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Michael H.G. Hoffmann’s research focuses on the question of how creativity, cognitive change, and learning can be stimulated by constructing diagrammatic representations, and by experimenting with those representations. This idea has first been developed by Charles S. Peirce in his concept of "diagrammatic reasoning." Since 2004, he developed "Logical Argument Mapping (LAM)," a method and diagrammatic system of representation that is supposed to stimulate critical thinking. LAM has been implemented in the interactive and web-based software AGORA-net: Participate - Deliberate! AGORA-net is an online world in which everyone can construct arguments or participate in debates. Its development is funded by the U.S. Department of Education. Most recently he works on collaborative and problem-based learning environments for ethics and for science education in which AGORA-net is used as a tool to focus and guide autonomous collaboration among small groups of students.

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Changing Engineering Ethics Education: Understanding ill-structured problems through argument visualization in collaborative learning

Abstract:
As a committee organized in 2009 by the National Academy of Engineering recognized, ethics education should foster the ability to analyze complex decision situations and ill-structured problems. This presentation aims to build on the NAE’s insights and reports about an innovative teaching approach that has two main features: first, it places the emphasis on deliberation and on self-directed, problem-based learning in small groups of students; and second, it focuses on understanding ill-structured problems. The first innovation is motivated by an abundance of scholarly research that supports the value of deliberative learning practices. The second results from a critique of the traditional case-study approach in engineering ethics. A key problem with standard cases is that they are usually described in such a fashion that renders the ethical problem as being too obvious and simplistic. Any description that already “frames” a case in this kind of way tends to trivialize the ethical challenge. The practitioner, by contrast, will mostly face problems that are ill-structured and for which it is not even clear if they include a real ethical challenge.

In the collaborative learning environment described here, groups of students use interactive and web-based argument visualization software called “AGORA-net: Participate – Deliberate!”. The function of the software is to structure communication and problem solving in small groups. The software guides students step by step through a process of argument mapping. Students are confronted with the task of identifying possible stakeholder positions and reconstructing their legitimacy by constructing justifications for these positions in the form of graphically represented logical argument maps. The argument maps are then presented in class so that these stakeholder positions and their respective justifications become visible and can be brought into a reasoned dialogue and deliberative process. Argument mapping in engineering ethics courses provides an exciting opportunity for students to collaborate in teams and to develop critical thinking and argumentation skills.

A New Focus in Engineering Ethics Education
Traditionally, the main objective of engineering ethics courses has been to foster awareness of and to stimulate reflection on the special responsibilities of professionals in technological fields. A well-established method to pursue this learning objective is to provide students with case studies from engineering practice. The case studies typically focus on common ethical issues such as taking a bribe from a vendor. However, a key problem with standard cases is that they usually describe the ethical problem in such a fashion that renders it as being something that is too simplistic. The more obvious the wrongdoing is, the easier it is to determine what should have been done. Thus, there may be no true ethical “challenge” presented in the case.

Clearly, the simplicity of ethics cases stands in contrast to the complexities of the real-life situations students will encounter after graduation. Aristotle astutely recognized in the first sentence of his Nicomachean Ethics that “every action and undertaking seems to seek something good” [1]. No professional wants something bad to happen. At times, the problem is not the engineer’s intentions but his or her inability to predict a bad outcome in spite of all
the good intentions. The most fundamental challenge from an ethical perspective is thus the fact that we need to realize, first of all, that there is an ethical challenge connected to one’s decisions.

Engineering ethics education needs to better prepare students for this kind of challenge. This conviction is conveyed within a workshop report on “Ethics Education and Scientific and Engineering Research” that the National Academy of Engineering (NAE) organized in 2009. The report emphasizes that the following skills should be developed in ethics education [2]:

- Recognizing and defining ethical issues.
- Identifying relevant stakeholders and socio-technical systems.
- Collecting relevant data about the stakeholders and systems.
- Understanding relevant stakeholder perspectives.
- Identifying value conflicts.
- Constructing viable alternative courses of action or solutions and identifying constraints.
- Assessing alternatives in terms of consequences, public defensibility, institutional barriers, etc.
- Engaging in reasoned dialogue or negotiations.
- Revising options, plans, or actions.

