ETHICS IN ENGINEERING

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FIFTH EDITION

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Mike W. Martin and **Roland Schinzinger** participated as a philosopher-engineer team in the National Project on Philosophy and Engineering Ethics, 1978–1980. Since then they have coauthored articles, team-taught courses, and given presentations to audiences of engineers and philosophers. In 1992 they received the Award for Distinguished Literary Contributions Furthering Engineering Professionalism from The Institute of Electrical and Electronics Engineers, United States Activities Board.

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Roland Schinzinger received his B.S., M.S., and Ph.D. in electrical engineering from the University of California at Berkeley. Born and raised in Japan where he had industrial experience with Bosch-Japan, Tsurumi Shipyard of Nippon Steel Tube Co., and Far Eastern Equipment Co., he worked in the United States as design/development engineer at Westinghouse Electric Corp. and taught at the University of Pittsburgh and at Robert College/Bosporus University (in Istanbul). He was a founding faculty member to the University of California at Irvine, from which he retired as Professor Emeritus of Electrical Engineering in 1993. He authored or co-authored *Conformal Mapping: Methods and Applications* (1991, 2003), *Emergencies in Water Delivery* (1979), and *Experiments in Electricity and Magnetism* (1961, accompanying a kit he designed for use in Turkey). His honors include the IEEE Centennial and Third Millennium medals, Fellow of IEEE, and Fellow of AAAS. He is a registered professional engineer.

FOR *ELLY B. ZHU,*
FOR *LILI GUAN*

QIN ZHU

FOR *SONIA* AND *NICOLE MARTIN,*
FOR *SHANNON SNOW MARTIN,*
AND IN MEMORY OF *THEODORE R. MARTIN*
AND *RUTH L. MARTIN.*

MIKE W. MARTIN

FOR *STEFAN, ANNELISE,* AND *BARBARA SCHINZINGER,*
FOR *SHIRLEY BARROWS PRICE,*
AND IN MEMORY OF *MARY JANE HARRIS SCHINZINGER*

ROLAND SCHINZINGER

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PREFACE

Technology has a pervasive and profound effect on the contemporary world, and engineers play a central role in all aspects of technological development. In order to hold paramount the safety, health, and welfare of the public, engineers must be morally committed and equipped to grapple with ethical dilemmas they confront.

Ethics in Engineering provides an introduction to the issues in engineering ethics. It places those issues within a philosophical framework, and it seeks to exhibit their social importance and intellectual challenge. The goal is to stimulate reasoning and to provide the conceptual tools necessary for responsible decision making.

In large measure we proceed by clarifying key concepts, sketching alternative views, and providing relevant case study material. Yet in places we argue for particular positions that in a subject like ethics can only be controversial. We do so because it better serves our goal of encouraging responsible reasoning than would a mere digest of others' views. We are confident that such reasoning is possible in ethics, and that, through engaged and tolerant dialogue, progress can be made in dealing with what at first seem irresolvable difficulties.

Sufficient material is provided for courses devoted to engineering ethics. Chapters of the book can also be used in modules within courses on engineering design, engineering law, engineering and society, safety, technology assessment, professional ethics, business management, and values and technology.

FIFTH EDITION

All chapters and appendixes in this edition have been updated with the most recent data, research findings, and teaching resources. Chapters 1, 3, 6, 8, 9, and 10 are either new or extensively reorganized and developed. This edition has extensively expanded the discussions on corporate social responsibility, research ethics in less traditional contexts (e.g., children, animals, cross-cultural, and online), environmental ethics in the Anthropocene, duty ethics, design ethics, life-cycle assessment, and the philosophy of technology. Particularly, one major strength added to this edition is the global and international dimension. Chapter 3 added one section on Confucian role ethics, which has not been well discussed in any other engineering ethics textbooks. Chapter 9 is completely new and it has incorporated a comprehensive review of four existing approaches to engineering ethics in the global context. Most recent studies in artificial intelligence and robotics have been added to Chapter 10. The pedagogical resources in Appendix A have been fully updated to 2021. Qin Zhu worked on revising this edition, with general approval from Mike W. Martin.

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Qin Zhu
Mike W. Martin
Roland Schinzinger

CHAPTER 1

ETHICS AND PROFESSIONALISM

Engineers create products and processes to improve food production, shelter, energy, communication, transportation, health, and protection against natural calamities—and to enhance the convenience and beauty of our everyday lives. They make possible spectacular human triumphs once only dreamed of in myth and science fiction. Almost a century and a half ago in *From the Earth to the Moon,* Jules Verne imagined American space travelers being launched from Florida, circling the moon, and returning to splash down in the Pacific Ocean. In December 1968, three astronauts aboard an Apollo spacecraft did exactly that. Seven months later, on July 20, 1969, Neil Armstrong took the first human steps on the moon. This extraordinary event was shared with millions of earthbound people watching the live broadcast on television. Engineering had transformed our sense of connection with the cosmos and even fostered dreams of routine space travel for ordinary citizens.

