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Beginning to Understand Student Indicators of Metacognition

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Beginning to Understand Student Indicators of Metacognition

Abstract
Metacognition, defined as the knowledge and regulation of one's own cognitive processes, is critically important to student learning and particularly instrumental in problem-solving. Despite the importance of metacognition, much of the research has occurred in controlled research settings such that much less is known about how to help students develop metacognitive skills in classroom settings. Further, there are significant bodies of research on the role of metacognition in writing and solving math problems, but little work has been done on the role of metacognition within engineering disciplines. As part of a larger project to generate transferable tools that can be used to teach and evaluate undergraduate engineering students' metacognitive skills, we are developing metacognitive indicators that instructors can use to assess their students' metacognitive processes. We posit that these indicators will assist instructors in assessing if their students are engaging in the metacognition modules and assist them in talking to their students about their learning strategies in their class. The following question guided our analysis: How can we use a rubric as an indicator of metacognitive function based on applications to student artifacts from a metacognition intervention? To answer this question, we report on the development of these metacognitive indicators, which will take the form of an *indicator rubric*.

Introduction

Students struggle to accurately report and classify their own learning behaviors, (Van Hout-Wolters 2000, Schelling & Van Hout-Wolters 2011) which adversely affects their abilities to make sound learning decisions. To pragmatically address this gap in student abilities within a course context, we have developed metacognitive indicators that instructors can use to classify student self-reports about approaches to learning (metacognitive behavior) and aid instructors in giving meaningful feedback to students about the self-reported approaches to learning. These indicators function much like a speedometer in a car indicates speed; student responses to prompts are coded (like the speedometer needle) as demonstrating low, medium, or high functioning (like actual speed) for specific metacognitive dimensions. It is important to note that these indicators do not classify the student, but rather they classify the students' responses, i.e., the indicators are meant to provide feedback to students and to prompt them to examine their behavior more critically so they can make more accurate self-assessments of their learning processes.

We developed the metacognitive indicators as a component of an intervention to: 1) teach engineering students about metacognition, and 2) provide them opportunities to practice metacognitive skills. This intervention was designed to be used within existing engineering courses, but can be adapted to other contexts. Metacognition involves knowing about and regulating one's own cognitive processes (Flavel 1979, Brown 1987), and is foundational to being a skilled learner (Pintrich 2002, Veenman, et al. 2006) and to navigating solutions to complex ill-structured problems (Kuhn 2000, Jonassen 2012), such as those encountered in engineering practice. Our metacognitive indicators essentially form a rubric that assists instructors in translating student vernacular about learning and learning processes into the formal elements of metacognition.

The metacognitive indicators provide a tool to help instructors process student artifacts from the six modules in the intervention and suggest meaningful feedback instructors can give students and questions instructors may ask students to aid their metacognitive growth. While engineering instructors in higher education are content experts, they are generally less familiar with the formal construct metacognition and its critical role in learning. Therefore, the metacognitive indicators also provide a path for instructors to understand metacognition better while simultaneously yielding valuable information about what students are doing in their attempts to learn the content of their courses. The indicators enable conversations between instructors and students about learning processes where the instructors can respond and suggest specific ways of processing, thinking about, or using the content to learn it better or more efficiently. Instructors may well find themselves reflecting on their own learning experiences – in general and specifically within their area of expertise – which can provide powerful points of connection with their students.

The next section of the paper explores important background on metacognition and the intervention and situates the metacognitive indicators among the various assessment methods for metacognition. This is followed by a description of our methods for developing the indicators including manual and natural language processing approaches to coding, a presentation of indicators for two specific dimensions of metacognition and the results from applying them to pilot data, preliminary natural language processing results, and a discussion of the interpretation and implications of these results. The paper ends with a summary of results, limitations, and directions for future work.

Background

Drawing on current theories of metacognition, our conceptual model for metacognition (shown in Figure 1) includes the interacting and complementary elements of knowing about and regulating our thinking or cognition. We have described this model and the key elements in detail elsewhere (Cunningham, Matusovich, Hunter, & McCord, 2015; Cunningham, Morelock, & Matusovich, 2016; Williams, Morelock, Matusovich, & Cunningham, 2016).

