content* is the information contained in a report, presentation, or other assignment.
2. *Communication* is the way that information is conveyed through writing and oral presentation. It includes elements such as the rules of communication (e.g., syntax and spelling), clarity of communication (e.g., brevity, logical flow, vocal enunciation, quality of figures and tables), and the elements of formatting and documentation (e.g., use of a coversheet and proper citations).

Under many traditional grading methods at USMA, between 85% and 95% of the available points on an assignment are dedicated to its technical content, and the remaining points are dedicated to its communication quality. These remaining points are added to the points earned for technical content to arrive at a total score, as illustrated in Fig. 1(a).

Under the CC method, all available points are dedicated to technical content. These points are then multiplied by a scaling factor—the *communication coefficient*—that represents how well the student communicated the technical content. The total score for an assignment is the result of this multiplication, illustrated in Fig. 1(b). Thus, rather than treating technical content and communication as discrete elements of an assignment's total score, the CC method integrates them into a single, combined product. This

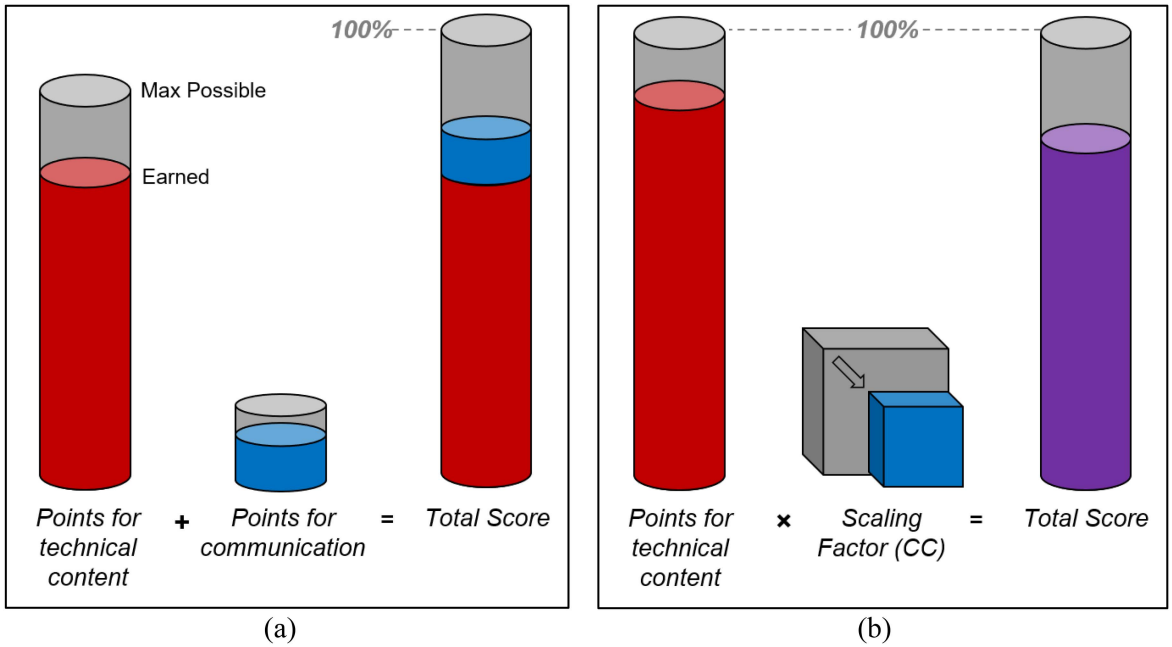


Fig. 1. Comparison of communication grading methods (not to scale). (a) Traditional method. (b) Communication coefficient method.

approach is motivated by the first philosophy of professional communication.

Philosophy 1: The way we communicate affects how others perceive our work. They perceive our work as more valid and useful when we communicate it well and less so when we communicate it poorly.

Therefore, students' grades calculated with the CC method represent how an audience would perceive their work based on the quality of their technical content, enhanced or diminished by the way that content is communicated.

This philosophy is the crux of the CC method: the way we communicate our work enhances or diminishes that work wholly, like changing the recording quality of a piece of music or the number of pixels in a photograph. Consider listening to a dynamic presenter versus one mumbling in monotone or reading a clear and direct technical paper versus one that meanders and buries its takeaways. To an audience, the way the work is communicated is as important as its methods and results, affecting their ability to understand the work and their feelings towards it. Scaling grades based on communication is simply a mathematical manifestation of this idea.

Scope of the Method The CC method is designed for assignments where technical content and communication are relevant and distinguishable. This article is focused on communication in engineering, but assignments in many other subject areas, such as the social sciences, may also meet these conditions.

The CC method is not appropriate when these conditions are not met. For example, in many composition class assignments, the quality of a student's writing may be much more important than the topic they are writing about, meaning that the instructor may not care about the assignment's "technical content" so long as it is communicated well. Similarly, the CC method is not appropriate for purely technical assignments where there is a "right answer" to be calculated, such as math-heavy homework assignments.

The CC method calls for instructors to consider an assignment's technical content and communication separately, despite communication's holistic effect on the perceived quality of that technical content. As we touch upon in Situating the Case, this simultaneous separation and integration, while paradoxical on its face, is a long-established teaching technique.