Most technology, however, has double implications: As it creates benefits it raises new moral challenges. Just as exploration of the moon and planets stand as engineering triumphs, so the crashes of two new Boeing 737 Max series aircrafts (Lion Air Flight 610 in 2018 and Ethiopian Airlines Flight 302 in 2019) were tragedies that could have been prevented, had urgent warnings voiced by experienced engineers been heeded. We will examine these and other cases of human error, for in considering ethics and engineering alike we can learn from seeing how things go wrong. Technological risks, however, should not overshadow technological benefits, and ethics involves appreciating the many positive dimensions of engineering that so deeply enrich our lives.

This chapter introduces central themes, defines engineering ethics, and states the goals in studying it. Next, the importance of accepting and sharing moral responsibility is underscored. Finally, we attend to the corporate setting in which today most engineering takes place and the communal setting in which an increasing number of engineers are working, emphasizing the need for reflecting on the broader social and ethical implications of engineering work.

1.1 SCOPE OF ENGINEERING ETHICS

1.1.1 Overview of Themes

In this book we explore a wide variety of topics and issues, but seven themes recur. Taken together, the themes constitute a normative (value) perspective on engineering and on engineering ethics.

1. Engineering projects are social experiments that generate both new possibilities and risks, and engineers share responsibility for creating benefits, preventing harm, and pointing out dangers.
2. Moral values permeate all aspects of technological development, and hence ethics and excellence in engineering go together.
3. Personal meaning and commitments matter in engineering ethics, along with principles of responsibility that are stated in codes of ethics and are incumbent on all engineers.
4. Promoting responsible conduct and advocating good works is even more important than punishing wrongdoing.
5. Ethical dilemmas arise in engineering, as elsewhere, because moral values are myriad and can conflict.
6. Engineering ethics should explore both micro and macro issues, which are often connected and more ethical issues are arising from the global context of engineering.
7. Technological development especially in the age of artificial intelligence warrants cautious optimism—optimism, with caution.

Let us briefly introduce and illustrate each of these themes.

(1) ENGINEERING AS SOCIAL EXPERIMENTATION. When the space shuttle *Columbia* exploded on February 1, 2003, killing the seven astronauts on board, some people feared the cause was a terrorist attack, given the post–September 11 concerns about terrorism. The working hypothesis quickly emerged, however, that the cause was a piece of insulating foam from the external fuel tank that struck the left wing 82 seconds after launch. The panels on the leading edge of the wing were composed of reinforced carbon carbon, a remarkable material that protected it from 3000-degree temperatures caused by air friction upon reentry from space into the earth’s atmosphere. Even a small gap allowed superheated gases to enter the wing, melt the wiring, and spray molten metal throughout the wing structure.

Investigators stated they were interested in far more than pinpointing the immediate cause of the disaster.[1] Several previous incidents involved insulating material breaking off from the fuel tank. Why were these occurrences not scrutinized more carefully? And why were so many additional hazards emerging, such as faulty "bolt catchers," which were chambers designed to capture bolts attaching the solid rocket boosters to the external fuel tank after their detonated-release? Had the safety culture at NASA eroded, contrary to assumptions that it had improved since the 1986 *Challenger* disaster, such that the independent judgment of engineers was not being heeded? Even during *Columbia*'s last trip, when crumbling shielding hit fragile tiles covering the craft's wings, some knowledgeable engineers were rebuffed when they requested that the impacts be simulated and observed without delay. Had the necessary time, money, personnel, and procedures for ensuring safety been shortchanged?

Very often technological development is double-edged, Janus-faced, morally ambiguous: As engineering projects create new possibilities they also generate new dangers. To emphasize the benefit-risk aspects in engineering, in chapter 4 we introduce a model of engineering as social experiments—experiments on a societal scale. This model underscores the need for engineers to accept and share responsibility for their work, exercise due care, imaginatively foresee hazards, conscientiously monitor their projects when possible, and alert others of dangers to permit them to give informed consent to risks. In highlighting risk, the model also accents the good made possible through engineering discoveries and achievements. And it underscores the need for preventive ethics: ethical reflection and action aimed at preventing moral harm and avoidable ethical dilemmas.

(2) ETHICS AND EXCELLENCE: MORAL VALUES ARE EMBEDDED IN ENGINEERING. Moral values are embedded in even the simplest engineering projects, not "tacked on" as external burdens. Consider the following assignment given to students in a freshman course at Harvey Mudd College:

> Design a chicken coop that would increase egg and chicken production, using materials that were readily available and maintainable by local workers [at a Mayan cooperative in Guatemala]. The end users were to be the women of a weaving cooperative who wanted to increase the protein in their children's diet in ways that are consistent with their traditional diet, while not appreciably distracting from their weaving.[2]

The task proved more complex than it at first appeared. The students had to identify plausible building materials, decide between cages or one open area, and design structures for strength and endurance. They had to create safe access for the villagers, including ample head and shoulder room at entrances and a safe floor for bare feet. They had to ensure humane conditions for the chickens, including adequate space and ventilation, comfort during climate changes, convenient delivery of food and water, and protection from local predators that could dig under fences. They also had to improve cleaning procedures to minimize damage to the environment while recycling chicken droppings as fertilizers. The primary goal, however, was to double current chicken and egg production. A number of design concepts were explored before a variation of a fenced-in concept proved preferable to a set of cages. In 1997 four students and their advisor, supported by a humanitarian aid group named Xela-Aid, traveled to San Martin Chiquito, Guatemala, and worked with villagers in building the chicken coop and additional structures such as a weaving building.

