The Utilization of Metacognitive and Sensemaking Strategies to Deepen Ethical Thinking in Engineering

Ethics in Engineering IQP Project Report

By

Brian Moore, Kimberly Stanway, Joshua DeNoncour

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Submitted to

Professor Geoffrey Pfeifer, PhD

Professor Kristen Billiar, PhD

Abstract

In engineering institutions, students are accommodated in learning preferences that are not analogous to the problem solving methods necessary for deeper consideration into ethical issues outside of humanities or ethics classes. This project tackled the issue of "engineer-ization", the technical and structured style of analysis favored by engineering students, by using metacognitive (thinking about how one thinks) learning tools to promote reflection and a deeper awareness into ethical issues by slowing down and expanding the thought process of students uninitiated with the difficult subject of discussing and reflecting on ethical issues. The qualitative and quantitative results of the three-phase metacognition module developed in this project showed that many students were able to more clearly identify their biases and the stakeholders involved in ethical case studies by using the metacognitive tools in conjunction with an in-class presentation. Specifically, the student responses from the exam wrapper style of assignment had the most profound results in prompting emotional engagement, and allowing students to make connections to and build their perspectives towards the ethical material posed within the modules' case studies. An exam wrapper type of assignment has potential to be implementable across the curriculum of engineering, without requiring significant training for faculty members to use and understand, fostering more desirable ethical learning outcomes for students.

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Executive Summary

Introduction: An engineer's education must not reflect just the techniques and theory of their discipline but other valuable social skills, including ethical problem solving. However, engineers look at technical knowledge as "engineering" and the discussion of ethics is neglected which can result in failures due to engineers not understanding the impact of their work on all stakeholders and environments associated with their products and services. In past project work at Worcester Polytechnic Institute, engineering students routinely cite cost or technical factors as the most important consideration in a design problem, instead of human health or safety, or a number of other possible ethical concerns associated with their work. This issue of engineering students conducting technical analyses of issues following linear thought patterns, weighing the pros and cons and the costs and benefits of potential solutions, and applying these same methods to ethical issues can be referred to as the "engineer-ization" of ethical decision making. This project addresses this issue by teaching an ethics module emphasizing the metacognition of learning, with the intent to build student's principles, increase emotional investment, and expand their scope of reasoning in ethical evaluation through exploring the complexities of the problem-solving thought process.

Methodology: The methodology developed in this project was a three phase module which focused on three different metacognitive tools which promoted reassessment of the problem solving approach, breaking up the linearity of thought process, and showing the interrelation between knowledge attitude and behavior in problem solving. The first phase of the module worked by introducing material to students in a preliminary case study assignment without specifically prompting students to talk about ethics, followed by a confidence survey. The second phase consisted of students completing an exam wrapper assignment which prompted reflection into their perspectives and how they would approach future problems, as well as introducing students to appropriate background material on metacognition and

ethics. An in-class presentation about metacognition followed afterwards, explaining how the tools explored in the project functioned to deepen student learning. The third and final phase had students revisit the same case study, this time specifically posing it as an ethical assignment and recording how student responses changed after using metacognitive learning techniques, followed by a final confidence survey.

Results: Various issues with implementation and student displeasure with the repetitive nature of the module resulted in mixed a wide variety of case study responses. The CE 4071 Land Use and Development module procured the most thoughtful responses and consideration of ethical issues was more prominent after the completion of the module in case study 2 responses. Overall Students scored highest in problem identification regardless of the class the module was implemented in. 110 pre-survey results and 46 post survey results were gathered from students.

Discussion: Upon analyzing all case study responses there is no definitive trend in the increase of quality of ethical consideration in student responses. However, considering only the CE 4071 responses, there is indication that the module could have resulted in increased quality of ethical consideration when analyzing engineering problems. Across classes, students scored highest in problem identification and responses often demonstrated a level of engineerization. In the qualitative analysis of the exam wrapper responses, it was observed that students were able to make thoughtful connections to their perspective and how it impacted decision making, with some students voicing favorability for future use of the module materials. Quantitative analysis showed no significant change in student averages in regards to ethics. Although the data was not able to be proven statistically significant, but this may be due to a false sense of confidence that students have from the superficial teaching of ethics they have received. It was observed that a number of student's confidence levels decreased as the module progressed.

Recommendations: In continued pursuit of using metacognitive tools as a means of deeping ethical learning for engineering students, a key area of improvement identified in this project was to ask the right

questions when surveying students. Student confidence was not the correct metric to analyze student responses on, as building confidence was not the goal of this project. In addition to asking the right questions, it is imperative for students completing these modules to understand the importance of continued ethical learning. The use of joint-venture style presentations with professional ethics speakers could help with this issue, as it has been shown in previous iterations of this project to be an effective means of presenting ethical content to students, by incorporating the two it may produce more thoughtful student responses in the future. For future research, increasing the scale of the study, possibly going outside of engineering classes, and incorporating more use of the metacognitive tools over the entire course of a term could give better insight into the efficacy of using metacognitive and sensemaking techniques.

Conclusion: Engineering students unfamiliarized with ethical learning often use technical problem solving methods which are not analogous to the problem solving methods used in ethics classes which are necessary for deeper consideration into ethical issues. The qualitative and quantitative results of the three-phase metacognition module showed that many students were able to more clearly identify their biases and the stakeholders involved in ethical case studies by using the metacognitive tools in conjunction with an in-class presentation. Specifically, the student responses from the exam wrapper style of assignment had the most profound results in prompting students to make deeper connections to the ethical material posed within the case studies.

I. Introduction

As the various fields of engineering continue to grow the education that an engineer is imparted with must not just reflect the techniques and theory of their discipline but other valuable social skills. Because companies demand that engineers enter the workforce with more than just the technical competency of a baccalaureate degree, institutions have been challenged with accompanying said technical competency of students with leadership skills, verbal communication skills, ability to work in teams, and ethical competence (Magun-Jackson, 2004 Koncz et al, 2017). Moreover, for engineering institutions the Accreditation Board for Engineering and Technology (ABET) also requires engineering curricula to reflect in their students professional and ethical responsibility (ABET, 2017). As such, thousands of newly educated engineers every year must be able to address and distinguish ethical issues within their prospective professions (Brightman et al, 2016). In general, engineers look at technical knowledge as "engineering" and the discussion of ethics is neglected which can result in failures due to engineers not understanding the impact of their work on all stakeholders and environments associated with their products and services (Schmidt, 2013). With this neglect of connecting ethics within engineering, it is found that many institutions do not have sufficient ethics integration into their engineering curricula (Magun-Jackson, 2004). Furthermore, education for ethics in engineering is not taught broadly and methodologies are confined to singular institutions, where these institutions or professors adopt their own principles abstract from what others teach. These issues call for the need of an effective widely usable methodology to teach and engage students on what it means to become an ethical engineer (Brightman et al, 2016).

Currently, there are many issues with integrating ethics education into engineering schools. Engineers pride themselves on being problem solvers; they are adept at identifying the nature of a

technical issue and conducting analyses to produce an optimized solution. Often such analyses follow a linear thought pattern as engineers weigh the pros and cons and the costs and benefits of potential solutions. Such linear and technical thinking is also often applied to ethical decision making regarding engineering solutions and can be referred to as the "engineer-ization" of ethical decision making. Both faculty members as well as students have strict preferences for these technical learning models which are not necessarily complementary to non-technical learning (Newberry, 2004). Furthermore, students and professors can see non-technical material as distracting when working within time constraints. Students also can perceive ethics material as less important as it is usually given inconsequential grading criteria or none at all (Colby, 2008). This tendency causes students to fall short in areas of emotional engagement such as inspiration and desire that are critical for deepening ethical thinking and encouraging future ethical consideration (Newberry, 2004).

This project takes the education of ethics to its logical beginning in challenging the engineer to reflect on what they consider ethical, what factors cause them to feel the way they do, and what issues are that constitute ethical dilemmas. The module implemented is intended to prompt students to utilize metacognitive tools in their day-to-day lives as a way of understanding the roots of their perspectives. By teaching an ethics module emphasizing the metacognition of learning, this project seeks to build student's principles, increase emotional investment, and expand their scope of reasoning in ethical evaluation through exploring the complexities of the problem-solving thought process. Metacognition has been classically defined as "thinking about thinking" and involves awareness and control of the thought process we use when making decisions. Metacognitive strategies promote general awareness of the observations, decision making, and thought processes required in pursuit of understanding engineering (Seraphin, 2012). A metacognitive approach to teaching ethics can condition students to better see the uncertainty and complexity of knowledge surrounding ethics and their applications to everyday engineering decisions. By encouraging more self-awareness of approach and perspective in ethical

thinking, metacognition can be implemented as an instructive tool to teach students how to identify and address the thought process required to adequately form ethical opinions in not only professional work settings, but in everyday life.