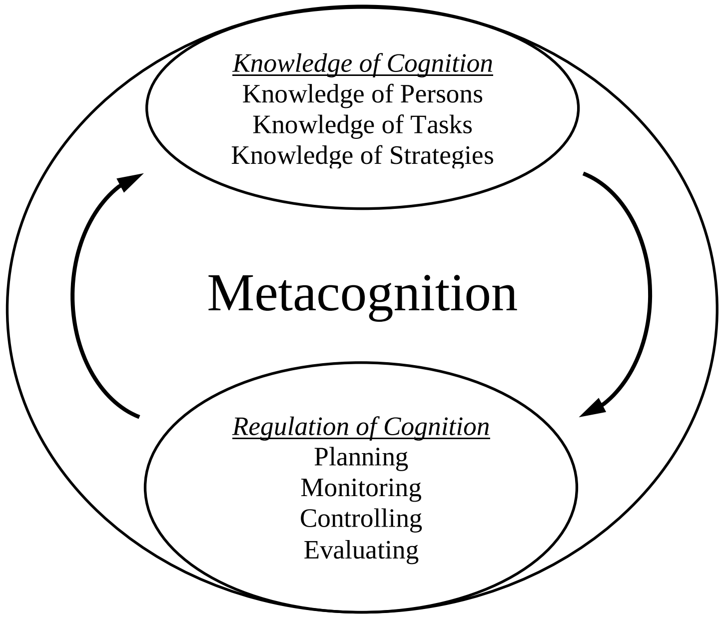

Figure 1: Conceptual Framework of Metacognition (reference removed for blind review)

General Assessment of Metacognition

Simply put, metacognition is difficult to measure or assess though not for lack of appropriate theory. Metacognition is studied directly as described by Veenman, Van Hout-Wolters, and Afflerbach (2006) or as a component of other frameworks such as self-regulated learning (Winne & Perry 2005), self-directed learning (Van Hout-Wolters 2000), and strategic learning (Weinstein, Husman, & Dierking 2005). Our brief review of current methods is informed by both of these perspectives as methods overlap between them. In particular, metacognition has been primarily assessed using questionnaires, such as the MSLQ (Garcia & Printrich 1995), oral interviews (Baker & Cerro 2000), think-aloud protocols (Pintrich, et al. 2000), direct observations (McCord, 2014), computer tools such as eye-movement registration and log file analysis (Veenman, et al. 2006). These various methods of assessing metacognition differ across a variety of dimensions; prominent among these are temporal proximity (online/offline), observer (self/outsider), specificity (aptitude/event), level of disruption (low/high), and required resources (low/high).

Questionnaires and oral interviews are offline measures, self-report instruments that require participants to recall a learning event or their general approaches to learning (aptitude). Self-reports are challenged due to poor correlation to performance or actual learning behavior (Schelling & Van Hout-Wolters 2011). Veenman (2005) goes on to assert that self-reports might represent individuals' knowledge of approaches to learning. However, these instruments still have practical utility (Schelling & Van Hout-Wolters 2011). This utility includes low disruption of the learning process, which enables them to be deployed within authentic learning contexts. Questionnaires require few resources to implement and process, while oral interviews require significantly more resources.

Veenman (2005) expresses preference for online metacognition assessment methods – such as think aloud protocols, direct observation, and computer tools – opposed to offline measures because of their predictive capability for student performance and the fact that they capture what students are actually doing in the moment. Think aloud protocols are still self-report, but are situated within a specific learning event. Direct observation and computer tools involve are still situated within a particular learning event, but are judged by outside observers, a person or computer.

As online measures, think aloud protocols and direct observations are moderately to highly disruptive to an individual's normal learning processes, in fact altering their processing. This disruption can also act as an intervention, which can distort the assessment. Both of these approaches require significant resources and often pull students out of their normal environment. One exception is direct observation of engineering students' study sessions in a natural setting, but this is still resource intensive (McCord & Matusovich 2013). Computer tools seem to ameliorate the unfavorable disruption and the level of resources needed, but to this point a limited range of tools have been developed, for example, in the context of reading comprehension (Schellings & Van Hout-Wolters 2011). Methods relying on external observation also suffer from the need to interpret or infer metacognitive thoughts and actions from specific behaviors, which may or may not be accurate, or that the metacognitive constructs assessed are limited to those few that are easily attributable (Van Hout-Wolters, 2000).