This list highlights the complexity of the issues that engineers confront. An engineer’s actions can have effects on stakeholders whose existence, perspectives, and values she does not necessarily see. An engineer does not always directly interact with the people whose lives are being altered as result of her decisions. Obviously, engineering students need to refine their technical competence. But it is crucially important that they develop “soft skills” as well [3]. Among these skills is the ability to identify hidden ethical challenges.

**Ill-Structured Problems**

A key intellectual challenge is acquiring the ability to identify and structure complex situations. This ability is an important precondition for problem solving, for decision making, for designing, and for planning. Several decades ago, Horst Rittel and Melvin Webber recognized this as “one of the most intractable problems” in their seminal paper “Dilemmas in a General Theory of Planning” [4]. Rittel and Webber came to the conclusion that the real challenge is not “tame” or “benign” problems that are clearly specified and that allow for a clear determination as to whether a solution has been achieved—for example, a standard ethical problem in a textbook. The real challenge is what they called “wicked problems” or what we refer to as “ill-structured problems,” a term that is also used by other authors in the engineering ethics literature [5, 6]. We prefer “ill-structured” because in common parlance, the term “wicked” carries with it the connotation of something being ethically wrong and this could be misleading; it is not a feature that we intend to capture. However, even though we are using different terminology, “ill-structured problems” is intended to mean the same thing as Rittel and Webber’s “wicked problems” (see also [7, 8]).

Among the ten defining characteristics of a wicked problem that Rittel and Webber delineated, the most important for our purposes is the first one: “There is no definitive

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formulation of a wicked problem” [4]. Any sufficiently detailed description of what the problem “is” is already predetermined by a certain vision of its solution—a vision that is often biased by diverse values and interests. This results from the fact that in pluralist societies, in which a multitude of worldviews and values compete, the determination and formulation of a problem as well as the assessment of its “solution” are in themselves controversial and open to discussion. Based on differing belief and value systems, problems and solutions can be “framed” in a variety of ways, and it is contentious whether anyone can legitimately claim the authority to decide who is right and who is wrong. We call this the “perspectivity” of ill-structured problems. It depends on the perspective, the vantage point, of who is involved in a complex situation how exactly a problem is perceived and framed.

Further characteristics of wicked problems are a direct consequence of perspectivity. As Rittel and Webber state, “Solutions to wicked problems are not true-or-false, but good-or-bad” [4]. This is because there are many parties with potentially varying interests, value-sets, and ideological predilections who are more likely to assess a solution as “better or worse” or “satisfying” or “good enough.” In addition [4]:

Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.

The fact that certain perspectives on an ill-structured problem might be overlooked is important because of two other characteristics of Rittel and Webber’s wicked problems that are crucial for engineering in particular [4]. There is “no immediate and no ultimate test of a solution” to it because any “solution, after being implemented, will generate waves of consequences” which “may yield utterly undesirable repercussions which outweigh the intended advantages.” And: “Every solution to a wicked problem is a ‘one-shot operation’... It leaves ‘traces’ that cannot be undone. One cannot build a freeway to see how it works, and then easily correct it after unsatisfactory performance.”

The concept of an “ill-structured problem” presented here refers to the fact that engineers are often confronted with situations that require structuring. Most worrisome are those situations that seem to be straightforward but are not. For the professional, the biggest challenge is to realize, first of all, that there might be perspectives on a problem other than his or her own. As Coughlin notes, it can be difficult to imagine, and take seriously, a perspective that is in opposition to one’s own ([9]; see also [5, 6]). The challenge is to identify the ethical dimensions of a decision especially in those situations where they are not obvious or are hidden, and where available descriptions do not contain any hint of the complexity and multi-perspectivity of the problem.

According to Rittel and Webber, the multi-perspectivity of wicked problems implies that they should be approached “based on a model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among the participants, as a product of incessant judgment, subjected to critical argument” [4]. Their insight about the importance of argumentation—which has been proven highly influential in educational sciences [10-13]—has helped to inform and guide the educational approach described here.

The emphasis on argumentation as a “powerful pedagogical strategy” in engineering ethics is shared also by Jonassen and his colleagues [6]. Following Haws’s argument that students...
should become familiar with ethical theories and “the language of ethics” in order to acquire the “theoretical grounding” that is necessary to “formulate, articulate and defend their ethical resolutions to the broader community” [14]. Jonassen emphasizes that students should also “acquire the ability to evaluate alternative solutions from different perspectives” [6]. A precondition for evaluating those perspectives is to understand them, and understanding can be achieved by reconstructing the arguments on which stakeholder positions are based. “Because ethics problems have multiple solutions, those arguments must not only pose a solution and support that solution but also anticipate alternative solutions and anticipate the counterarguments in support of those solutions” [6].