II. Background

Importance of Ethics

In society, specifically technologically developed democracies, people place trust in engineers to develop safe and effective products. In the development of said products, ethical behavior must be exercised to ensure the safe production of goods (Whitbeck, 2011). Ethics can be considered the study of "morality." More specifically, ethics is the discussion of morally evaluating persons or institutions in their actions as being good or bad, fair or unfair, just or unjust and so on. Being aware of the ethical importance of problems is the first step in responding effectively to them (Whitbeck, 2011). The skillset of ethical awareness has become increasingly important in the field of engineering, significant decisions by engineers are made based on what is presumed best for themselves and their employers, and what is considered morally favorable for all stakeholders (Magun-Jackson, 2004). These decisions become increasingly important as a moral grey area emerges in developing fields of bionanotechnology, sustainable manufacturing, human enhancement devices, smart warfare technology, and other fields with issues such as using robotic soldiers, or isolating and expressing desired genes in early development of fetuses, where public perception is not well developed, along with ethical codes not yet being clearly defined for professionals (Brightman et al, 2014). With these complex issues entering the sphere of engineering, it is important for workers to be equipped for ethical decision making in both existing and developing fields. By preparing engineering students to understand and reflect upon the significance of ethical implications of their fields, they will be better prepared to identify and resolve problems that engineers commonly face in profession (Whitbeck, 2011). As such, the accrediting agency ABET, under the Engineering Technology Accreditation Commission (ETAC) and the Engineering Accreditation Commission (EAC), requires post-secondary institutions to incorporate ethics training and education to

their engineering students (ABET, 2017). The descriptions for such requirements outline student outcomes that graduates of the programs in question must be able to demonstrate at the end of their respective programs. The actual language describing the ethical requirements is vague; because of minimal strict requirements in this area it is up to the individual engineering program to demonstrate proficiency of instruction in ethics and can be approached in a variety of different ways.

Engineers are commonly required to be familiar with ethical codes and standards that govern their work. Printed editions of the International Building Code (ICC 2012), or codes designated by the American Society of Civil Engineers (ASCE 2006), can contain upwards of 4000 pages of printed rules and responsibilities regarding professional ethics (Schmidt, 2014). Since it is unrealistic for engineers to be well versed in all the responsibilities such a doctrine of their profession may require, a general education of ethics can suffice to give engineers competency to navigate through ethical decisions with a general understanding of their profession's ethical requirements. Furthermore, because the monotony of these previously mentioned ethical codes and standards may be off-putting, engineers can become disinterested in learning ethics (Schmidt, 2014). This problem is not isolated to professional engineers, and can be found even within student written reports. Review of senior project reports of students at Worcester Polytechnic Institute (WPI) produced statements claiming that social political and ethical concerns were not relevant because the project did not involve human testing or controversial topics (Yamajala 2013). Other projects stated similar thoughts, claiming that there were little to no ethical concerns in projects such as designing a viral reduction system for FDA approval in fibrin sutures (McConnaghy 2017), or evaluating the commercial pathway of emerging cardiac patch technology (Maiola 2018). This unimportance felt by students in academia is not uncommon, but a proper ethics education using realistic examples can help students make connections and expand their perspectives of the ethical implications of their professions and how to approach them without the use of exhausting professional conduct literature (Schmidt, 2014).

Metacognition

In previous years, the IQP teams that precede our project focused largely on ethical analysis and education of ethical theories as a way of deepening ethical thinking. While these IQPs developed effective means of prompting thought and discussion in their own way, our IQP seeks to utilize metacognition, sensemaking, and reflection as tools to encourage self-awareness of one's own perspective and the impact an individual's thought process can have on problem solving and their ethical self-awareness. Metacognition, defined as the "selection and monitoring processes, as well as to more general activities of reflecting on and directing one's own thinking,", can be applied to scientific and engineering practices to aid students and professionals in the development of self-awareness and competency in the identification of ethical questions in everyday decisions (Pellegrino, Chudowsky, Glaser, 2001). By practicing metacognitive techniques an individual can become more well versed in the limitations of their perspective and problem-solving approach and become a more effective problem finder rather than problem solver. The shift in focus from a solution-based approach to a problem-based approach is especially important when considering the identification of ethical engineering questions.

To effectively employ metacognitive techniques one must be aware of one's own capabilities as well be able to reflect on techniques and strategies employed in problem solving to evaluate progress (Pellegrino et. al, 2001). By integrating reflection and other metacognitive strategies into the engineering process an engineer may generate problems, questions, and perspectives that would not have been previously considered and garner a greater understanding of how one thinks and approaches problems so as to better self-evaluate progress and growth and ultimately better understand and identify the ethical implications of engineering decisions.

Metacognitive Methods, Frameworks, And Tools

Sensemaking and Metacognition

Sensemaking in a metacognitive context is an exercise in recovering the understanding of a query or situation following the introduction of critical information that forces the individual to doubt prior understanding (Hutton, Klein, Wiggins, 2008). The Sensemaking Critical Incident Method (SCIM), a derivative of the Critical Decision Method (CDM), focuses on not only drawing conclusions from known data, but also encourages the individual to seek out new data to elaborate upon inquiry and assess the implications and importance of new understandings of information already analyzed (Hutton et. al, 2008). By encouraging the expansion of individual perspective and reevaluation of conclusions sensemaking promotes metacognition through reflection. Sensemaking also allows an individual to practice reevaluation of behaviors and attitudes as knowledge changes and can be applied very easily to ethical engineering problems. In an ethical engineering problem exercise the introduction of critical information on impacts of engineering decisions can assist professionals and students alike in reevaluating decisions through different perspectives.

A study published in the *Journal of Science and Engineering Ethics* applied sensemaking techniques to ethics training in the physical science and engineering with promising results. The study conducted ten modules over two days administered to forty-two research center members and focused on cultivating the integrity of the professional through the use of broad metacognitive reasoning strategies (Kligyte et. al 2008). The modules included a variety of activities including discussions, individual and group work on case studies, role play, and assignments completed both in and out of scheduled instruction time. The implications of this study indicated that such instruction in sensemaking and metacognitive techniques may be adapted to fit a wide variety of programs and can provide valuable skills and techniques for approaching ethical problems.

Assignment Wrappers

Assignment wrappers as metacognitive tools are used often as an exercise for students to apply to graded assignments to encourage reflection on study habits and attitudes. An assignment wrapper usually poses three kinds of questions to a student to prompt reflection. These question focus on how students prepared for and approached the assignment, the errors a student made on the assignment and areas for potential improvement, and how students can approach and prepare for future assignments (Kaplan, Silver, LaVaque-Manty, Meizlish, 2013). In order to be effective assignment wrappers must be easy to complete, repeatable, flexible, and exercise the skills hoping to be developed. Assignment wrappers are utilized using five steps. Step one: the wrapper is prepared and the assignment is completed prior to wrapper distribution. Step two: the wrapper is distributed to students with a graded assignment that will be the focus of the reflection. Step three: the wrapper is collected to be handed back later. Step four: The completed wrapper is returned to the students while the students should be preparing and completing the next assignment (Kaplan et. al, 2013). The goal of an assignment wrapper is to provide students with an outline for metacognitive reflection and can be adapted to fit within almost any class and to fit a variety of subjects. Because of their adaptable nature, assignment wrappers can prove to be a useful tool to improve metacognitive reflection in the realm of engineering ethics alongside other tools and assignments such as the TSI method and case studies.

Understanding Metacognition through the KAB Framework

The Knowledge, Attitude, and Behavior framework as an approach to understanding metacognition is based on the acknowledgement that knowledge influences attitudes and behaviors of an individual, attitudes can influence behaviors and the seeking out of new knowledge, and behaviors can in

turn influence the knowledge available to the individual and the individual's attitude in approaching new concepts (Cardella & Purzer, 2014). The KAB framework emphasizes the importance of assessing changes in behavior and attitude as well as knowledge. In an engineering context, employing the KAB framework to assess understanding and identification of ethical issues in engineering would promote reflection and metacognition again by encouraging professionals and students to understand the limitations of one's perspective and understand the influence of changes in knowledge, behavior, and attitude in problem solving situations.

Teaching Science through Inquiry and Mind Maps as Metacognitive Tools

The Teaching Science as Inquiry (TSI) approach to science and engineering education can be implemented through applying metacognitive techniques to the five phases of the TSI model; initiation, invention, investigation, interpretation, and instruction (Seraphin, Philippoff, Kaupp, Vallin, 2012). The TSI philosophy recognizes the nonlinear nature and multiple stages of scientific inquiry through which scientists seek new knowledge. Each phase of the TSI model can be defined as follows:

- Initiation: Interest is developed and the focus for inquiry is determined
- Invention: Problem solving and information gathering occur in the form of creating testable hypotheses, design of experiments, etc
- Investigation: The garnering of new knowledge and information
- Interpretation: The information gathered in the investigation phase is interpreted to determine impact and value
- Instruction: Occurs during each phase. Communication between student and professor and student to other students.

One study published in *Science Education International* linked TSI and metacognition and employed TSI diagrams in a professional development course to be used by teaching professionals and

then their students to understand how individuals work through scientific inquiry. The students and teachers drew lines between the different phases of the TSI model (example below) to communicate their individual problem-solving approaches (Kaupp et. al). Such “mind maps” allow for student progress in approaching scientific inquiry to be monitored and for students to visualize metacognitive reflection through physically viewing their thought processes on paper. The results of this study noted the difficulties associated with trying to help students think about how they think, but also noted the value the participating teaching professionals placed on the exercise as a teaching tool and cited repetition as an effective means of improving understanding of metacognition in science (Kaupp et. al, 2012). TSI model ”mind maps”, as seen in this study, could prove to be a valuable tool in introducing students to the process of metacognitive reflection and are versatile enough to be potentially implemented alongside other teaching tools, such as case studies.

The promotion of reflective engagement in science through the TSI model provides perfect context for ethical problems. By exploring scientific and engineering problems through inquiry and monitoring the problem solving process and approach one can better assess limitations of perspective and consider ethical questions that may have once been beyond scope of the individual's understanding.