An additional challenge with all of the methods described herein is that such assessments for metacognition are generally for research purposes and in many cases are conducted in manufactured laboratory settings and on inauthentic problems. While helpful for developing our understanding of metacognition, its function, and its development, we need assessments that aid the metacognitive development of our students. While we have grounded our metacognitive indicators and their interpretations in current metacognitive assessment literature and practice, the indicators are designed specifically for aiding instructor judgements of student artifacts and prompting student self-reflection. In particular, we aim to prompt students to rarify their metacognitive knowledge and refine their practice of metacognitive skills within the context of a metacognitive intervention.

An Intervention for Teaching Metacognition

To teach students about the critical elements of metacognition (Figure 1), we designed a six-module intervention. As described elsewhere (Cunningham et al., 2015; Cunningham et al., 2016; Williams et al., 2016), each module includes a video operationalizing elements of metacognition within an engineering education context, reflection questions following the video, an in-class activity, and a post-class assignment. The videos are designed to be domain-general within engineering such that they do not focus on specific course content, i.e., they provide a general view of metacognition situated within a STEM higher education context. The activities are designed to be adaptable such that an instructor can make them course-specific. Table 1 shows the title and purpose of each module and correspondence with elements of the metacognition framework in Figure 1.

Table 1: Title and purpose of each of the six metacognition modules.

Module	Title	Purpose
1	What is metacognition and why should I care?	Introduce students to the metacognition framework and argues for importance of metacognitive knowledge and regulation
2	Knowing about Thinking (Knowledge of Cognition)	Focus on metacognitive knowledge of self, tasks and strategies
3	Reflecting on Our Thinking (Evaluation)	Introduce students to the idea of assessing a learning experience to determine what worked and what did not
4	Planning for Our Thinking (Planning)	Introduces students to the idea of focusing on tasks that are part of big project and part of important gorals rather than tasks that are distractions
5	Optimizing Our Thinking (Monitoring & Control)	Introduces students to monitoring and controlling their learning during a learning experience, operationalized through Kolb's experiential learning cycle.
6	Thinking Back and Thinking Ahead	Serves as a summary that asks students to reflect on topics from the prior weeks and think about how they can apply what they have learned going forward

Drawing on student submissions for multiple modules (as described in greater detail in the Methods), our goal was to create indicators faculty could use to gauge individual and collective class progress with regard to developing metacognitive skills. Similar to the video, the metacognitive indicator rubric is designed to be content domain-general such that it would not need significant revision to be useful across engineering contexts using the intervention. The metacognitive indicator rubric is tailored to the context of the metacognitive intervention.

In this paper we are primarily concerned with the development of the metacognitive indicator rubric and its use. Our guiding research question for this paper is:

How can we use a rubric as an indicator of metacognitive function based on applications to student artifacts from a metacognition intervention?

To answer this question, we used both manual rating of student submissions and Natural Language Processing (NLP) based textual data analytics. Our findings suggest both are promising approaches and that additional work should continue to test the function of the rubric from the instructor perspective.

Methods

We developed the metacognitive indicator rubric using assignments submitted by students as part of the modules described above. In accordance with our approved human subjects research protocols, we obtained consent to use student assignments at the end of the term after all assignments had been completed so that students would fully understand to what they were agreeing. Following the consenting process, we removed the assignments for students who had not consented and de-identified the remaining assignments for analysis.

Research Site and Participants

Participants for this study were second year engineering students enrolled in a problem-solving course at a small, predominantly undergraduate institution in the Midwest region of the United States. The students had engaged in the metacognition modules other than Module 5,which was not ready at the time. Approximately 50 students completed the modules as a modest part of the overall homework grade for the course. As with any homework assignment, not all students completed all module assignments.

Data Collection and Analysis

The first step in the analysis process was to identify a question from each assignment that exemplified the main purpose of each module. For the purpose of this paper, we will only provide discussion about two of the modules, Modules 1 and 3. We had 39 student responses for Module 1 where we analyzed the question that asked students to explain their primary learning strategy and talk about their expectations related to its effectiveness. We had 34 responses for Module 3 Where we analyzed the question that asked students to explain what they have been doing, in terms of learning strategies, since their last metacognition assignment and to explain how this new strategy helps them in becoming a more skilled and efficient learner.