**An Overview of the Educational Approach**

A major objective of engineering ethics education should be to provide opportunities to acquire the skills that are necessary for engaging in such an “argumentative process.” Ethics education should foster the ability to cope creatively and constructively with ill-structured or “wicked problems” in the sense described by Rittel and Webber. The educational challenge, as we see it, can be summarized in the following formulation that is built upon the list of skills identified in the aforementioned NAE report.

A precondition for making ethical decisions that meet the challenges posed by ill-structured problems is the ability to analyze complex decision situations in a way that the involved stakeholders can be identified and their varying perspectives and values understood. Appreciating another person’s needs, interests, and the resulting intellectual or ideological position presupposes the ability to grasp the arguments that justify this position. Thus, ethical decision making in complex situations requires an argument-based dialogue about a wide range of stakeholder perspectives and their justifications that can lead to imagining alternative courses of action and hopefully better decisions.

Promoting this ability requires a new focus in engineering ethics education. Thus, we present one possibility of how this challenge can be met. It is an educational approach that includes four main components:

1) Learning materials that describe a case from a multitude of perspectives

2) A different set of learning materials that refer to technologies which are not yet available and that pose unique challenges, especially with regard to identifying and imagining, first of all, possibly involved stakeholders and affected populations

3) An educational environment in which small groups of students collaborate on projects and present and discuss the results in class. This component is motivated by research that supports the effectiveness of Problem-Based Learning (PBL) and collaborative learning [15-22]. This strategy aims to increase student engagement, provide opportunities for peer-to-peer (P2P) learning, stimulate creativity, and improve student-faculty interaction, communication skills, and critical thinking

4) An interactive and web-based software tool (AGORA- net) that (a) challenges students to develop the rational reconstruction of an argument that stakeholders might provide to justify their position, which offers the students a means through which they can understand the stakeholders’ needs, interests, beliefs, and values, and (b) provides system-generated step-by-step guidance to create those arguments in visual form.
Since the AGORA-net software has been developed to guide and support collaboration in small of groups that work more or less autonomously on the two sorts of materials mentioned above, we will elaborate on these four components in the following sections based on a presentation of the “AGORA collaborative learning approach.” After that, we present a simplified example that illustrates how the AGORA-net software tool can be used to represent the graphical structure of a stakeholder position on genetically modified (GM) crops.

The AGORA Collaborative Learning Approach

Traditional engineering ethics courses normally focus on the major concepts, cases, and problems in engineering ethics and introduce students to professional codes of ethics and to theoretical approaches to ethical decision making. We call this the “content side” of Engineering Ethics education; it refers to the convincing assumption that certain core content and materials should be covered.

However, there is another side that might be more important when it comes to the complexities of the real-life situations students will encounter after graduation. These real-life situations require, first of all, certain skills and abilities. We call this the “skill side” of engineering ethics education. The new approach to teaching engineering ethics that we are in the process of developing will focus primarily on two skills: first, the ability to cope with complexity and ill-structured problems and second, the ability to collaborate in teams.

While there is general agreement that the experience of team work, problem-based learning, and developing the skills necessary to cope with problems of communication is crucial for the education of future generations, realizing these goals in practice can be problematic. Research on problem-based learning (PBL) in small groups has shown that collaboration in these settings works only when it is supported and guided by an experienced facilitator. “The facilitator helps monitor group discussions, guides students in the learning process, pushes them to think deeply, and models the kinds of questions that students need to be asking themselves” [19]. The PBL approach, for example, that has been implemented by the Department of Biomedical Engineering at Georgia Tech pairs each group of six to eight students with a facilitator [24]. This means that problem-based learning environments can be much more resource intensive than traditional instruction. In times of limited resources, this poses a serious threat to the quality of ethics education.

The AGORA-net approach addresses this problem by providing a web-based software application called “AGORA-net: Participate – Deliberate!” The AGORA-net software guides the activities of small groups of students (about four students per group) who collaborate on challenging problems and cases. The guidance and “scaffolding” provided by the software allows the integration of an AGORA-net component in classes without the need of facilitators; an instructor who is familiar with the AGORA-net approach will be sufficient to organize this innovative learning experience and to support the groups.