Inadequacy and Constraints

Currently, the existing ethics infrastructure in many institutions is not to have ethics presented as part of engineering curriculum, rather it is taught separately as stand-alone philosophy or ethics courses part of a humanities requirement or supplemented by using outside professionals as guest lecturers (Lynch 1997). The limited and episodic nature of using guest lecturers sets the precedent for students that ethics is still disconnected from engineering (Lincourt et al, 2004).

Within technical institutions, outside of humanities and ethics courses, there is a tendency to the "engineer-ization" of ethics training where in accommodating the learning preferences of engineering students, ethical decision making is often conducted using rational scientific methods including decision matrices, and flowcharts to quantitatively rank approaches as most ethical to least ethical (Newberry, 2014). The primary issue with this tendency of teaching ethics is that non-technical knowledge isn't always complementary to technical learning strategies, and this may further exacerbate the tendency for students to understand ethics in a superficial sense, or to completely misunderstand how to apply ethical decision making in a practical work environment (Newberry, 2004).

When teaching ethics to engineering students, they can assimilate material regarding ethical theories very well in terms of intellectual engagement and particular knowledge (learning facts and how they are applied), but fall short in areas of emotional engagement such as inspiration and desire that would drive them to have more than just a superficial response to practicing ethics (Newberry 2004). Furthermore, the academic structuring in engineering curricula create a large gravitational effect that pulls students and faculty towards the preference for technical knowledge, and the large amount of it leaves little space for other subjects (Newberry, 2004). With little time for incorporating anything that lies outside the realm of technical learning, the very act of squeezing in non technical subject matter becomes difficult and can be seen as distracting from the core curricula (Newberry, 2004). When ethics content is

included in the curriculum, it is often not graded, or given less importance in grading criteria which indicates to students that the ethics material is less important than the technical material (Colby, 2008).

Many engineering faculty do not have the background necessary to prepare students to engage into the discussion of ethics, and most post secondary institutions lack incentives for faculty members to develop this background knowledge (Newberry, 2004). Some faculty do not recognize the importance of such an ethics education and will resist the implementation of those classes (Sockell, 2013). This problem of lack of faculty expertise is compounded by the need for ethics training under ABET's accreditation requirements, where teachers may be forced to create an ethics curriculum without sufficient knowledge of what ethics is or how to teach it (Newberry 2004). The result of this can be a superficial understanding of ethics being imposed on students that creates disinterest or further cements disbelief in ethics pertaining to engineering (Colby, 2008). In light of this, some engineering faculty members perceive the work involved in ethics modules and courses as ultimately subjective and personal, so they are challenged by the prospect of establishing standards of quality against which it can be assessed (Colby, 2008). It is however, possible to achieve this, as it has been routinely done in humanities courses where professors use guidelines to strengthen their students writing and presentation skills (Colby, 2008).

At WPI in particular there are several constraints on teaching ethics. WPI runs on a four-term schedule rather than a two semester schedule, meaning all classes are only seven weeks long. This short class length means that any time taken out of a lesson plan to allocate to ethics education has a far greater impact on the course than on the same course if taught in a semester long time frame.

On top of the short terms, WPI's lack of a concrete ethics requirement compounds the problem. WPI curriculum does not require all students to take any form of ethics course over their four years at the school. This leaves it to individual professors to include ethics material in their lectures. Another shortcoming of WPI's lack of ethics curriculum is the lack of structure for what ethics a student will learn by the time they graduate. Many professors will only review ethics related to their course briefly, without

going in depth about the theories or reasoning behind the ethics (Colby, 2008). This leads to students only knowing how to resolve ethical dilemmas without being able to identify, or freely consider the ethical dilemma using their own moral code. Students do not develop a complete ethical education, but rather a haphazard knowledge of ethics (Colby, 2008). Arising out of these constraints is the need for an effective methodology usable for both faculty and students that slows down and deepens the thinking process, more closely emulating the nature of problem solving students are exposed to in an ethics classroom setting.

Strategies and Methods

Many different methods have been implemented in educational institutions through the years to teach ethics including surveys, written course assignments, student reflection, and group activities (Cochran and Weaver, 2017). Surveys were used more as a feedback tool rather than as an actual method of teaching. Such surveys provided critical information about the material the students learned during a study. These studies found that a combination of different methods was the most successful (Doorn and Kroesen, 2013). More specifically, a module of in class and out of class activities spanning more than just a single lecture time was the most successful method (Springer and Stanne, 1999). Integrating this modular option has proven to be an effective way of bringing ethics into an engineering classroom which promotes discussion between students (Lynch 1997). The modular option of teaching ethics can bring a classroom closer to real ethics education without the need of a stand-alone philosophy or ethics course and avoids using outside professionals to teach ethics to engineers. For this project several different methods were considered, including the joint venture style method used in a previous IQP (Rogers et al, 2015), an online approach using pre-recorded videos recorded by ethics professionals (Renshaw et al, 2016), and the case study method used by the 2014 iteration of this IQP project.

Case study method

In the case study method students are given a case study and asked to analyze the situation as well as provide what they believe to be the solution to the ethical issue. Students then discuss and debate as a class to be exposed to other viewpoints and schools of thought they may not have considered when evaluating the problem on their own. A second assignment is then given, where the student is asked to analyze a case study and argue an opposing viewpoint to the one presented in the first case study response. This method provides the student with an opportunity to experience a more neutral perspective of the dilemma (Reyer et al, 2014). This method is easily adaptable for a variety of subjects and fields. Pre-existing case studies are widely available on the internet or at a local source of scholarly material, allowing for quick and easy production of a lesson plan and its materials. Although the case study method is widely used, it may not be the best method for this situation because it is rather cut and dry, and normally requires a large amount of in-class time to utilize its full potential. In addition, case studies do not always allow a reader to draw conclusions, as some biased information can be introduced in the writing of a case study.

Video method

The video method involves students being assigned several videos to watch outside of class. The actual content of the videos would not be able to be specific to the class material in the first iteration of this project, as the variation of subject matter would result in a large number of videos that would need to be recorded. The video content would have to be about ethics itself, most likely about ethical theory or the specific schools of thought within ethics such as kantianism, or utilitarianism (Renshaw et al, 2016). The video method is readily available to students, and can be used at any time, most notably outside of class

time. Videos can be used time and again without any preparation, but videos may need to be updated periodically to maintain student interest, or to add new subject matter the professor deems relevant. Students would need to have some form of computer access to complete this type of assignment.

Joint Venture Method

The joint venture method would combine the online and in class aspects of the strategies discussed previously to achieve a more blended approach to teaching ethics. The 2015 IQP group used a variety of strategies, including case studies, point/counterpoint assignments, guest lectures and heuristics analysis (Rogers et al, 2015). Varied methods have been proven to be more successful in student retention of information (Springer et al, 1999). The varied methods provide a myriad of viewpoints for students to experience, which should lead to a better, more holistic ethics education. Although effective, varied methods require far more time to implement in lesson plans, and to design the lesson plans.

III. Methodology

Statement of Goal

To integrate metacognitive techniques into technical curricula to deepen student understanding of perspective and encourage reflective thinking on ethical issues in engineering. The metacognitive techniques presented here could be used in conjunction with other methods of teaching ethics in the engineering classroom that focus on the analysis and resolution of ethical issues to create a reflective problem solving experience for students. By developing a better understanding of one's perspective and approach to problem solving students can potentially expand the scope of their potential solutions to problems and better evaluate the impacts of everyday engineering decisions.

The Sensemaking and Metacognition Module

The first iteration of this ethics module centered around the discussion of metacognition, specifically of sensemaking and reflection on how students came to make ethical judgements (Figure 1). The lecture portion of the module lacked much class participation which resulted in the need for reevaluation of the approach of the discussion. After the module was run in the first class we revised the in-class discussion portion of the implementation but kept the assignments largely consistent with those of the pilot module.The module first required students to read a case study relevant to their course material and was followed by a carefully phrased question that would require students to reflect on the case study without necessarily being directed into the discussion of ethics or metacognitive strategies. Following the brief response, students completed a confidence survey (Appendix A) assessing how comfortable they

were answering the material, and whether they have taken an ethics class before. In addition to the confidence survey, students were given a document containing some background information on metacognition, sensemaking, and various ethical theories. The students were then asked to complete an assignment wrapper, a metacognitive tool to assist them in reflecting on the case study, in preparation for an in class discussion. The assignment wrapper prompted the students to reflect on the information on metacognition and reflection strategies found in the background provided and how the strategies could be applied when approaching the case study (Appendix A).

Figure 1. The Three Phase Metacognition Module

After the preliminary assignment, an in-class discussion was conducted on the topic of metacognition and how students evaluated their approach to the first case study with the assignment wrapper. The discussion then elaborated on the content presented in the background information that was distributed to the students before the class and largely focused on the discussion of how to expand one's perspective when approaching engineering problems by using various metacognitive techniques. The in-class discussions were run by one or more student team members who focused on encouraging class participation and reflection by prompting discussion in small student groups during the course of the

lecture. The use of small group discussion activities as part of the lecture was a result of revisions made to the module after the pilot.. Furthermore, during the lecture students were shown examples of how to use mind maps as a metacognitive tool to track their thought processes during a problem solving activity to identify and interpret new knowledge to strengthen their ethical perspectives and understanding of the non-linear nature of scientific inquiry. The goal of the discussion was to unearth and reflect on how the students approached the problems presented within the case study and how reflection and metacognition can be valuable tools that engineers can apply to day to day decisions. The discussion also served to reinforce the information the students read before class through repetition.