Scoring Communication The CC method evaluates students' writing and speaking based on how well they support the technical content being communicated. Writing and speaking that enhance

TABLE I
RUBRIC OF COEFFICIENTS

Coefficient	Effect of Communication on Technical Content	Description of Communication
1.01—1.05	Enhances	Communication is **exemplary**, well crafted, and clear. It is free of obvious errors. It eases the burden* on the audience.
0.96—1.00	Sustains	Communication is **competent** and appropriate. Errors, if any, are isolated one-off mistakes. Communication imposes no extra burden on the audience.
0.91—0.95	Detracts	Communication **needs work**, is distracting, and is unrefined. Errors suggest lack of proofreading. Communication imposes a light burden on the audience.
0.86—0.90	Obscures	Communication is **rough**, hard to follow, and unclear. Errors suggest carelessness. Communication imposes a medium burden on the audience.
0.80—0.85	Confounds	Communication is **poor**, unclear, illogical, fragmented, and confused. Errors suggests a lack of understanding of the rules and best practices of good communication. Communication imposes a heavy burden on the audience.
0	Undermines	The technical content is **impossible to understand** because of poor communication.

*"Burden" refers to "burden of understanding," meaning the amount of work it takes the audience to understand the technical content being communicated.

the technical content by conveying it in a compelling, clear, and purposeful way will earn a high CC, while writing and speaking that diminish the technical content by conveying it in a frustrating, opaque, or meandering way will earn a low CC.

Table I is the rubric matching communication quality to CC numerical values. Note the following:

1. The CC nominally ranges between 0.80 and 1.05, although it can also equal 0 when a student's communication is so poor that their technical content is impossible to understand. We explain these choices below.
2. Because the CC can exceed 1.00, students can earn total scores beyond 100% by communicating good technical work especially well.

This rubric is subjective and minimally prescriptive by design, giving instructors wide latitude to judge a student's communication based on their own experience and the particulars of each assignment. This is in keeping with the second philosophy of professional communication:

Philosophy 2: Individuals judge communication quality based on a host of personal factors, including their experiences, preferences, technical background, linguistic background, and membership in professional groups.

In other words, the effect of communication on audience perception depends on the attributes of the audience. That said, instructors should evaluate students' work based on the same elements of good communication, even if they choose to weigh those elements differently. Table II outlines these elements. It is based on USMA's signature writing event rubric and is general enough to be applied to a wide variety of assignments (see https://www.westpoint.edu/academics/curriculum/west-point-writing-program).

The numerical bounds of the CC determine the extent to which it can scale grades. In this study, the bounds of 0.80–1.05 were chosen to capture the effect of communication on perceived technical quality as estimated by the implementers of the method, to encourage students by offering extra points for excellent communication, and to avoid making the method punitive.

The inclusion of a 0 option may seem strange given the CC method's sensitivity to punitiveness. In some respects, the inclusion of 0 is redundant. If an assignment is impossible to understand, how could an instructor assign it any technical points to multiply by the CC? However, keeping the 0 in play heightens a psychological phenomenon known as the "endowment effect," which is driven by loss aversion or anticipated regret [21]. The regret is evoked when a student imagines losing all the credit earned for his or her technical content, thereby increasing the premium placed on these points. Confronted with this possibility, the student should be inspired to lessen its likelihood by increasing the quality of his or her communication. We elaborate on the important

TABLE II
ELEMENTS OF GOOD COMMUNICATION

Element	Description
Substance	Expresses ideas, arguments, or findings with insight, nuance, and precision in a way appropriate for the intended audience. Enlists credible, relevant evidence; develops sound logic and convincing analysis.
Organization	Structures work according to appropriate disciplinary or generic expectations. Develops orderly, cohesive paragraphs or sections, as well as a clear, logical flow guided by effective transitions.
Style and Presentation	Models style suitable to the genre or discipline, e.g., regarding tone or diction. Adheres to conventions in formatting, layout, elements of visual rhetoric, etc. For oral presentations, uses appropriate physical bearing, tone and volume of voice, enunciation, fluency, and rate of speech.
Mechanics and Correctness	Uses language with clarity, accuracy, and concision. Uses correct syntax, punctuation, and spelling. Errors or awkwardness that are present do not significantly impede understanding.
Documentation and Formatting	Documentation and formatting are correct and complete according to the applicable standard.

relationship between the CC method and loss aversion later in this article.

All of this said, the essence of the CC method is the scaling approach depicted in Fig. 1, not a particular choice of numerical bounds. Instructors should set the numerical bounds based on the needs of their individual departments and even courses. This flexibility is meant to capture the third philosophy of professional communication:

Philosophy 3: Communication matters during all interpersonal interactions, to varying degrees.

Communication always matters, but the stakes are higher in some situations than in others, and the effects of one's communication on how their work is perceived is also situational. Consider one example among many: the stakes of communicating experimental results externally to a grant funding agency will be higher than when communicating those results internally to fellow grant collaborators. This variation is captured mathematically by the choice of bounds for the CC method.

Effect on Grades The CC has the largest effect on student grades when technical content scores are high. For example, a CC of 0.95 reduces 100.0 to 95.0—a change of 5.0—while it reduces 80.0 to 76.0—a change of 4.0. This represents how the stakes of communicating change with the quality of technical work. For example, when a student has earned a high technical content score, it suggests that they have more substantive information to communicate than if the score was lower, meaning there is "more to lose" when that information is not communicated well.