We coded responses to each question using a priori codes (Patton 2002) based on our metacognition framework (i.e. knowledge of persons, tasks, and strategies, and regulation of cognition). Once we identified metacognition elements in each response, we ranked responses as "high", "medium", or "low". A "high" response answered the question, described their strategies clearly and provided concrete, demonstrable evidence to their claims. A "medium" response had a clear strategy description and weak evidence to support their claims. A "low" response had vague description of strategies and no evidence to support their claims. The details of the rankings and examples are presented as the Results.

Recognizing the intensity of manual labor associated with coding many responses, we also used Natural Language Processing (NLP) based textual data analytics, to gain insight on the choice of words and word pairs used by participants in each of the high, medium, and low metacognition levels. Following the manual coding, the student responses along with the researcher assigned high-medium-low labels were analyzed using textual data analytics technique by calculating the TF-IDF. TF-IDF, short for term frequency–inverse document frequency, is a numerical statistic. This type of approach has been used by researchers to reflect how important a word is to a document in a collection or corpus (e.g. Jegadeesh & Wu 2013, Murugesan & Zhang 011). For example, Sultana (2012), who used a modified TF-IDF based classification algorithm to detect “blog spam” – spam comments generated by automated engines on blog posts that support posting of comments. In another work, Vuotto (2015) used TF-IDF for semantic analysis of a collection of documents related to Psychology program to detect the level of professional ethics present in each document in their corpus. Finally, Ying (2015) used a variant TF-IDF approach to classify songs into different genres using the song lyrics as an input to their intelligent classification algorithm. We believe a TF-IDF approach serves as a check of manual coding but also offers a potentially faster way to code responses that could be useful for large classes in particular. The TF-IDF was computed by determining the relative frequency of words in a specific document, compared to the inverse proportion of that word over the entire document (Ramos 2003). This approach is used because it extracts certain words (such as articles) may have high frequency in a document, but comparing it to the inverse document frequency lowers the score assigned to often repeated words and levels the field for rare words which may be of greater interest.

Quality of the Research

To ensure the quality of the research, we used researcher triangulation and interrater reliability (Creswell 2008). For the former, two researchers coded the data and engaged in regular conversations with each other to establish the definitions for a priori codes and high/medium/low ratings. In cases of non-agreement, researchers discussed them and came to a singular ranking. For the later, we trained a third researcher in the application of the codes. This researcher then coded a subset of data independently and comparison yielded 100% agreement. As noted, the TF-IDF approach also serves as a form of a quality check.

Results

The metacognitive indicator rubric is designed to assist instructors in assessing how their students are engaging in the metacognition modules and in giving students specific and actionable feedback to improve their approaches to learning in their course. The metacognitive indicator rubric provides examples of student behavior in the students' own words (represented in aggregate rather than as direct quotes) categorized by level and metacognitive dimension. Note that the table represents aggregate responses to be more inclusive rather than representing single examples. Moreover, students consented to have their responses used in research but not as direct quotes. As students' progress through the modules, instructors will be able to track individual students' metacognitive growth and target their feedback accordingly, praising progress and appropriately challenging less effective approaches to learning. The metacognitive indicator rubric for Module 1 (Knowledge of Persons) and 3 (Regulation) is shown below in Table 2. This table aligns types of responses with the low, medium, and high categories, giving instructors examples of what to look for in student responses.

Table 2: Preliminary metacognitive indicator rubric with examples of student responses.