Once the in-class discussion was completed, students answered ethical identification questions on the same case study as presented earlier in the module, this time requiring them to use a mind map as a means of tracking their thought process, how they identified solutions to problems, where biases may or may not occur, and where they interpret or find new knowledge that changed or reinforced their perspectives. After the second case study assignment, students were required to complete a final confidence survey (Appendix A) for comparison to the pre-survey and to gather feedback for the module.

Development of In-Class Discussion

Pilot Module In-Class Discussion

As per the methodology of our pilot module, an in-class discussion was necessary as a means to introduce the project goals and to educate students on the topic of metacognition and metacognitive tools. Initially conducted in Transport Analysis in Bioengineering, a class of 8 students, the first iteration of the in-class discussion was solely used to introduce students to the metacognitive tools that were expected to be utilized in the second case study response. In this introductory presentation, the majority of class time was used to educate students without the use of much student engagement and responses. This initial

discussion only ran the course of 30 minutes, where a one hour period of time had been reserved for the module presentation. Discussion relevant to the case study was overlooked and only was discussed when prompted by the professor during extra time, which resulted in much more student engagement and more thoughtful responses from students pertinent to the discussion of ethics. In the following days students had reached out to team members for clarification on the details of the assignment This discussion initiated the first revision of material that was covered and how students were engaged during the presentation.

Revising the In-Class Discussion

After the pilot module presentation in Transport Analysis in Bioengineering, a need arose for better engagement of students and more discussion of the metacognitive tools that were being covered in the module, and how to use them in context of ethical problem solving . The solution proposed for this issue was think-pair-share activities, where students were grouped up and had the opportunity to discuss among peers their opinions and interpretations of the materials during the presentation. The think-pair-share method of in-class discussion was used in the presentation for Biomechanics, a class of roughly 75 students. Using this method, in-class activities prompted more responses from students, and discussion along with understanding of not only the metacognitive tools, but the ethical implications of the case study became more apparent to the students. Furthermore, no students required clarification of the assignment details after the presentation contrary to the first presentation. The think-pair-share model also adequately used the class time allocated for the presentation. Incorporation of discussion towards the ethical implications of the case study and the student discussion introduced with the think-pair-share activities ran the entire length of the class (approximately 50 minutes).

In the third presentation for Social Implications of Robotics, the only major revision that took place from the previous iteration was a more guided discussion of the potential ethical implications

regarding the case study, as well as being more concise for parts of the presentation that didn't warrant as much class time (primarily interpretative questions). These final iterations that were used in were ultimately used again in the final presentation for Land Use, Development, and Controls which concluded the development of the in-class discussion.

IV. Results

Survey Results

Figure 2. Comparison of Students who have taken an ethics class vs. those who have not

Figure 3. Graph of student confidence before and after module.

Figure 4. Individual student confidence in identifying ethical issues pre and post survey.

Case Study Response Results

The quality of student responses was scored according to a rubric adapted from the rubric used in the Engineering Professional Skills Assessment (EPSA) (McCormack et al., 2014). The EPSA rubric was developed based on ABET professional skills criteria. Student responses were scored against the sections of the EPSA rubric associated with the "understanding of professional and ethical responsibility" (skill 3f) and "the understanding of the impacts of the impact of engineering solutions in global, economic, environmental, and cultural/societal contexts" (skill 3h). See Appendix B for grading rubric. The distribution of case study response scores for each class broken down by rubric criteria are detailed in figures 5 through 13. Mean score values for each rubric criteria broken down by class and case study can be found in Table 1 and the mean overall score value for each rubric criteria broken down by class and case study can be found in Table 2.

Table 1: Mean Values of Case Study Responses by Rubric Category

Class and Case Study	Rubric Criteria			
	Ethical Consideration	Impact/ Context	Problem Identification	Stakeholder Perspective
CE 4071 Case Study 1	1.7	2.7	3.9	2.2
CE 4071 Case Study 2	2.9	2.6	3.2	2.3
RBE 310X Case Study 1	1.5	2.4	2.6	2.2
RBE 310X Case Study 2	1.5	1.1	2.0	1.7
BME 361X Case Study 1	N/A	N/A	N/A	N/A
BME 361X Case Study 2	3.0	3.3	4.1	2.6
BME 4504 Case Study 1	0.9	1.4	1.8	1.2
BME 4504 Case Study 2	1.8	0.9	1.2	0.8

Table 2: Mean Overall Values of Case Study Responses

Class	CE 4071		RBE 310X		BME 361X		BME 4504	
Case Study	1	2	1	2	1	2	1	2
Mean Overall Score	10.4	10.95	8.7	6.5	N/A	13	5.36	4.7

Figure 5: CE 4071 Case Study 1 Response Results

Figure 6: CE 4071 Case Study 2 Response Results

Figure 7: RBE 310X Case Study 1 Response Results

Figure 8: RBE 310X Case Study 2 Response Results

Figure 9: BME 361X Case Study 2 Response Results

Figure 10: BME 4504 Case Study 1 Response Results

Figure 11: BME 4504 Case Study 2 Response Results

Figure 12: Case Study 1 Response Overall Rubric Scores

Figure 13: Case Study 2 Response Overall Rubric Scores

V. Analysis and Discussion

Survey Results Discussion

Pre survey results yielded 110 student responses from four separate classes, one Robotics, two Biomedical Engineering classes, and one Civil Engineering class. As shown below in Figure 2, only 20% of students surveyed had taken a dedicated ethics class. Post survey results yielded 47 responses from the same four classes, 40 of which also completed the pre survey. While Figure 3 only takes into account the students that completed both surveys, a general trend can be observed that students were more confident after the module, but this data is not able to be proven statistically significant. A two tailed, paired t-test was performed on the data collected from students who completed both the pre and post survey. A p value of .3484 was obtained for question two[1] from the survey, putting the data well outside of statistical significance by a factor of seven. Question one[2] came close to statistical significance with a p-value of .0648. A single tail test resulted in a p-value of .174 for question two, and a value of .0324 for question

[1] Question 2 reads: "How confident are you in identifying ethical aspects of engineering?"
[2] Question 1 reads: "How confident were you in your discussion of the design topics?"

one. This is to be expected as students in this sample group are well educated to deal with technical or design problems, and seeing a problem twice allows a greater amount of time to think about a problem, resulting in higher confidence. Based on the survey responses, students were observed to have a high level of confidence in dealing with ethical issues, but upon review of student case study responses, this level of confidence did not transfer over to successful identification of ethical issues. This high level of observed confidence but low success raises questions about confidence being the correct metric for measuring the success of this module. As shown in Figure 3, there is no apparent upward trend in confidence, further proving confidence was not the correct metric to use. It was discovered that students believed themselves confident, even when they were not fully capable of determining ethical issues because of their method of exposure to ethics. Very few had taken an ethics class (Fig 2), causing the majority of the students surveyed to have only brief touch and go levels of ethics education from within a technically oriented class or classes. These ethical experiences would not have involved much deep thought or in depth analysis of ethics, but rather a brief overview of what ethics is, or a few ethical standpoints that can easily be found in ethics literature. While many students improved, most improvements were by a small margin, whereas students who went down in confidence tended to drop much further. This appears to indicate a false sense of confidence, more specifically a false sense of confidence in dealing with ethical issues. This is most likely stems from the constant top level exposure to ethics without fully exploring the depths of the subject. Tangentially, students who responded with high confidence levels did not necessarily score well on their case study responses.

Case Study Response Analysis

CE 4071 Land Use and Development

Twenty students completed both Case Study 1 and Case Study 2 for the Ce 4071 module. Case Study 1 results from the CE 4071 class yielded overall thoughtful responses, with a mean overall rubric score of 10.4; the overall mean rubric score for Case Study 2 was 10.95 (see table 2). There was no significant change in the overall quality of the case study responses. As shown in Table 1, the mean rubric score for Impact/ Context, Problem Identification, and Stakeholder Perspective criteria also stayed fairly consistent between the Case Study 1 and Case Study 2 responses with students scoring highest in Problem Identification.However, the mean rubric score for the Ethical Consideration criteria of the rubric increased by 1.2 rubric points, indicating that the metacognitive tools introduced to and the information shared with the students through the background information and class discussion prompted students to make connections between ethical issues and the case study that they had not considered in their initial problem solving approach.

RBE 310X Social Implications of Robotics

Eleven students completed Case Study 1 and six students completed Case Study 2 for the RBE 310X module. The mean overall rubric score for Case Study 1 was 8.7, which decreased to 6.5 for Case Study 2 (See Table 2). The mean rubric score for Problem Solving was consistently the highest. Students in the RBE 310X class voiced displeasure on the repetitive nature of the case study assignments and found the the module to be unnecessarily exhaustive. The negative response to the repetitive case study exercise could account for the decrease in overall quality of student responses. Another possible factor that could have impacted student response could have been the nature of the class. The other three classes the module was launched in were more technical in nature while RBE 310X focused on the social

implications of robotics, therefore the exercises included in the module could have mirrored many of the preceding discussions and topics covered in class.

BME 361X Transport Analysis and Transport Engineering

Seven students completed Case Study 2 for the BME 361X module. Results for Case Study 1 were not submitted to the IQP team. The students in BME 361X scored an overall mean overall rubric score of 13 for Case Study 2. Overall, students scored well in problem identification as well as the impact and context of the problem, but scored poorly on stakeholder perspective, demonstrating the propensity engineering students have for a technical mindset to problem solving. The mean rubric score for ethical consideration for the class was rated as a 3.