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2 Not to be confused with the software “Agora” that is available at http://www.ethicsandtechnology.com and described by van der Burg & van de Poel [23]. Whereas AGORA-net is a tool for the presentation of arguments in graphical form for all sorts of purposes, Agora focuses on the integration of ethical theories and codes of ethics in case-based engineering education. It provides theories, codes, cases, and exercises, and it offers templates and hints that structure user input in form of texts.
The key idea of the AGORA-net approach is to confront small student groups with the task of developing a position—or set of possible positions—on a challenging case and to defend this/these position(s) by chains of arguments that will be visualized by means of the interactive AGORA-net software. The software guides students step by step through a process of argument mapping. In contrast to other Computer Supported Argument Visualization tools (CSAV tools), AGORA-net is specifically designed to direct and guide students’ activities and collaboration in small, independent learning groups. The software provides the sort of guidance and scaffolding that otherwise a facilitator would contribute. AGORA-net can overcome, thus, the problems of existing CSAV tools that have been identified in previous research.3

We suggest to structure engineering ethics courses in two parallel tracks. This is based on a teaching schedule with two class meetings per week, each one is 80 minutes. In this setting, one track focuses on content issues, the other on skills that will be acquired in project work. A basic outline of an AGORA-generated project is as follows:

1) Students read individually text materials at home and submit a homework assignment before they come to class, answering the question: “What is the main conclusion of this text? What are the reasons that the author provides for this conclusion?” This is to help ensure that each student prepares for the project. During the course of the project, students are encouraged to search for additional material and to prepare it for the group work.

2) In class, students collaborate in groups of four on the construction of an argument map. The duration of this is from one to three weeks, depending on the complexity of the relevant topic. In each group at least one computer with an internet connection must be available. Since the software allows synchronous online collaboration, each student can work on his or her own computer. All maps are stored on the AGORA-net server and are publicly available unless they are password-protected in a “Project” by the user or instructor (the plan is to have this feature available by the summer of 2012).

3) The groups present their argument maps in class, followed by a class discussion. Depending on the class size, the collection of presentations will take one or two weeks since every group will need on average twenty minutes for a more complex project, including discussion. If several groups are working on the same case or topic, it is possible that not all of the groups will present.

4) In the class meeting after the presentations, the groups revise their argument maps based on the feedback that they receive in the discussion and submit it for grading. Since all of the groups are working on the same schedule, they have to collaborate outside of class on the maps if they need additional time.

Preliminary testing of this approach occurred at the Georgia Institute of Technology over the past few years in a series of approximately eight 3-credit hour courses.4 In general, one of

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3 [25]. See also [26], [27], [28]. With regard to the function of CSAV to enable students to cope with ill-structured problems, see [12], [30-34].

4 In these courses, the AGORA-net software was not yet available. Instead, the students used the freely available concept mapping software Cmap (http://cmap.ihmc.us/) to perform “Logical Argument Mapping (LAM).” LAM presupposes that students learn the basics of propositional logic. This is no longer necessary since the rules on which LAM is based are implemented in the AGORA-net software. A first AGORA-based version of an
In order to achieve the learning objectives mentioned above, three different class phases should be distinguished [35]. In a first phase, students need to become familiar with the AGORA-net software and learn how to map the structure of a simple argument or debate. The students are prompted by the software to enter a claim into the AGORA system (e.g., “we should study today”). Then they are asked to provide a reason that supports the claim (e.g., “we want to earn a good grade”). After that, the AGORA-net software offers the students a selection of logical argument schemes, such as modus ponens or modus tollens, that structure the connection between the claim and the supporting reason in a logically valid way. After selecting a scheme and a corresponding language form, such as “if-then” for modus ponens, the software automatically completes a logically valid argument (see Figure 1). The software permits students to offer additional reasons to support the initial claim or a previously stated reason. It also gives others who are viewing the argument map the ability to refute those reasons and offer counterarguments (by clicking on “Add…” in one of the boxes in Figure 1).

In the second phase, each group refines their argument mapping skills by analyzing one stakeholder position on a controversial technology. A list of preselected positions is presented to all students in advance, together with short abstracts that describe each of the positions. The stakeholder positions focus on different aspects of the technology such as whether there is an ethical obligation to share the technology, considerations of safety and risk, and the technology’s environmental implications. Groups typically form according to the interests of the students. The analysis of one position is supposed to promote an in-depth understanding of this position, its justification, and its limits and weaknesses. In recent semesters, students have focused on GM crops for this phase. A fuller description of this phase will be provided in the section below.