	Low	Medium	High
	Disconnected from question OR vague strategy with no or weak evidence.	Strategy named. Weak evidence, but attempt is made.	Clear strategy named. At least one piece of clear evidence (i.e. concrete, demonstrable, objective) for strategy attempted.
Knowledge of Persons Examples (39 responses total)	**Disconnected from question.** Responses include students feeling overwhelmed with their class loads. **Vague strategy.** Responses include phrases like: "getting work done on time", "always finishing homework", and "studying". **No/weak evidence for strategies**. Responses include phrases like: "it helps me learn" or "due to my high standards". Most responses in this ranking do not cite evidence for their strategies.	**Strategy named.** Responses include phrases like: "I schedule my time" or "I make lists of what I have to get done". **Weak evidence.** Responses include phrases like: "I feel that I am on top of my work", "I am more efficient with my time", or "I know how long things take".	**Clear strategy named.** Responses include phrases like: "I offer incentives for when I complete my work" or "I schedule my study/homework time in my planner". **One piece of clear evidence for strategy use (i.e. concrete, demonstrable, objective).** Responses include phrases like: "I timed myself so I know I am getting faster" or "I am more organized, I can find what I need in minutes".
	Total responses scored at this rating: 8	**Total responses scored at this rating: 20**	**Total responses scored at this rating: 11**
Evaluation Examples (39 responses total)	**Disconnected from question.** Responses include phrases like: "I don't plan much" or "I haven't implemented anything new". **Vague strategy.** Responses include phrases like: "doing homework", "studying", or "getting work done". **No/weak evidence.** Responses include phrases like: "it makes me faster" or "it makes me comfortable with the content". Most responses in this ranking do not cite evidence for their strategies.	**Strategy named.** Responses include phrases like: "I talk to my peers about what's happening in class", "I think about why I'm choosing an approach", and "I set up times to study before exams". **Weak evidence.** Responses include phrases like: "it helps me learn", I get everything done faster", and "it helps me understand the content".	**Clear strategy named.** Responses include phrases like: "I change the layout of past problems and imagine what [instructor] could ask to make it more difficult", "I bring up things I have gotten wrong in the past and think about why I got them wrong", and "I go talk to the professor after I have attempted the homework". **One piece of clear evidence for strategy use (i.e. concrete, demonstrable, objective).** Responses include phrases like: "I did better on the second exam", "I saw problems like the ones I made up on the next exam", and "I can explain concepts to my peers so they can solve new problems".
	Total responses scored at this rating: 8	**Total responses scored at this rating: 20**	**Total responses scored at this rating: 11**

As described in the Methods, we also examined some of the data using a TF-IDF approach to test the utility of such an approach. Table 2 shows the top 10 bigrams (combination of two simultaneous words), based on the 34 responses for Module 3. Each response had previously been categorized as: high, medium and low metacognition based on the strategies discussed in Table 1.

Table 3: Results from doing a TF-IDF analysis to highlight differences in word choices for responses characterized into each ranking.

High	Medium	Low
understand material	read note	look note
problem focus	help less stressed	look note class
specific topic	last minute	note class
good understanding	last minute thing	instead one
help learn	less stressed	earlier night
previous class	less stressed procrastination	earlier night often
solve problem	minute thing	homework earlier night
practice problem	minute thing help	not often
material also	stressed procrastination	work homework
understand material also	thing help	work homework earlier

As can be seen from the table, the choice of words seems to be representative of the assigned metacognitive category. For instance, "understand material" was the bigram with the highest TF-IDF score, based on responses categorized as high. Similarly, for medium category to Module 3, the terms "last minute" and "procrastination" seemed most popular as word choice used by students to describe their activity. Finally, for the low category words and phrases such as "look note" and "earlier night" seemed to be most used by the students. These preliminary results serve to indicate the word choices provide an idea about phrases and words that seem to characterize the vocabulary of the three different groups based on their metacognition.

Discussion

The design of the metacognitive indicator rubric attempts to mitigate the drawbacks of self-report offline measures and promote practical usability within the authentic learning context of a course. In self-report questionnaires there is often disconnect between students' reported behaviors and students' actual behaviors (Veenman, et al. 2006). To partially address this, the metacognitive indicator rubric is designed for application to student responses to prompts that are situated within the learning context of a course or even specific learning tasks in a course as suggested by Schelling and Van Hout-Wolters (2011). However, even if student responses are inaccurate, they are still useful. The responses at least represent student perceptions, which dictate their behavior choices. Once documented, responses (perceptions) can be available for examination and discussion – in particular, using the metacognitive indicator rubric feedback and prompts described here. This approach creates the opportunity for self-discovery of inconsistencies between what students say and do, which provides openings for correction and change. The design of the metacognitive indicator rubric is meant to make generating the critical feedback needed to develop metacognition efficient and accessible to engineering instructors, even without formal experience with metacognition.