BME 4504 Biomechanics

Fifty-five students completed Case Study 1 for the BME 4504 Module, and forty students completed Case Study 2. The mean overall rubric score for Case Study 1 was 5.36, which decreased to 4.7 for Case Study 2. Overall, responses were very short and not indicative of deep though. Responses ranged from one sentence to a paragraph. The short and superficial responses submitted by students could be a result of poor implementation of the module. There was quite a bit of confusion on when material should be released to the students. Page length requirements were not included on the case study assignments, as they were in all other classes, which also could have contributed to the short responses

Overall Observations

Overall, the CE 4071 module yielded the highest overall quality responses, which allowed for more comprehensive analysis. Across the classes involved, students scored highest in Problem Identification. High scores in Problem Identification with lower scores in all other rubric criteria indicate

a level of engineerization in student responses. The responses from RBE 310X and BME 4504 were fairly low in quality, comprehensiveness, and consistency between case studies and were difficult to draw conclusions from as a result. Case study 1 responses from BME 361X were not submitted to the IQP team so a before and after analysis cannot be completed.

Exam Wrapper Analysis

In evaluation of the module, students were assessed by the thoughtfulness of their answers and how they pertained to the core ideology of using metacognition as a means of reflection to increase emotional investment and awareness into the perspectives and biases that one might have when navigating through ethical issues. The exam wrappers assigned prompted students to consider new ways of acquiring knowledge, and contrast them with their existing thought processes, as well as helping students identify and evaluate their approaches towards ethical problem solving, and how they will adjust in the future with a series of questions. The first required question of the assignment wrappers was as follows: ***How did you approach this assignment? Note previous knowledge, attitudes, and/or behaviors that contributed to how you approached the assignment. Refer back to the module background information provided and try to describe the perspective you adopted***. In evaluating student responses to this question, one of the module's goals was for students to mention specific ethical theories, knowledge, or behaviors that may have influenced their decision making and how well they could elaborate on how it affected their thought process for the assignment. One student quoted below, adopted the perspective of social contract theory which they identified as a possible hindrance to a proper ethical evaluation of the case study and by doing so opened up an avenue for further investigation in future ethical problem solving.

"Based on the module information I think I adopted the perspective of the social

> contract theory in that the roles of the entities involved in this case are in sorts predetermined and defined by societal norms. I think that this approach influenced my response to the case presented because I had these pre-notions of how each entity should act and what they were responsible for. In hindsight I think this led me to focus too much on the details of the case and the roles of the players rather than the bigger picture."

Similarly, another student responding to a case study identified a kantian perspective as what shaped their outlook and approach to the problems presented:

> "I believe if an action respects people and human dignity then it's justified. I therefore approached this assignment with the viewpoint that the morality of any action, regardless if it be a business or single person, faces total judgment by this rule. Therefore, I identify most with Kantianism because what this pharmaceutical company did in skimping on testing a product whose risks are not fully known, just to get a quick buck, is just gross and despicable. My deal is no one can exploit and endanger people to leverage their business without looking like a criminal."

This student identified a perspective that resonated with their emotional response to the case study material, and furthermore, identified why that emotional response was important to them and how it affected their attitude when resolving the issues poised in the case study response. One student even cited virtue ethics, kantianism, as well as the principle of justice as influences in their case study response:

> "...I approached this assignment from a "Virtue Ethics" theory, as I usually do. I use my morals which, I feel, are based on the guiding principle that all humans should be afforded the same opportunities to partake in society... If the land in question was converted to gated vacation homes it would violate The Justice Principle by reducing non-wealthy individuals access to communal outdoor space. I also feel that I embodied Kantianism, but I value all living things as the "humans" cited in this theory…"

When students are given the opportunity to explain and reflect on the perspectives that they adopted for the case study response, it promotes a deeper emotional connection between the students and their responses. When answered thoughtfully, the exam wrapper prompted students to legitimize and understand not just their responses, but their perspectives, which helps break the structuredness of the "engineered" response to ethical problem solving.

The second required question of the exam wrapper prompted students to consider exactly how they would approach future ethical issues in light of being exposed to metacognitive processes where they could identify their preferences and biases that influenced the previous response. The question was as follows: ***If faced with another assignment similar to this one, how would you prepare for/approach the assignment now****?* When answering this question, students voiced favorability for the metacognitive tools used in the module, as well as using metacognition in its broadest sense if faced with future situations involving ethical problem solving. Several students, quoted below, found that they would use metacognitive and metacognitive tools when faced with future issues, and that true consideration for these issues could be adequately met for them by using metacognition as an avenue to reshape their perspective.

> "Looking back now and further analyzing the different perspectives and approaches that

exist in engineering ethics I wish that I really could have been more metacognitive in the whole process. Being exposed to ethical dilemmas and concepts before this case study I believe led me to approach the case in the way that I thought was right and not truly consider the approaches that could be taken and how they would influence my response....further looking into the background now makes me think that next time I would use metacognition to expand my perspective and throw away what notions I had in my head about these types of problems."

"I would be more "metacognitive" I guess. Reflecting now so much on what stances I take has lead me to adopt a greater self-awareness than what I held previously. I show tact where I naturally can, but to reflect on the consequences of not doing so adds another dimension to my personality…."

".... Based off the background information module, the perspective that I took on this case study was mostly metacognition. After reading that through, I would probably consider approaching a similar assignment in a different manner than just my initial thoughts...."

The TSI mind map method was also referenced by students as helpful for identifying the stakeholders and the possible perspectives involved in the case study material. One student quoted:

"I would try to incorporate the mind-map approach with the five different I's. I would be sure to consider the perspectives of everyone involved with the design or problem at hand before making any final judgments."

From the more specific example of using the mind map approach, to the more broad sense of using metacognition to expand their perspectives, students were able to identify that the metacognitive model of learning helped them gain a more complete understanding of the material and the stakeholders that were involved in the case studies. These answers showed that students were able to identify why heuristic analysis in ethical problem solving can open pathways, but true understanding of the issues can require approaching a problem from several different points of view.

Another question of the exam wrapper also provided students to give a more personal perspective into why they have developed their perspectives: ***As an individual, what beliefs, knowledge, values, environmental factors, etc have shaped your perspective****?* Student responses from this question bridged the gap from technical to personal effectively and gave students the opportunity to reflect on their personal development and how it impacted their decision making, for better or for worse. One student identified their religious background as paramount to their perspective towards ethical problem solving:

> "....I grew up religiously and in a community that promotes sharing and communal spirit rather than individuality.…"

This same student also identified Kantian ethics as important to their ethical decision making, as it was the ethical theory closest to their religious ideals. The importance of upbringing, specifically parental influence, was emphasized as critical to the development of ethical perspectives as explained by two different students:

> "My parents have mostly shaped my outlook and beliefs. As the people I respect most and

> always turn to for guidance, they have and will always aid me in maneuvering along the bumpy road that is life. While others may teach me, they are only adding onto the intellectual foundation my parents have so generously laid out throughout my childhood..."

The second student explaining the foundation of their beliefs specifically mentioned the socioeconomic factors that shaped their parents life perspectives, and in turn theirs.

> "I believe I have a well-rounded and comprehensive global perspective, as well as a well-formed sense of empathy taught to me from a young age. My parents came from two separate worlds; my father grew up poor in Los Angeles, one of twelve kids sharing two bedrooms. He managed to learn his way out of his situation and is now a doctor. My mother, on the other hand, grew up living a privileged lifestyle in Topsfield, Massachusetts…"

These responses showed that prompting students to reflect on previous factors that influenced their responses helped them personalize the assignment and develop an emotional connection to the material that was present within not only the case study, but their answers to the questions they gave. Furthermore, it helped build the importance, or even establish a connection, to the perspectives that students have towards ethical issues. Some students, such as the one quoted below, were able to identify how these perspectives influenced bias in their problem solving, and how it could potentially impact the quality of the solutions that they formulated in their case study response:

> "I value environmental preservation and direct community benefit. I'm particularly biased because I don't like vacation home developments, I much prefer campgrounds, or just not having tourist type developments. That being said, I understand their benefit, I just wouldn't like living around one. I'm also biased in that I like being right and I tend to not open up to different ideas very easily, though I'm working on the habit."

Students more passionate about the subject matter, even were able to use the prompts on the exam wrapper as way to be emotionally expressive, further deepening the meaning of their ethical exploration of the case study topics. One student, as shown below, expresses their personal philosophy against human domination and subjugation of nature:

> "Prior to college, I lived in an area surrounded by lots of wildlife and forest, and the absence of that in Worcester has been devastating to my level of connection with nature as well as my emotional well-being. I believe that without seeing the interactions among species and waking up to birds outside my window, I would not be as invested in protecting the environment from human activity as much as possible. I am disgusted with how humankind has dominated and destroyed the one planet on which we are supposed to live, so any mention of development or encouraging the building of unnatural barriers angers me…"

These connections are critical in the effort to make students deepen their ethical thinking. When done thoughtfully, simply prompting students to think in a way that works outside the structuredness and efficiency of the technical lense of engineer-ization slowed down the ethical thinking process and promotes student identification towards key areas of perspective, bias, and emotional investment.