Presenting Grades and Feedback Instructors should present scores as follows to make the effects and intentions of the CC clear:

$$\boxed{\text{Technical Points} \times \text{CC} = \text{Total Score.}}$$

For example, say that a student has earned an 89.2% for his or her technical content and a CC of 1.04, leading to a total score of 92.8%. This should be presented as follows:

$$\boxed{89.2 \times 1.04 = 92.8.}$$

The leftmost number represents the quality of the student's technical content on its own, while the combined score represents how this technical content would be perceived by an audience—a higher number because it was communicated especially well.

Presenting grades this way makes the effect of communication on audience perception clear. It shows what the technical content would have earned with competent communication, corresponding to a CC of 1.00, alongside what it actually earned. This presentation may be especially effective when the CC is less than 1.00, as in the following:

$$\boxed{92.5 \times 0.88 = 81.4.}$$

In this case, poor communication caused a loss of $92.5 - 81.4 = 11.1$ points. Under the traditional grading method depicted in Fig. 1(a), where points for communication are added to points for technical content, poor communication would appear to have caused a smaller gain of points rather than a loss of points. Research suggests that the psychological difference between these two presentations may be significant: humans are

naturally loss averse [22], a phenomenon that has been observed in the literature with respect to grading [23], [24], so the CC method may be more motivating than the traditional one for reasons beyond the effects that each one has on total points earned.

Further Guidance for Instructors The accountability that the CC method seeks to instill in students extends to instructors, who should explain the importance of writing and speaking to their students and provide them with useful communication feedback. This feedback should be easy to differentiate from feedback on technical content and should be based on the elements of communication outlined in Table II.

The CC is appropriate for assignments involving significant writing or presenting where the instructor can differentiate between a student's technical content and the way it is communicated. Occasionally, the differences between the two are not clear, requiring instructors to look beyond what a student wrote or said to interpret what they meant. When doing so, it is important that instructors avoid double-penalizing students by docking both technical points and the CC for a single mistake.

The CC method requires engineering faculty to teach their students to communicate like professionals. Conrad's research captures the value of this arrangement: engineering faculty, especially those with recent practitioner experience, are best equipped to teach the communication practices specific to their field—practices that will likely not be addressed in composition or even general technical writing classes [25]. This CC method assumes that engineering faculty are willing and able to take on this task.

Finally, it might be assumed that the CC method would increase instructor workload by increasing their focus on communication quality. The results of this study suggest that this workload increase is not inevitable, as subsequent sections will describe.

Situating the Case

Our review of the literature has revealed no grading technique for technical communication like the CC method. Many papers describe rubrics and other related techniques for assessing communication [11], [23], [24], [26], [27]. Others address those differences between the classroom and professional workplace that skew student expectations of communication's importance and best practices [5], [11], [14], [16]. However, we found no description of a method that attempts to bridge these differences using a grading technique, as opposed to the equally important pursuit of designing assignments, courses, and curricula [28], [29], [30], [31], [32].

That said, the elemental principles of the CC method are captured in the literature. In this section, we review the literature pertaining to three such principles: the philosophies described above, the CC method's hybrid analytic and holistic grading approach, and the consideration of communication as both separate from and linked to technical content.

Three Philosophies The ideas behind Philosophy 1 have been demonstrated across a variety of studies for both technical and nontechnical communication. For example, studies show that quality of communication affects audience perception of news articles [33], [34]; research proposals [35]; positive product reviews on the internet [36]; email responses to housemate advertisements [37]; job applications [38], [39]; author writing ability [40], [41]; PowerPoint slides [42]; and, of course, technical writing [25]. In all cases, language problems, such as spelling errors or vagueness, had a negative effect on audience perception. A study of composition errors found that spelling mistakes lowered the mean student grade from B to C, even though teachers were told to assign grades based on content only [43]. Similar phenomena have been observed on the negative effects of poor handwriting [44] and the positive effects of an "impressive writing style" [45, p. 27].

In keeping with Philosophy 2, some studies demonstrated that the magnitude of the effects noted above depended on the attributes of the audience, such as their spelling ability or their professional background [37], [38], [39], while others demonstrated that communication quality is "in the eye of the beholder" [46], [47]. Philosophy 2 is also consistent with examples in engineering education, such as how departments teach memo writing [48] or account for the influence of professional communities of practice on student communication needs [49].

Philosophy 3 captures the idea that technical communication always matters, but to varying degrees depending on the situation. The importance of technical communication is evident from its presence in the ABET requirements and

our professional experience. We base the variance in its importance on our experience with situations of differing stakes, differing opportunities for editing and correction, and differing audience skepticism, hostility, and attention. We expect that this experience is shared by other engineering professionals.

Analytic and Holistic Grading Sadler distinguishes between *analytic* and *holistic* grading [50]. In analytic grading, "separate qualitative judgements" [50, p. 161] of the various aspects of a student's work are made based on specified criteria, and these judgments are aggregated into a final score using a formula. In holistic grading, the score instead stems from a single judgment that is based on a "complex mental response" [50, p. 161] to the student's entire work, built up progressively as that work is reviewed. The CC method is a hybrid of these approaches. It is analytic because separate scores for technical content and communication are combined into a final score using a formula, although with important differences from the traditional method depicted in Fig. 1(a). It is holistic in how it treats communication's effect on the perceived overall quality of an assignment, in keeping with Philosophy 1, and in how the CC itself is made up of a single score rather than an aggregation of separate judgements.