In the third phase, the groups are confronted with the task of developing a clear and convincing position to an open-ended problem. Whereas in second phase stakeholder positions are given in advance, the challenge in the third phase is to imagine possible stakeholder perspectives and their respective justifications. For example, would it be appropriate to bring an extinct species such as Neanderthals back to life [36]? The framing of this particular problem derives directly from a colleague’s work. Drawing from skills that they have developed during the earlier phases, the students must creatively imagine possible perspectives on this issue. As a starting point, they might try to identify who the potential groups of stakeholders (e.g., scientists, historians, etc.) might be.

**AGORA-net and Genetically Modified Crops**

In order to more concretely illustrate how the AGORA-net software works, we will briefly describe how one group of students in a recently taught engineering ethics class “mapped” the argumentation of a stakeholder position with respect to GM crops. They selected an article written by Lucy Carter, titled “A Case for a Duty to Feed the Hungry: GM Plants and the Third World” [37]. Figure 1 visualizes Carter’s main argument based on the students’
In Figure 1, the graphical arrangement was changed. The entire argument contains 28 textboxes, all leading to the claim on the left side of Figure 1.

Figure 1: An excerpt of an AGORAnet argument map originally created by a group of four students. What is meant by the reasons on the right side becomes visible in the following figures that represent arguments that the students developed for both of these reasons. The step-by-step process of creating such a map in AGORAnet is described in the previous section of this paper.

The textbox under the “Therefore” has been created by the software based on the two reasons that the students provided and their selection of what was deemed to be a suitable argument scheme (modus ponens). The text in this box is called the “enabler” because this premise guarantees that the two reasons provided are sufficient to justify the claim. The enabler guarantees that an argument is logically valid. In the case of this example, the enabler represents an ethical rule or principle; it could be justified by further arguments that refer to ethical theories.

Starting from this main argument, the students provided further arguments for the reasons that can be seen on the right side of Figure 1. Figure 2 represents an excerpt of an argument that justifies the second reason.

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6 The students’ names were removed to protect their identities. Their argumentation was recreated in part; based on limited space, only a few excerpts are displayed here. The students were contacted electronically to give them the opportunity to object to the publication of these excerpts and the students did not express an objection.
Figure 2: Two independent arguments for the second reason in Figure 1

Part of the argumentation that the students developed for the first reason in Figure 1 is depicted in Figure 3.
In short, the three figures above illustrate how the AGORA system works. It can enable students to refine their reasoning ability and to more fully appreciate the hidden assumptions that are relied on to support a stakeholder position.

**Conclusion**

In many engineering ethics courses, a typical strategy is to give students hypothetical and historical cases with an ethical problem that is fairly clear and which has a solution that is rather intuitive. However, in order for students to develop necessary skills, ill-structured problems should be more fully integrated into these courses. In this paper, we describe one way of accomplishing this goal through the use of the web-based tool called AGORA-net. The overarching hope is that this will enable students to grapple with messy and complex problems, ones that require creative and critical thinking.

The AGORA-net learning approach aims to help students understand the justifications of a multitude of stakeholder positions through projects in which they reconstruct these justifications in the form of graphically represented logical argument maps. Argument
mapping in problem-based learning environments provides an exciting opportunity for students to develop critical thinking skills and the ability to collaborate in teams.

In future research, we plan to assess the AGORA-net approach with regard to the following learning objectives: (a) fostering student engagement and collaborative skills, (b) improving student-faculty interaction, (c) assessing the student’s ability to cope with complexity and ill-structured problems, and (d) enhancing critical and ethical thinking skills. Some of these effects, including the quality of student-faculty interaction, will likely be measured by means of an exit survey. The effectiveness of the AGORA-net approach with regard to critical and ethical thinking skills will be measured—in a pre- and post-test format—by means of ArguSkill, a new assessment instrument that has been developed by one of the authors for this purpose. It measures three distinctive components of critical thinking that are not covered by other instruments, which are the ability to: (a) understand the structure of arguments; (b) self-critically examine and correct one’s own thinking about a problem; and (c) structure the understanding of an ill-structured problem situation.

Bibliography