VI. Recommendations

For Continuing Research

In continued pursuit of using metacognitive tools as a means of deeping ethical learning for engineering students, a key area of improvement identified in this project is to ask the right questions when surveying students. In hindsight, student confidence was not the correct metric to analyze student responses on, as there was no significant distinction from pre to post surveys. Better questions to use for understand the efficacy of these tools could include: *How effective was the reflection in the exam wrapper in changing your understanding of the case study?* Or: *Do you think the exam wrapper helped you identify and deepen your thinking into the ethical issues posed in the case study?* And specifically in the interest of understanding of how it affected perspectives, a question could be asked such as: *Did your perspective change after using the metacognitive tools to complete the second case study response?* In addition to asking the right questions, it is imperative for students completing these modules to understand the importance of continued ethical learning. Many students, in either their case study responses or their survey feedback, felt they had already satisfied ethical learning in other courses and that these types of exercises are not necessary. It would be important in the future to structure the importance of ethical learning to students in either literature or a presentation before hoping that they give thoughtful input to the case study material. Additionally, the use of joint-venture style presentations with professional ethics speakers could help with this issue, as it has been shown in previous iterations of this project to be an effective means of presenting ethical content to students, by incorporating the two it may produce more thoughtful student responses in the future (Rogers et al, 2015). For future research, increasing the scale of the study, possibly going outside of engineering classes, and incorporating more use of the metacognitive

tools (ie: exam wrappers after several assignment over the course of a term) could give better insight into the efficacy of using metacognitive and sensemaking techniques.

For Faculty and Students

For faculty or student members interested in using metacognitive learning strategies such as the ones explored in this project, while some students voiced favorability for the entire module, the most effective tool explored in the module was the exam wrapper. Using the exam wrapper type of assignment is an easy way to engage students emotionally into the ethical learning process. It has the ability to prompt students to analyze their own perspectives as well as challenge them to think beyond just the technical aspects of ethical problem solving. Exam wrapper style assignments would be easily implementable across the curriculum, and are simple to understand and use. A detailed explanation of how to create an exam wrapper can be found in Appendix C.

VII. Conclusion

Due to the fast past and structured nature of learning in technical institutions, students often apply complementary problem solving methods which are not analogous to the problem solving methods used in ethics classes necessary for deeper consideration into ethical issues. This project tackled this issue of "engineer-ization" by using metacognitive learning tools to promote reflection and a deeper awareness by slowing down and expanding the process of ethical learning. The qualitative and quantitative results of the three-phase metacognition module showed that many students were able to more clearly identify their biases and the stakeholders involved in ethical case studies by using the metacognitive tools in conjunction with an in-class presentation. Specifically, the student responses from the exam wrapper style of assignment had the most profound results in prompting students to make deeper connections to the ethical material posed within the case studies. An exam wrapper type of assignment would be implementable across the curriculum of engineering and wouldn't require significant training for faculty members to use and understand. Future research into using metacognitive tools, or tackling the issue of "engineer-ization," could be improved by surveying students on metrics other than student confidence, incorporating join-venture style lectures, as well as having continued use of the metacognitive tools several times over the course of course of a term, rather than assignments for just the module itself.

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Appendix A: Core Module Materials

Case Studies

BME361X Case Study

The Orphan Drug Act (ODA) is a set of regulations released by the Food and Drug Administration (FDA) to help financially benefit companies in developing potentially life-saving treatment for small populations of patients with rare diseases. A rare disease is defined in the ODA as one that affects fewer than 200,000 patients in the United States. Given that there are approximately 7,000 such diseases, rare diseases overall are estimated to affect more than 25 million patients in North America alone (Coté et al, 2010). A new startup pharmaceutical company, Polytechnic Pharmacological, is in the process of developing a drug for the treatment of non-hodgkin lymphoma. The company has been working on this drug for some time now and has sunk a lot of capital into it in this process. It has recently discovered that it is eligible to develop the drug under the Orphan Drug Act as it could also inadvertently be therapeutic for a small population of patients with leiomyosarcoma, a rare type of malignant smooth muscle cell tumor. Due to the small population of patients with leiomyosarcoma the company has increasing pressure from shareholders to inflate drug prices past insurable amounts of money to maximize possible profit margins to recoup money lost in the process of initial development.

With the new FDA approval, the company could now conduct testing on a smaller number of people who suffer from leiomyosarcoma with hopes to be beneficial for this new patient population. With the regulatory hurdles of large patient populations and trials being lifted from the development process, Polytechnic Pharmacological would now have less comprehensive data on the effects the new drug has on the broader cancer patient population and adverse effects on patients may become apparent only after the drug is cleared for market sale Furthermore, with reciprocity (mutual exchange between countries) of prescription drugs being illegal, the company would have the possibility of cornering the market. However, without the incentives in place from the ODA, the development of the drug may never be

possible, and the small population of cancer patients suffering from leiomyosarcoma wouldn't have the market size to gain attention for development of the new drug.

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BME 4504 Case Study

A biomedical device company designed an investigational device which is implanted outside the medial side of the knee joint to reduce load and osteoarthritis symptoms. Originally tested in Europe, the biomedical implant technology seeks it way to the U.S. If it gains FDA approval, younger, or more active patients with mild to moderate knee osteoarthritis might choose this option to delay knee replacement. Symptomatic knee osteoarthritis (OA) affects more than 1 in 10 U.S. adults aged 60 or older. In 2011, 757,000 knee replacements and revisions were performed in the United States; the mean age for the procedure was 68 years (Moximed, 2016). Procedure volumes for knee OA continue rising, and the Atlas system may address some of this need if approved for the U.S. market. However, testing of the newly developed device in its first five years on the European market was only about 550 procedures. Patient enrollment and use is speculated for being low due to so few studies being available on the safety and efficacy of the device. Additionally, use might also be limited because the device is intended for patients with mild-to-moderate OA who are younger (ages 45 to 55 years) than those typically receiving total knee arthroplasty (TKA) and a subset of the symptomatic knee OA population. In the United States, data from three small single-arm clinical trials (n = 99) of patients with knee OA showed significantly improved clinical success rates for pain, function, and stiffness. However, some patients experienced soft tissue pain and/or infection. The new implant might allow greater activity, which could indirectly improve patients' overall health and well-being if they can engage in activities prevented by knee symptoms. However, most patients will eventually require revision surgery, high tibial osteotomy (HTO), or TKA. Availability of the newly developed implant might cause some younger patients with symptomatic knee OA to choose it as a minimally invasive surgical procedure if they cannot get relief from conservative therapies. If approved for marketing, the implant would compete with HTO procedures. Reducing the number of HTO procedures would result in less follow-up care and some formal physical therapy sessions could be obviated (Moximed, 2016).

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RBE310X Case Study

A Chinese robot named Xiaoyi recently became the first machine to pass a medical licensing exam, according to a recent story in *China Daily*, the largest English-language newspaper in China. The robot scored 456 points out of 600 (a passing score is 360) to pass the written section of China's national medical licensing examination, which the article called an "essential" entrance exam for doctors. The robot can automatically capture data and analyze patient information to make initial diagnoses, the article said, and it will be used to assist doctors to make future treatment more efficient. The robot is set to launch in March 2018, said the chair of the company that designed Xiaoyi, adding that the robot is "not meant to replace doctors." General practitioners are, however, in short supply in China's rural areas, and the article noted that the company hopes the addition of robots can help bring quality healthcare to more people. A November 27, 2017, article noted that Xiaoyi, which means "little doctor" in Chinese, scored only 100 points on a practice test, but improved because it has the ability to learn and make judgments. According to the article, to prepare for the exam, Xiaoyi processed "dozens of medical textbooks, 2 million medical records, and 400,000 articles. This helped Xiaoyi do well on questions that required memorization and information recall; however, the robot did not score as well in the parts of the tests that involved answering questions about patient cases.

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CE 4071 Case Study

A client that you have agreed to work for has come to possess a parcel of land. Historically, the piece of land has been used as a campground but has since been abandoned for a number of years. Your client has no previous planning or development experience and has not decided if they want to invest and build on the land themselves or develop the land with the assistance of one of three private companies; they have hired you to assist them in the first stages of deciding how to use this land.

Your client has expressed interest in the possibility of developing a gated vacation-home community, Company One has proposed that your client develop the land into a small single family home community, and Company Two has suggested that your client restore the campground.

Below you will find a map detailing the general layout of the parcel, followed by some preliminary findings about the parcel.

Current Layout of Parcel

Preliminary Findings:

- The land surrounding the river located in the North-West Corner of the parcel has been severely eroded.
- A man-made beach surrounds the access to the beach in the South-West corner of the parcel with absolutely no vegetation.
- The parts of the parcel that are not forested or covered in sand or structures is for the most part clear cut and covered in grass with minimal regrowth of other vegetation. The slopes are also steepest in this area.
- The individual campsites are mostly clear cut with some regrowth since the abandonment of the site. Most of the sites have also accumulated a large amount of litter over the years. It is possible that over the years much of the soil on this parcel has become contaminated with various chemicals.
- In general, the roads are narrow with no centerline and filled with potholes.
- Much of the pavement is in relatively good condition, although there are no defined parking spaces.
- Some of the buildings have fallen into disrepair. The two of the three main buildings near the center of the parcel could be salvaged, but the roofs of the remaining building as well as the smaller building to the south of the parcel have completely fallen in.