Sadler points out that holistic appraisals are a "more authentic representation of the ways many appraisals are made in … everyday contexts," [50, p. 178] in keeping with the CC method's goal of more closely aligning the classroom with the realities of professional work. Sadler also points out the challenges of holistic methods, especially the tendency for instructor mood or bias to compromise their reliability. The CC method accepts and emphasizes the subjectivity of instructor evaluations (Philosophy 2), but arbitrariness is not its intent. The guidelines in Tables I and II are designed to mitigate this potential pitfall, and instructors can take further steps to do so, such as collaborative grading or ordered ranking of student assignments based on communication quality.

Technical Content and Communication Quality The CC method considers technical content and communication quality as inextricably linked, yet it also requires instructors to consider them separately as they evaluate assignments. This paradox has been addressed in the literature. For example, the Dutch Renaissance philosopher Erasmus said the following regarding the tension between *expression* (i.e., communication) and *content*.

> It might be thought that these two aspects are so interconnected in reality that one cannot easily separate one from the other, and that they interact so closely that any distinction between them belongs to theory rather than practice. Even so, I intend to separate them as a teaching procedure, doing it in such a way that I lay myself open to the charge neither of drawing hair-splitting decisions, nor of being careless about details. [51, p. 301]

Closer to the present, Carville et al. say the following in their discussion of integrating writing into technical courses.

> Rather than separating a student's grade into two parts—one grade for technical content, one for writing—you can show students that writing is integral to communicating technical information by tying writing to content. [52, p. 4]

Similar sentiment regarding the integration of writing into engineering assignments can be found in abundance within the American Society for Engineering Education's repository of conference proceedings [53], [54], [55], [56], [57].

Summary Our literature review has shown that although the CC method appears to be an innovation, the constituent ideas and techniques of the method are already well established. Thus, the newness of the method is in how it unifies these established ideas and techniques rather than any revolutionary departure from established thought. As a result, we expect that the CC method is compatible with the sensibilities of much of the engineering community. We have yet to articulate its value, however; that is the subject of the next section.

Methods and Approach

The purpose of the study described below was to answer the following pair of research questions:

> **RQ1.** What should be sustained or improved about the CC method?
> **RQ2.** Is the CC method worth further experimentation in more classes and across more departments?

The purpose of RQ1 is to inform the long-term, iterative development of the CC method: to discover what adjustments to it may be necessary to maximize its usefulness. The purpose of RQ2 is to

TABLE III
NUMBER OF SECTIONS, INSTRUCTORS, AND STUDENTS FOR COURSES PARTICIPATING IN THIS STUDY*

Course	Sections	Instructors	Students Enrolled	Students Consented
Course A	4	3	71	41
Course B	5	3	85	59
Course C	5	5	83	53
Total	14	11 (10)	239 (230)	153 (149)

*Some instructors taught more than one participating course, and some students were enrolled in more than one participating course. The values in parentheses indicate the totals that do not count these overlaps.

determine whether follow-on studies are worth considering based on the results of our initial study. It acknowledges that one semester is not long enough to evaluate whether the CC method meets its goal of improving student communication; assessing these effects would require longer term, longitudinal studies, potentially involving more students and courses. For this further experimentation to be worthwhile, the results of this study must show the following:

- **Evidence of benefit:** The study must show that the CC method encourages students to do things that will ultimately improve their communication. For example, results indicating that the method encourages students to pay more attention to their communication and those of others would be evidence of benefit.
- **Lack of evidence of harm:** The study must not show, in any obvious systematic way, that the CC method discourages students to improve their communication or otherwise harms their ability to complete their assignments and learn. For example, results indicating that students perceive the CC method as punitive would suggest that it is discouraging and therefore potentially harmful.

To answer the research questions outlined above, we constructed our study as follows.

1. **Use the CC method over one semester (Spring 2020) in three courses within the Department of Systems Engineering.** Details of these courses are outlined in Tables III and IV. All instructors within each course were directed to use the CC method as described in previous sections of this report, including the 0.80–1.05 numeric scale. The traditional method of grading communication depicted in Fig. 1(a) was employed in all three of these courses prior to the semester of this study, with the number of points dedicated to assessing communication quality varying by course and assignment.
2. **Collect and analyze feedback from students through a quantitative, end-of-semester survey about the CC method.** This survey consisted of 16 Likert scale questions, each with five response options ranging between "Strongly Agree" and "Strongly Disagree." These questions are outlined in Table V. Among the 149 students who consented to participate in the study (see Table III), 45 submitted this survey (~30%). A variety of factors may have caused this low response rate, including USMA's transition to remote teaching at this study's midpoint due to the COVID-19 pandemic and the fact that no course credit or penalty was attached to completion of the survey.
3. **Collect and analyze feedback from instructors through a qualitative, end-of-semester survey.** Instructor surveys consisted of 11 questions requiring long-form answers. These questions are outlined in Table VI. Note that two of the 10 instructors in the participating group are also creators of the method; their feedback was excluded. Another of these instructors is an author on this paper; this instructor's feedback was not excluded. As a result, eight instructors' responses to the survey were used in this study. Research on the sample size necessary to achieve saturation in qualitative research indicates that a respondent size of eight was likely sufficient to "capture the diversity, depth, and nuances of the issues studied" [58, p. 2], [59]. That said, eight is at the lower end of an acceptable sample size, and to apply, the respondents must be drawn from a "relatively homogenous study population" [58, p. 9]. This requirement seems to have been met for the instructors surveyed in this study but will limit the generalizability of the results.
4. **Collect and analyze the CC scores earned by students.** These scores were compared to external data such as grades in English classes and standardized test scores to identify any concerning correlations, such as a negative correlation between CC scores and English grades. Such concerning correlations might suggest that the method is not accurately representing student communication ability, potentially doing harm as a result.