Still, care must be exercised when using the metacognitive indicator rubric and providing feedback to students. The metacognitive indicator rubric evaluates **students' responses** to specific prompts within the metacognition intervention. The metacognitive indicator rubric does not evaluate students or their behavior. This is a critical distinction. Student omissions of strategies or clear evidence in their responses, evidence used to discriminate levels in the metacognitive indicator rubric, does not necessarily mean students are not using effective strategies or lack clear evidence. Similarly, naming strategies and evidence does not necessarily mean students use them. In other words, rating a student response as "low" in a particular metacognitive dimension does not necessarily imply the student exhibits low metacognitive function, and rating a student response as "high" does not guarantee the student exhibits high metacognitive function. Instead, the rubrics represent what students articulate that they are doing.

There are several possible explanations for mismatches between students' responses and students' actual behaviors. Students' perceptions may indeed be inaccurate. As noted earlier, students' response represent their perceptions of their learning behaviors, whether or not they are accurate. Veenman (2005) goes on to suggest that students' self-reports may only demonstrate student metacognitive knowledge, over-reporting their behaviors. Students may also over-report their learning behaviors by a desire to provide "correct" answers. The condition of under-reported learning behaviors is also possible. Even with contextualized prompts, students may omit relevant behaviors (Cunningham, et al. 2016). Students may lack knowledge of how they learn or of suitable strategies for the specified context, known as *availability deficiency* (Veenman, Kok, & Blöte 2005). Alternately, students may possess such knowledge, but fail to apply it to the specified context, known as *production deficiency* (Veenman, Kok, & Blöte 2005). It may also be that students possess such knowledge, but choose not to apply it (Veenman, Van Hout-Wolters, Afflerbach 2006). Students can also be poor writers in general or choose not to fully engage in the metacognition intervention causing their responses to be scored lower than their actual ability or behavior. In summary, students may fail to articulate their behaviors because they lack ability, fail to transfer or produce behaviors in the present context, choose not to use certain behaviors, or choose not to fully engage in the metacognition intervention.

Based on challenges associated with assessing metacognition, it might seem difficult to know what students are actually learning and how they are adapting their learning processes. However, there is still much to gain by using the metacognitive indicator rubric, imperfect as it is. Within the metacognitive intervention, the feedback and prompts generated by evaluating student responses with the metacognitive indicator rubric start a dialogue. This may be an internal dialogue a student has with themselves or it may be with peers or their engineering educators. Regardless, this dialog enables students to articulate and critically examine their perceptions of their learning behavior. The metacognitive indicator rubric is not for researching metacognition, but rather a tool, accessible to engineering educators, for promoting student metacognitive development.

So, what value comes from implementing the metacognitive indicator rubric or how can it best be used? We have identified four possible values/uses: 1) students may need training to develop and cite clear evidence, 2) how feedback is delivered matters, 3) the need for feedback questions for low/medium/high rated student responses, and 4) there may be ways to develop coding processes using Natural Language Processing (NLP) to increase efficiency and utility.

Developing and Citing Clear Evidence

Most student responses for Knowledge of Persons and Evaluation were coded at the medium level because students cited weak evidence. Weak evidence was defined as subjective, unmeasurable, or not measured. This is in contrast to the definition of clear evidence, which is concrete, demonstrable (or measurable), and objective, required for a high level rating. At the medium level students might say something like, "it helps me learn," without providing demonstrable evidence for how they determined it helped them learn or, "I get everything done faster," without reporting a quantified result, though faster could be measured. This weak evidence does not need to imply that such students do not have more concrete evidence. As noted earlier, there are a variety of reasons students did not cite stronger evidence. It may be necessary to clarify expectations within the prompts students are responding to, or it may be necessary to train students to identify clear evidence and then practice citing it. This may be fundamental to helping students develop their metacognitive skill because students' metacognitive monitoring accuracy has been shown to be fundamental to performance-based course outcomes (Nietfeld, et al. 2006). Students make learning choices based on their perceptions, regardless of their accuracy. Therefore, more accurate perceptions should lead to better learning choices (Winne and Perry 2005). The metacognitive indicator rubrics could be used as tools in training students to develop and cite clear evidence.

Feedback Matters

Simply stated, the way we give feedback matters. When using the metacognitive indicator rubric to assess student responses, we must avoid evaluating students or applying labels on them, which students may view as fixed. Instead, feedback should be given in a way that acknowledges its limitations, such as, "Your response indicated (low/med/high) knowledge of persons." Feedback to students should also include exploratory questions promoting them to critique the validity of their responses and encouraging them to expand their thinking. All feedback derived from the metacognitive indicator rubric should be authentically affirm a growth mindset – the belief that students' abilities can be developed with persistence and effort (Dweck 2016). The metacognitive indicator rubric is designed to facilitate conversation (as noted above with regard to developing and citing clear evidence) rather than applying labels to students or behaviors.