Assignment Wrapper Template

This assignment is intended to be used as a reflection tool. There are no correct or incorrect answers. Please answer each question to the best of your ability with 1 to 2 paragraphs. Questions marked with an * are required for completion of the module to earn full credit. Please bring a copy (electronic or paper) of your completed wrapper to class on mm/dd/yy and submit the wrapper as a PDF on Canvas before class that day. Late submissions will not be accepted for credit.

1) How did you approach this assignment? Note previous knowledge, attitudes, and/or behaviors that contributed to how you approached the assignment. Refer back to the module background information provided and try to describe the perspective you adopted. *

2) If faced with another assignment similar to this one, how would you prepare for/approach the assignment now? *

3) Reflect on the issues presented within the case study.

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4) As an individual, what beliefs, knowledge, values, environmental factors, etc have shaped your perspective?

Survey Questions

Pre-survey Questions

- How confident were you in your discussion of the design topics? (0-10)
- How confident are you in identifying ethical aspects of engineering? (0-10)
- Have you taken an ethics class previously? (Yes/No)

Post-survey Questions

- How confident were you in your discussion of the design topics? (0-10)
- How confident are you in identifying ethical aspects of engineering? (0-10)
- How much did the module increase your confidence in identifying ethical dilemmas? (0-10)
- How useful were the metacognitive tools (exam wrappers and mind maps) in developing ethical thought processes? (0-10)
- If encountered with an ethical issue in a professional setting, how confident would you be in identifying it?
- How distracting was this ethics module from core coursework? (0-10)
- How interested would you be in having an engineering ethics requirement for graduation? (0-10)
- Would you like to see this module used in future classes? (0-10)
- Do you have recommendations to improve this module? (Text answer)

Background Information

Perspectives in Engineering - Sensemaking and Metacognition

Metacognition - Thinking About How You Think

Metacognition is the use of **"selection and monitoring processes, as well as [the] more general activities of reflecting on and directing one's own thinking,"**(Pellegrino, Chudowsky, Glaser, 2001). Basically, metacognition is the practice of **reflecting** on one's perspective, thoughts, and conclusions and on how they came about.

By practicing metacognitive techniques an individual can become more well versed in the limitations of their perspective and problem-solving approach and become a more effective **problem finder** rather than problem solver. By integrating **reflection** and other metacognitive strategies into the engineering process an engineer may generate problems, questions, and perspectives that would not have been previously

considered and **garner a greater understanding of how one thinks** and approaches problems so as to better self-evaluate progress and growth.

Sensemaking

Sensemaking in a metacognitive context is an **exercise in the understanding of a query or situation** while incorporating the use of **reflection** strategies. This occurs usually following the introduction of critical information that forces the individual to **doubt prior understanding;** this is called the Sensemaking Critical Incident Method (SCIM) (Hutton, Klein, Wiggins, 2008).

SCIM, a derivative of the Critical Decision Method (CDM), focuses on not only drawing conclusions from known data, but also encourages the individual to **seek out new data to elaborate upon inquiry** and **assess the implications and importance** of new understandings of information already analyzed (Hutton et. al, 2008).

Metacognitive and Sensemaking Approaches

TSI Approach (Teaching Science through Inquiry)	The TSI philosophy recognizes the nonlinear nature and multiple stages of scientific inquiry through which scientists seek new knowledge. Each phase of the TSI model can be defined as follows: ● Initiation: Interest is developed and the focus for inquiry is determined ● Invention: Problem solving and information gathering occur in the form of creating testable hypotheses, design of experiments, etc ● Investigation: The garnering of new knowledge and information ● Interpretation: The information gathered in the investigation phase is interpreted to determine impact and value ● Instruction: Occurs during each phase. Communication between student and professor and student to other students.
KAB Framework (Knowledge Attitude Behavior)	The Knowledge, Attitude, and Behavior framework as an approach to understanding metacognition is based on the acknowledgement that knowledge influences attitudes and behaviors of an individual, attitudes can influence behaviors and the seeking out of new knowledge, and behaviors can in turn influence the knowledge available to the individual and the individual's attitude in approaching new concepts (Cardella & Purzer, 2014). The KAB framework emphasizes the importance of assessing changes in behavior and attitude as well as knowledge.

Metacognitive and Sensemaking Strategies

TSI Mind Maps	The TSI approach to science and engineering education can be implemented through applying metacognitive techniques to the five phases of the TSI model by arranging the TSI phases into a visual mind map. These mind maps can then be used to track the progression of an individual's thought process and approach to complex problems. How to Use a TSI Mind Map: ● Start tracking your thought process by assessing what phase of the TSI model fits with your initial reaction on how to approach a problem. Do you first generate questions to be answered? Do you first go to research to see what the literature on the topic says? Read through the phase definitions and mark this phase on your mind map. ● As you progress through your investigations, note when you shift between phases and mark each shift on your mind map with an arrow to show the direction of progression. ● You may shift between phases as many or few times as you desire and you may return to the same phase multiple times. ● You may color code, use symbols, define a legend, and get creative with how you express your thought using the mind map. ● Incorporate KAB principles. Note how you knowledge, attitudes, and behaviors help or inhibit you and if they change throughout the investigations
Assignment Wrappers	Assignment wrappers are used often as an exercise to apply to graded assignments to encourage reflection on study habits and attitudes. An assignment wrapper usually poses three kinds of questions to prompt reflection. These question focus on preparation for and approach to the assignment, the errors made on the assignment and areas for potential improvement, and how to approach and prepare for future assignments. 1. the wrapper is prepared and the assignment is completed prior to wrapper distribution. 2. the wrapper is distributed to students with a graded assignment that will be the focus of the reflection. 3. the wrapper is collected to be handed back later. 4. The completed wrapper is returned to the students while the students should be preparing and completing the next assignment (Kaplan et. al, 2013) *Note* For this module you will not be receiving a graded assignment to reflect on. Instead please reflect on your answers to the first case study after reviewing this background information.

Example of Completed Mind Map

Metacognition - Expanding your Perspective

As stated previously, metacognition and metacognitive strategies are designed to help an individual think about how they think. An awareness of our perspective and an ability to interpret a problem through multiple different perspectives can help us as engineers understand the shortcomings and strengths of our knowledge, attitudes, and behaviors and identify aspect of research and engineering problems that may have not been so obvious before. Our environment, beliefs, ethical values, as well as many more variables can also shape how we approach a problem.

On the following pages you will find short descriptions of some well known ethical theories. Reflect on the perspectives presented within each and note which ones you identify with the most as well as the ones you disagree with.

Consequentialism (Utilitarianism)

Utilitarianism is the moral principle that what is right or wrong is determined by the outcome of an action and it is so in relation to the 'amount' of good or bad the outcome of a given action produces. An action is correct (morally right) if it brings about the greatest amount of happiness among the greatest number of people. So, to determine what is right or wrong, you have to think carefully about how much good/bad that outcome will produce for how many people and you choose the action that will bring about the most

good and the least bad. The key here is to see that for act-utilitarianism, there is nothing that is good/bad in itself- actions are made good or bad based on outcomes and only in this way (Pfeifer, 2017).

Kantianism (Deontology)

Kantianism is a moral theory based on the ideals of the German philosopher Immanuel Kant. Kant argues that all humans are deserving of respect based on the fact that they are human. Because of this, any action that is moral or right is one that respects this rule regardless of outcomes. This means that, as Kant argues, you cannot treat other humans as a 'mere' means to your own satisfaction or as tools to advance your own goals. This is because humans are not tools or means to ends. They are free beings that are deserving of respect- to treat them as a mere means to your own ends would be like treating them as things, not people. The key here is that a Kantian perspective on morality is one in which outcomes do not matter in determining the rightness or wrongness of actions- what determines rightness/wrongness is whether or not the action respects the humanity of all involved. If it does not, then it is immoral and wrong. If it does, then the action is moral and right (Pfeifer, 2017).

Social Contract Theory

Social contract theory is an ideology in which individuals agree upon social arrangements within a culture or society, and as such the roles in which these arrangements are made have implicit value agreed upon by the members of said society. The central tenet of social contract is that members agree to rules or laws, and as such give up certain freedoms to ensure safety and protection to pursue their interests and be competitive in society. Governments or authoritative bodies are formed to enforce these rules agreed upon by society and to punish citizens who violate the rules agreed upon by society. Many philosophers have criticized social contract because when law becomes a standard for morality context for judgements is often lost and a more complete sense of justice can be compromised as a result (D'Agostino et al, 2017).

Virtue Ethics

Originating from classic Greek philosophers Plato and Aristotle, virtue ethics is the moral theory that focuses on character traits and individual values influencing the ways we act. In this context, virtues are any kind of excellence in character that lead people to act for good. In the same way that virtues are the cause for good, virtue ethics cite vices as the cause for humans to be morally deficient. According to Aristotle, people acquire moral excellence similar to the way that certain skills in sports are gained through practice. As such, the virtue ethicist conducts behavior out of the virtuousness that it inherently has in order to cultivate the development of virtuous communities (Peirce et al, 2012).

Moral Relativism

Moral relativism is an ethical point of view where moral judgments are right or wrong based on particular cultural or historical standpoints. Moral relativism denies the notion of universal morality, and that morality is subject to what is considered right or wrong by the specific groups making such judgments. As such, a moral relativist only comments on the morality of a standpoint within a culture that they have sufficient understanding, and can only speculate on the morality of judgments existing within groups that they are loosely or unaffiliated with (Gowans, 2004).

Principlism

The commonly accepted principles of health care ethics include:

1. the principle of respect for autonomy,
2. the principle of nonmaleficence,
3. the principle of beneficence, and
4. the principle of justice.