In Fig. 2, arrows illustrate which survey questions were used to answer each research question. As depicted, individual survey responses bear primarily on RQ1 or RQ2, while the results of RQ1 also bear on RQ2. The figure also distinguishes

TABLE IV
DESCRIPTION OF COURSES PARTICIPATING IN THE STUDY

Course	Description
Course A	An introductory engineering class attended primarily by juniors and seniors. The CC was applied to written reports and oral presentations in this course, completed as part of a semester-long system design.
Course B	A methods class that teaches students to manipulate and visualize data. The CC was applied to oral presentations and submitted computer code in this course, judged based on readability and adherence to standards.
Course C	A principles of engineering design class for students who are not engineering majors, making this the only one of the three courses consisting primarily of non-engineering students. The CC was applied to written reports and oral presentations in this class.

TABLE V
STUDENT SURVEY QUESTIONS (QUANTITATIVE RESPONSES, FIVE-LEVEL LIKERT SCALE)

#	Question
S1	I have paid attention to the communication feedback offered by my instructor.
S2	I understand the communication feedback offered by my instructor.
S3	I have enjoyed writing and presenting in this class.
S4	I am a better technical communicator now than I was at the beginning of the semester.
S5	I understand why I have received the CC scores that I have received.
S6	The CC is designed to help students develop.
S7	The CC has been applied fairly.
S8	I understand how the CC works.
S9	The CC has increased the amount of attention I pay to my writing and presenting.
S10	I would like to see the CC used in other science and engineering classes.
S11	The CC is subjective.
S12	I prefer the CC over the “standard way” of assessing communication quality.
S13	The CC has increased the amount of attention I pay to others’ writing and presenting.
S14	Having the CC used in this class added to my workload.
S15	The CC scores I have received seem arbitrary.
S16	The CC is designed to punish.

TABLE VI
INSTRUCTOR SURVEY QUESTIONS (QUALITATIVE RESPONSES)

#	Item
I1	Describe your use of the CC up to this point, including the number of assignments in which you have used the technique and their cumulative percentage of the final grade in your class.
I2	Provide your overall assessment of the value of the CC.
I3	In what ways does the CC affect your comfort and willingness to teach and give students feedback on technical communication?
I4	Describe the ways in which you have adapted the CC to the needs of your class and students.
I5	Describe any lessons you have learned or difficulties you have encountered in separating technical content from communication quality when using the CC.
I6	What do you think should be sustained about the CC?
I7	What do you think should be changed or improved about the CC?
I8	In what ways and with what magnitude does the CC contribute to your workload?
I9	[This question is not relevant to this study and is therefore excluded.]
I10	Do you think that the CC should be employed in other classes in your department? Describe why or why not.
I11	Given what you have experienced, if you were to teach your class again, would you want to use the CC? Describe why or why not.

Fig. 2. Mapping of survey responses and research questions. For some student survey questions, an "agree" response indicates a favorable opinion of the CC method; these questions are marked in bold, green text. Those for which a "disagree" response indicates a favorable opinion are marked by red, normal weight text.

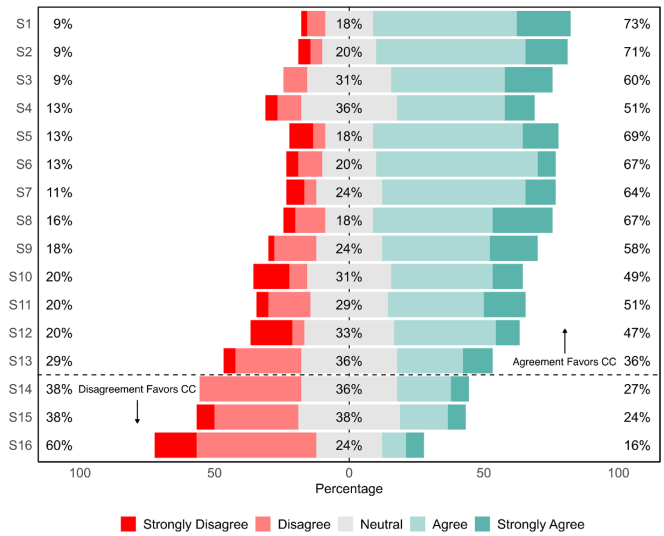


Fig. 3. Student responses to survey questions ($n = 45$). Survey questions are noted at the left (see Table V). The three percentages noted for each question represent the proportions of responses corresponding to three groupings: both levels of disagree (at left), neutral (center), and both levels of agree (at right). Figure created using Likert package for R [64].

those student questions for which an "agree" answer is favorable to the CC method, S1–S13, from those for which a "disagree" answer is favorable, S14–S16.

This study was classified as human subjects research and was approved by USMA's institutional review board. A control group was not used in this study because of the complications brought about by using more than one grading method in the same course. All instructors and students were given the choice to participate in the study. All instructors and 149 out of 230 students (~65%) consented to participate. Students that did not consent were not asked to fill out the student survey, although they were still graded using the CC method.