We cannot help students develop and believe they can develop their metacognitive skills if we do not sincerely believe they can. This is not empty praise, rather it is helping students connect their effort and strategy use to outcomes (Dweck 2016). In the context of the metacognitive indicator rubric, this means being forthright about a response receiving a "low" rating, but not assuming the student is deficient. Rather, ask questions to help them explore if they are actually doing more than they thought they were and suggest alternative strategies and/or evidence to support their growth. Likewise, if a student response receives a "high" rating, it means praising their effort and clear evidence of their outcome, and then continuing on to prompt them to consider strategies and measures that can further improve their learning effectiveness and efficiency. In all cases, students can develop their metacognitive skills, and we can help them with encouragement and honest feedback.

Example Feedback Questions

As part of the dialogs we hope the metacognitive indicator rubrics promote with students, we recognize a need to help instructs with prompts for such conversations. Specifically with regard to helping students develop. Therefore, we suggest questions for prompting students at each rating level: low, medium, and high. As noted earlier, these questions should help students explore the validity of their responses and encourage them to expand their thinking. Consider the examples in Table 4. Each example feedback in the table seeks to affirm good things while continuing to prompt further growth and thinking about their learning processes.

Table 4: Example feedback questions.

Low – Evaluation I haven't implemented anything new.	**Exploring** Okay. What different ways do you work with class concepts? (for example, working homework problems, making up and solving problems, explaining course concepts to someone else) **Expanding** What do you think would happen if you added short daily recall and review or asking and solving what-if scenarios on example problems to your study time?
Medium – Knowledge of Persons I schedule my time. It helps me feel that I am on top of my work.	**Exploring** Great! Keeping a schedule is important. What does it mean to you to be on top of your work? (for example, adequate sleep, time to relax, or no late assignments) **Expanding** How do you handle overlapping tasks, such as two assignments due on the same day or two exams on the same day? Do you plan ahead for such circumstances? How?
High – Evaluation I make up problems and ask how it could be more difficult. I know it is working because I did better on the second exam.	**Exploring** Terrific strategy I am sure it helped you improve your exam performance. What other things did you do to study for the exam? When or how often do you make up problems while you study for this course? **Expanding** What other ways could you use to check your level of understanding of course concepts and your long term retention of course concepts?

NLP
Finally, the metacognitive indicator rubric has value for future research. Our first attempt at analyzing data using NLP demonstrated promise. Even on a small sample, the algorithm yielded unique words/pairs of words that fit each rating level. As described in the Future Work section, more work is needed to fully yield the promise of the NLP approach to facilitate what may seem like a labor-intensive instructional tool.

Conclusions, Limitations, and Future Work

In conclusion, we believe we have developed an approach instructors can use to examine student's metacognition. Like other means of assessing metacognition, our approach is not perfect. Specifically, our approach is still limited to being a self-report measure. However, different than existing measures, is it an online approach developed in common student vernacular rather than the more sterile words propagated through theory. Instructors can use our metacognitive indicator rubric to rate student responses and then engage in dialog with students about metacognition and how to further develop and apply metacognitive skills.

Clearly there is room for continued development. Our immediate plans are to test and refine the metacognitive indicator rubric using student data from a second implementation. We then plan to work with instructors on further refinement to ensure the utility and ease-of-use of the metacognitive indicator rubric.

With a refined metacognitive indicator rubric, we also plan to continue our work using NLP. We believe a next step in this area is to incorporate machine learning such that the algorithm could be trained on a set of coded responses and then it could be used to code a larger quantity of responses. By also identifying key words and phrases, the algorithm would still enable the instructor to identify the type of feedback needed by each student. NLP and machine learning would just streamline the process.

We also believe the metacognitive indicator rubric could be a launching point for additional work with students on how to develop and cite clear (concrete, demonstrable, and objective) evidence when making arguments. Although important for students to learn, it can be challenging for them to understand what clear evidence looks like. The metacognitive indicator rubric offers examples and by incorporating discussions throughout the modules, opportunities for practice.

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