The Principle of Respect for Autonomy

Any notion of moral decision making assumes that rational agents are involved in making informed and voluntary decisions. In health care decisions, our respect for the autonomy of the patient would, in common parlance, mean that the patient has the capacity to act intentionally, with understanding, and without controlling influences that would mitigate against a free and voluntary act. This principle is the basis for the practice of "informed consent" in the physician/patient transaction regarding health care (McCormick, 2013).

The Principle of Nonmaleficence

The principle of nonmaleficence requires of us that we not intentionally create a needless harm or injury to the patient, either through acts of commission or omission. In common language, we consider it negligence if one imposes a careless or unreasonable risk of harm upon another.

Providing a proper standard of care that avoids or minimizes the risk of harm is supported not only by our commonly held moral convictions, but by the laws of society as well. In a professional model of care one may be morally and legally blameworthy if one fails to meet the standards of due care. The legal criteria for determining negligence are as follows:

1. the professional must have a duty to the affected party
2. the professional must breach that duty
3. the affected party must experience a harm; and
4. the harm must be caused by the breach of duty.

This principle affirms the need for medical competence. It is clear that medical mistakes occur; however, this principle articulates a fundamental commitment on the part of healthcare professionals to protect their patients from harm (McCormick 2013).

The Principle of Beneficence

The ordinary meaning of this principle is the duty of health care providers to be of a benefit to the patient, as well as to take positive steps to prevent and to remove harm from the patient. These duties are viewed as self-evident and are widely accepted as the proper goals of medicine. These goals are applied both to individual patients, and to the good of society as a whole. For example, the good health of a particular patient is an appropriate goal of medicine, and the prevention of disease through research and the employment of vaccines is the same goal expanded to the population at large. It is sometimes held that nonmaleficence is a constant duty, that is, one ought never to harm another individual. Whereas, beneficence is a limited duty. A physician has a duty to seek the benefit of any or all of her patients, however, the physician may also choose whom to admit into his or her practice, and does not have a strict duty to benefit patients not acknowledged in the panel. This duty becomes complex if two patients appeal for treatment at the same moment. Some criteria of urgency of need might be used, or some principle of first come first served, to decide who should be helped at the moment (McCormick, 2013).

The Principle of Justice

Justice in health care is usually defined as a form of fairness, or as Aristotle once said, "giving to each that which is his due." This implies the fair distribution of goods in society and requires that we look at the role of entitlement. The question of distributive justice also seems to hinge on the fact that some goods and services are in short supply, there is not enough to go around, thus some fair means of allocating scarce resources must be determined. It is generally held that persons who are equals should qualify for equal treatment. This is borne out in the application of Medicare, which is available to all persons over the age of 65 years. This category of persons is equal with respect to this one factor, their age, but the criteria chosen says nothing about need or other noteworthy factors about the persons in this category. In fact, our society uses a variety of factors as a criteria for distributive justice, including the following:

1. to each person an equal share
2. to each person according to need
3. to each person according to effort
4. to each person according to contribution
5. to each person according to merit
6. to each person according to free-market exchanges

John Rawls and others claim that many of the inequalities we experience are a result of a "natural lottery" or a "social lottery" for which the affected individual is not to blame, therefore, society ought to help even the playing field by providing resources to help overcome the disadvantaged situation. One of the most controversial issues in modern health care is the question pertaining to "who has the right to health care?" Or, stated another way, perhaps as a society we want to be beneficent and fair and provide some decent minimum level of health care for all citizens, regardless of ability to pay (McCormick, 2013).

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Appendix B: Case Study Rubric

Skill 3f is identified as an understanding of professional and ethical responsibility

Skill 3h is identified as an understanding of the impact of engineering solutions in global, economic, environmental, and cultural/societal contexts

Case study grading rubric example

Skill 3f	0 Missing	1 Emerging	2 Developing	3 Practicing	4 Maturing	5 Mastering	Score
Stakeholder Perspective	Students do not identify stakeholders	Students identify few and/or most obvious stakeholders, perhaps stating their positions in a limited way and/or misrepresenting their positions.		Students explain the perspectives of major stakeholders and convey these with reasonable accuracy.		Students thoughtfully consider perspectives of diverse relevant stakeholders and articulate these with great clarity, accuracy, and empathy	
Problem Identification	Students do not identify the problem(s) in the scenario.	Students begin to frame the problem, but have difficulty separating primary and secondary problems. If approaches to address the problem are advocated, they are quite general and may be naive		Students are generally successful in distinguishing primary and secondary problems with reasonable accuracy and with justification. There is evidence that they have begun to formulate credible approaches to address the problems		Students convincingly and accurately frame the problem and parse it into sub-problems, providing justification. They suggest detailed and viable approaches to resolve the problems.	
Ethical Consideration	Students do not give any attention to ethical considerations	Students give passing attention to related ethical considerations. They may focus only on obvious health and safety considerations and/or fair use of funds involving primary stakeholders.		Students are sensitive to relevant ethical considerations and discuss them in context of the problem(s). Students make linkages between ethical considerations and stakeholder interests. Students may identify ethical dilemmas and discuss possible trade offs.		Students clearly articulate relevant ethical considerations and address these in discussing approaches to resolve the problem(s). Students make linkages between ethical considerations and stakeholder interests and incorporate them into their analysis and resolutions. Students may discuss ways to mediate dilemmas or suggest trade offs.	
Skill 3h	0 Missing	1 Emerging	2 Developing	3 Practicing	4 Maturing	5 Mastering	Score

Impact/ Context	Students do not consider the impacts of potential solutions	Students give cursory consideration to how their proposed solutions impact contexts. Contexts considered may not be relevant. Students don't seem to understand the value or point of considering impacts of technical solutions or the contexts within which the solution is proposed.	Students consider how their proposed solutions impact major relevant contexts, and possibly re- think their understanding of the problem(s) themselves, justify possible solutions with reasonable accuracy. Impacts considered may be associated with relevant secondary problems.	Students clearly examine and weigh how their proposed solutions impact major relevant contexts, justify possible solutions with reasonable accuracy. Impacts considered may be associated with relevant secondary problems, and understand how different contexts can affect solution effectiveness.	
				Total Score:	

Citation:

McCormack, Dr. J.P.; Beyerlein, Dr. S.W. ; Kranov, Dr. A.A.; Pedrow, Dr. P.D.; Schmeckpeper, Dr. E.R. (2014, June 15th) *Scenario and Scoring Sheet Development for Engineering Professional Skill Assessment* [Paper #9942 121st ASEE Annual Conference and Exposition, Indianapolis, IN]

Appendix C: Guide to Creating an Assignment Wrapper

How To Create an Assignment Wrapper:

Metacognition in the Classroom

Metacognition: The "selection and monitoring processes, as well as to more general activities of reflecting on and directing one's own thinking," (Pellegrino, Chudowsky, Glaser, 2001). Alternatively defined as thinking about how you think.

The repetition of reflection provided by metacognitive tools can help students develop an understanding of how their perspectives influence their behaviors and attitudes and assist them in becoming more effective problem solvers. **An assignment wrapper is a metacognitive tool** often used as an exercise for students to apply to graded assignments to encourage reflection on study habits and attitudes and performance. Assignment wrappers should be easy to complete, repeatable, flexible, and exercise the skills hoping to be developed. After the completion of an assignment return the graded assignment to the student along with a blank assignment wrapper; students should then fill out the wrapper and return it to the professor, who will then return the wrappers to the students for their reference with a subsequent assignment.

To Create an Assignment Wrapper:

1. Identify the skill you wish to develop. Such skills could include identification of ethical issues, emotional engagement with the topic, and reflective skills.
2. Determine the kinds of questions that fit your purpose. Assignment wrappers can include questions on:

a. How the student prepared for and approached the assignment.
b. What kinds of errors were made on the assignment
c. How the student plans to prepare for subsequent assignments based on a reflection on their performance.
d. General reflective questions on the assignment topic or to engage the desired skill.

3. After deciding what kinds of questions you want to include on the Assignment Wrapper draft the questions. Following is an example assignment wrapper that includes all the above question types. Question 1 prompts students to reflect on their problem solving approach, question 2 focuses on how the student will approach similar future assignments, question 3 allows for the students to have an opportunity for general reflection on the assignment, and question 4 promotes students to make personal connections to the assignment and helps them develop an emotional stake in the solution.

Assignment Wrapper Example

This assignment is intended to be used as a reflection tool. There are no correct or incorrect answers. Please answer each question to the best of your ability with 1 to 2 paragraphs. Please submit a copy of your completed wrapper in class on mm/dd/yy.

1. How did you approach this assignment? Note previous knowledge, attitudes, and/or behaviors that contributed to how you approached the assignment.

2. If faced with another assignment similar to this one, how would you prepare for/approach the assignment now?

3. Reflect on the issues presented within the assignment.

4. As an individual, what beliefs, knowledge, values, environmental factors, etc have shaped your perspective?

For Further Information on Metacognition and Assignment Wrappers See:

Kaplan, M., Silver, N., LaVaque-Manty, D., Meizlish, D. (2013). *Using Reflection and Metacognition to Improve Student Learning*. Sterling, Virginia: Stylus Publishing.

Pellegrino, J. W., Chudowsky, N., & Glaser, R. (Eds.). (2001). *Knowing What Students Know : The Science And Design Of Educational Assessment*. Retrieved from https://ebookcentral-proquest-com.ezproxy.wpi.edu