Results and Discussion

Student Results Raw student survey responses are depicted in Fig. 3 as relative frequency distributions. An alternate perspective on these results featuring means and confidence intervals is depicted in Fig. 4. Although Likert data are inherently ordinal, the mean of a survey question's responses can be calculated using parametric methods [60], provided the Likert scale consists of at least five levels and at least five levels of the scale are observed in the response data [61]. As Fig. 3 shows, these conditions hold for all student survey responses except to questions S3 and S14, which have no "Strongly Disagree" responses. Accordingly, following the recommendations set forth by Harpe [61], we used resampling with replacement (commonly known as nonparametric *bootstrapping* [62]) to derive the 95% confidence intervals seen in Fig. 4. Observations follow.

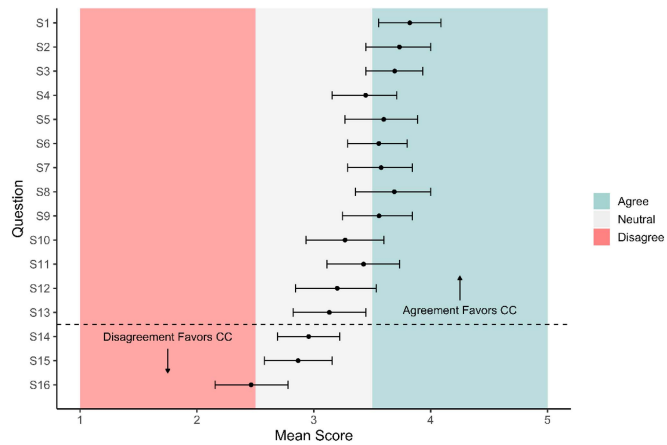


Fig. 4. Mean student responses to survey questions with 95% confidence intervals ($n = 45$). Survey questions are noted at the left (see Table V). Responses were converted to numeric scores ranging between 1 (strongly disagree) and 5 (strongly agree). Confidence intervals were created using resampling with replacement, commonly known as bootstrapping [62].

1. On aggregate, there was no clear unfavorable reaction to the CC method among the survey results. As Figs. 3 and 4 show, student responses overall agreed or were neutral for questions in which agreement was favorable to the CC method, and they disagreed or were neutral for questions in which disagreement was favorable. These facts lend credence to a *lack of*

evidence of harm, in keeping with the condition for RQ2 outlined above.
2. There is some *evidence of benefit*. For example, students agreed that the CC method increased the amount of attention they pay to their own writing and presenting (question S9) and to that of others to a lesser extent (S13). Both findings suggest benefits of the CC method, as we can expect increased attention to communication to yield improvements to this skill. These findings were expected; as one study notes: "For engineering students, writing is work to 'get done' and perhaps not viewed as important as 'engineering work'" [63, pp. 12–13]. Such sentiment suggests that calculation typically overshadows communication in the eyes of engineering students, which is problematic when improving their communication skills is a professional imperative. Fortunately, earning good grades tends to motivate students, and scaling students' "engineering work" by the CC appears to have had the desired effect in general.
3. On aggregate, students seemed to understand how the CC method works (S5, S8, and S11) and found it to be fair and developmental (S6, S7, S15, and S16). Their preference for it being used in other classes was also weakly favorable (S10 and S12).

These results suggest that, on aggregate, the CC method is not harmful and may be helpful. That said, some students had strongly unfavorable opinions of the method that must be considered, for it is possible that for these students, the method was not helpful and was potentially harmful. For example, a significant minority of students did not understand the basis for their CC scores (S5), found the method to be applied unfairly (S7), and/or did not want to see it used in other classes (S10 and S12). The reasons for these results are not clear, but it is possible that they would be mitigated if instructors were better trained to explain and use the method or if its numeric bounds were adjusted, as described below.

Instructor Results Given the novelty of the CC method, we inductively coded the open-ended instructor survey questions, the results of which were analyzed thematically [66]. The most important code, used to bin all other responses, was derived from question I2: Provide your overall assessment of the CC approach. We derived three ordinal codes from an initial reading of this question's responses: *in favor*, *neutral*, and *not in favor*. Due to its special importance as a top-level categorizer, two of the authors independently coded this question, and their interrater agreement was assessed via Cohen's weighted kappa [67] with linear weights [68] using R's vcd package [69]. With a weighted kappa value of 0.86 ($p < 0.0001$), their agreement was excellent [70], lending validity to the assigned codes. The lone coding discrepancy involved one author coding a response *in favor* and the other coding it *neutral*, but after discussion, the discrepancy was resolved to *in favor*. This produced the final coding in which four instructors were *in favor*, two were *neutral*, and two were *not in favor* of the CC method. Other questions were coded independently by one author. Common codes included those pertaining to the use of the CC method (e.g., "proper"), the attitudes of students toward the method as perceived by the instructors (e.g., "resentful"), and the effects of the CC method as perceived by the instructors (e.g., "helpful"). Thematic results are summarized below. Where not otherwise noted, the question being responded to is noted parenthetically after each instructor quotation.

Example responses to question I2 include the following.

1. **In favor:** "I think [the CC method] is critical in reinforcing the importance of communication on the cadets."
2. **Not in favor:** "I do not like the CC approach, or at least I think it needs to be refined."
3. **Neutral:** "[The CC method] helps fix routine minor oversights and format. [It] does not impact cadet writing ability."

Those instructors who opposed the CC method found it punitive and were concerned that students resented it. They disliked the grade scaling aspect of the method because of the way it can reduce points.

> I am not comfortable assigning a grade only to downgrade it based on the CC. I think that a clean grade is more straightforward and causes less resentment. (I3)

When asked if they would like to use the CC method again, one instructor in opposition replied, "No, I think it causes too much uneasiness and resentment with the cadets …" (I11).

Those instructors who supported the CC method found that it was a useful way to reinforce the importance of good communication: "I like [the CC method]. It seemed to get [the students'] attention and improve [their] attention to detail …" (I2). These instructors generally reported that the method compelled them to increase their

communication feedback: "It is a nice forcing function for providing feedback on the quality of communication" (I3). They also expressed a preference for using the method in more classes, explaining that the method's value would increase if students gained more exposure to it: "This system gains utility with every course that uses it because it builds familiarity among the cadets and instructors" (I10). These instructors also suggested improvements to the method (I7), including changing its numeric scale based on the needs and focus of individual courses and standardizing how grading using the CC method is performed across instructors.

Most instructors reported minor increases to the amount of time they spent grading because of the CC method. The most significant reported increase, which was not representative of the general response, was 25%, resulting from reading "every paper twice, once straight for content, and once for communication." (I8) This response was from an instructor in favor of the method.

Some instructors used the method in a way not intended or otherwise showed a lack of understanding of its purpose:

1. One instructor in favor of the method used the CC like a metaphorical control knob, adjusting it until final grades matched the "holistic grade [they] thought an assignment deserved." (I7)
2. Another automatically assigned CC scores of 1.00 to circumvent the method.
3. One instructor in favor of the method deducted 0.01 points from each assignment's CC score for every communication error within it. (Note that this instructor did not submit their CC scores to the authors; therefore, they do not factor in to the score analysis detailed below.)
4. In response to question I2, one instructor not in favor related a CC score of 0.80 to a grade assignment of B–, which is not the way the scores should be viewed.

Finally, instructors reported mixed levels of difficulty in separating technical content from communication quality (question I5). Two instructors, both in favor of the method, reported difficulty; three instructors, one in favor, one not, and one neutral, reported no difficulty; and the remaining instructors described their methodology rather than reporting a clear difficulty level: "It has added time in that, to make the approach work, I read a document first for communication quality and then reread for technical content."

Our takeaways from these results are as follows.

1. Under the right circumstances (see below), the CC method appears to increase student attention to their communication and the amount of communication feedback offered by instructors, which together we would expect to improve student communication over time.
2. These "right circumstances" are not to be taken for granted: instructors must actively create them. The results of this study do not define these circumstances explicitly, but we can expect that they involve an environment in which students feel that their grades are fair [23]. Fairness in classroom assessment is a rich area of research [71]. One principle of assessment fairness is that when grading procedures are explained to students, they are more likely to perceive those procedures as fair [72], suggesting that students will perceive the CC method as fairer if they understand how it works. Another principle is that students' perception of fairness increases when they are given adequate feedback [73], as the CC method encourages. From the results outlined above, we can expect that the CC method's numeric bounds and grade scaling effect also influence students' perception of fairness. Regarding the former: it could be that numeric bounds of 0.80–1.05 leave too much room for point deduction for some students in some courses. If, for example, students are not explicitly taught technical communication in a dedicated course before being exposed to the CC method—the typical situation in this study—then a lower bound of 0.80 may seem like an unfair misalignment between "what is taught and what is assessed," as phrased by Tierney [71, pp. 134–135]. Raising the lower bound of the scale to promote a sense of fairness is in keeping with Philosophy 3, so long as enough points are in play for the method to remain motivating. As for the grade scaling effect—the manifestation of Philosophy 1—some instructors clearly dislike this core aspect of the CC method because they believe it creates resentment. If we accept Philosophy 1, then grade scaling represents a reality of professional work that students will benefit from being exposed to [74]. If instructors using the method explain this aspect of professional work to their students, it will hopefully help them to see its value and prevent them from resenting it.
3. Instructors must use the CC method in an agreed-upon, standard way to ensure that it is used consistently, in keeping with the fairness

TABLE VII
THREE COMMUNICATION PHILOSOPHIES AND THE WAYS IN WHICH THE CC METHOD CAPTURES THEM

Philosophy	CC Method Approach
1. The way that we communicate affects how others perceive our work. They perceive our work as more valid and useful when we communicate it well and less so when we communicate it poorly.	Scaling of technical content points based on communication quality to determine total score of assignments.
2. Individuals judge communication quality based on a host of personal factors, including their experiences, preferences, technical background, linguistic background, and membership in professional groups.	Instructors are given wide latitude in assessing communication quality based on their subjective judgement, mediated by a common framework of the general qualities of good communication.
3. Communication matters during all interpersonal interactions, to varying degrees.	The bounds of the CC can be adjusted based on the needs of specific classes and subject areas.

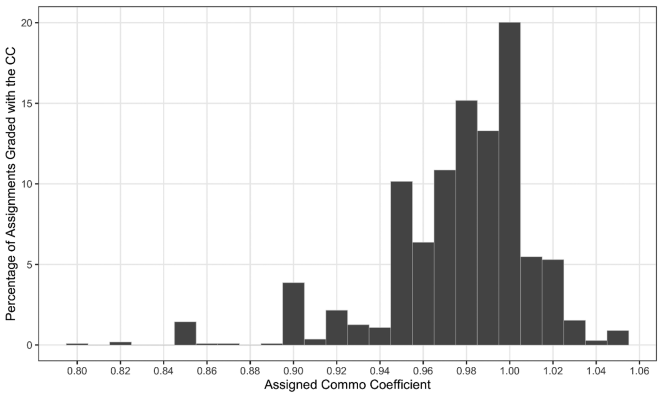


Fig. 5. Distribution of communication coefficients assigned by instructors.

principle of procedural justice described in the literature [73]. Philosophy 2 encourages instructors to rely on their subjective judgement when evaluating communication quality, but this subjectivity does not extend to the misapplications of the method outlined above. Such misapplications will compromise those "right circumstances" under which the method will be helpful.

These takeaways share a common theme: instructors must understand the CC method, use it properly, and convey it to their students so they understand it. It appears to be a method with the potential for good and harm, depending in large part on how instructors use it and explain it. The literature suggests that many instructors may resist the changes that using the CC method necessitates [75]. Understanding instructors' attitudes towards the method should help departments overcome this resistance, as will understanding the barriers and incentives in the improvement of teaching [76].

CC Score Analysis Fig. 5 shows the distribution of assigned CC scores. Of the over 1100 assignments graded with the CC method, 10% of them lost more than 5 percentage points from the CC and 2% lost more than 10 percentage points, roughly equivalent to one letter grade. Instructors kept their CC scores largely within the 0.95–1.05 range, meaning it was uncommon for the CC to substantially lower grades. It is not clear how much this result reflects the actual quality of the students' communication as represented in the rubric (see Table I) or a hesitance of instructors to lower their students' grades too much for poor communication. (Keep in mind that at least one instructor routinely assigned CC scores of 1.00 to circumvent the method.)

For completeness, students' CC scores were analyzed against their scores on standardized tests and in English classes to identify any correlations that might exist between their CC scores and these variables. Our analysis found low or no such correlations. This was expected: the CC method as employed in this study gauged quality of technical communication, which is not directly measured by these other variables.

Answering the Research Questions Given these findings, we answer the two research questions as follows.

RQ1. What should be sustained or improved about the CC method? The core elements of the CC method described in Situating the Case are valid and should be sustained. Under the right circumstances, the method can encourage students to pay more attention to their communication and encourage instructors to provide them with the feedback needed to improve without significant increases to their workload. That said, improvements to the method may be necessary to create the "right circumstances" described above. These improvements are rooted in its implementation

rather than its core design. First, the numeric bounds of the CC should be adjusted to encourage a sense of fairness while maintaining a motivating effect. And second, instructors must use the method properly and explain its motivation, mechanics, and philosophical underpinnings to their students.

RQ2. Is the CC method worth further experimentation in more classes and across more departments? Yes. The method has shown potential for good and its potential for harm may be mitigated or eliminated through the steps outlined above. The challenge of any further experimentation will be to fully define the "right circumstances" introduced above and to ensure that they are brought about.

Conclusion

The purpose of the CC method is to give students a realistic sense for the effects and importance of communication in the professional engineering workplace. It does this by capturing three "philosophies" of professional engineering communication, summarized in Table VII, and by making the effects of these philosophies apparent to students in their grades.

Our experience with the CC method suggests that it encourages good student communication. It also encourages instructors to offer the feedback necessary to help students improve their communication. Our experience also suggests that the method can appear punitive to both instructors and students, potentially discouraging the developmental environment it seeks to create. This perception may be mitigated through proper introduction of the method and by taking advantage of its flexibility.

"An ability to communicate effectively with a range of audiences" is among ABET's student outcomes [4], meaning engineering departments must demonstrate their focus on this outcome and their students' ability to communicate for accreditation. The CC method may provide a way for engineering departments to demonstrate their compliance with this outcome. It could do this by providing a consistent metric of communication ability used across a department and by documenting the parts of students' grades earned for technical content separately from those earned for communication ability.

In this article, we have explained the fundamentals of the CC method and a formal study conducted on it. The results of the study are encouraging, but follow-on work is necessary to determine how well the CC method fulfills the need that motivates it: to improve the communication skills of engineering graduates. This work must expand upon the narrow scope of this study: three classes in one department over one semester. It must also address several potential sources of bias in this study. First, the sampling of students was not random—there may be a correlation between a student's willingness to fill out the survey and that student's general opinion of new grading techniques like the CC method. Second, the CC method was evaluated for this study, in large part, by those who created the method, who may have a natural hesitance to criticize their own creation, a form of ownership bias [77]. And, finally, instructor surveys were conducted nonanonymously, potentially allowing interpersonal and intradepartmental social pressures to color their stated opinions: a form of social desirability bias [78].

We conclude with a question to be addressed in future work: Could the CC method motivate better student communication even if it does not impact student grades? Consider an alternate use of the CC method in which students still receive the feedback required by the method, including the "perceived" final grade resulting from grade scaling, but in which their actual final grade is not affected by the method. Research demonstrates that the presence of a grade can interfere with interpretation of instructor "descriptive" feedback [79], a primary element of the CC method, and several studies illustrate the sometimes-harmful effects of grades on student motivation [80]. Based on this research, it is possible that by detaching the method from grades, its virtues would be enhanced and its issues—including potential resentment among students—mitigated. An alternate, hybrid approach would involve detaching the CC method from grades for early assignments and applying it to later ones, thereby giving students a chance to get used to the method and the feedback of their instructor before their grades are affected. We suggest exploring these alternate means of employing the CC method as a next step in assessing its potential.

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