Moral values are embedded at several junctures in engineering projects, including: the basic standards of safety and efficiency, the social, cultural, and environmental contexts of the community, the character of engineers who spearhead technological progress, and the very idea of engineering as a profession that combines advanced skill with commitment to the public good. In engineering, as in other professions, excellence and ethics go together—for the most part and in the long run. In general, ethics involves much more than problems and punishment, duties and dilemmas.[3] Ethics involves the full range of moral values to which we aspire in guiding our endeavors and in structuring our relationships and communities. This emphasis on moral aspiration was identified by the ancient Greeks, whose word *arete* translates into English as either "excellence" or as "virtue."

(3) PERSONAL COMMITMENT AND MEANING. A team of engineers are redesigning an artificial lung marketed by their company. They are working in a highly competitive market, with long hours and high stress. The engineers have little or no contact with the firm's customers, and they are focused on technical problems, not people. It occurs to the project engineer to invite recipients of artificial lungs and their families to the plant to talk about how their lives were affected by the artificial lung. The change is immediate and striking: "When families began to bring in their children who for the first time could breathe freely, relax, learn, and enjoy life because of the firm's product, it came as a revelation. The workers were energized by concrete evidence that their efforts really did improve people's lives, and the morale of the workplace was given a great lift."[4]

Engineers' motives and commitments are as many and varied as those of all human beings. The desire for meaningful work, concern to make a living, care for other human beings, and the need to maintain self-respect all combine to motivate excellence in engineering. For the most part, they are mutually reinforcing in advancing a sense of personal responsibility for one's work. As we emphasize repeatedly, engineering is about people as well as products, and the people include engineers who stand in moral (as well as monetary) relationships with customers, colleagues, employers, and the general public.

All engineers are required to meet the responsibilities stated in their code of ethics. These requirements set a minimum, albeit a high standard of excellence. The personal commitments of individual engineers need to be aimed at and integrated with these shared responsibilities. Yet some responsibilities and sources of meaning are highly personal, and cannot be incumbent on every engineer. They include commitments concerning religion, the environment, military work, family, and personal ambitions. When we speak of "personal commitments" we have in mind both commitments to shared responsibilities and to these more individual commitments as they affect professional endeavors.

Engineers' motives and commitments are critical for them to actually devote themselves to ethical actions. Based on the findings in moral psychology, it is very likely that an engineer knows what the right action is but feels hesitant to do it as the engineer lacks motivation.[5] Engineering ethics education programs in the United States tend to teach students to separate their personal commitments and meaning from *professional ideals*. Arguably, the traditional approach to engineering ethics education often assumes that engineers are isolated, rational, and autonomous human beings and engineering as a profession needs to be *depersonalized*.[6] Therefore, personal traits such as emotion, virtues, and commitments are sometimes invisible in engineering education or are considered irrelevant.[7] Philosopher Michael Davis argues that emotion is quite normal and sometimes can be justified and necessary in the everyday practice of engineers. For instance, an engineer can feel angry when their company generates chemical pollutants to the community and the company leadership has kept overlooking this engineer's remonstration. The emotional state of this engineer in fact well demonstrates their commitment to the safety, health, and welfare of the public.

(4) PROMOTING RESPONSIBLE CONDUCT, PREVENTING WRONGDOING, AND ADVOCATING GOOD WORKS. Beginning in 2001, a wave of corporate scandals shook Americans' confidence in corporations.* In that year, Enron became the largest bankruptcy in U.S. history, erasing about $60 billion in shareholder value.[8] The following year the scandal-ridden WorldCom bankruptcy set another new record. Arthur Andersen, a large and respected accounting firm charged with checking the books of Enron and other corporations, was charged with complicity and was forced to dissolve. We return to these events later in this chapter.

Compliance issues are about making sure that individuals comply to professional standards and avoid wrongdoing. Procedures are needed in all corporations to deter fraud, theft, bribery, incompetence, and a host of other forms of outright immorality. Equally essential are reasonable laws and government regulation, including penalties for reckless and negligent conduct. We should examine the pressures that sometimes lead engineers to cooperate in wrongdoing, rather than reporting wrongdoing to proper authorities.[9]

Having said this, an important part of engineering ethics is preventing wrongdoing in the first place. There is a need for what we have referred to as

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*The term "corporation" will be used freely to include companies that may not be incorporated. In its strict sense, a corporation is a legal construct that enables investors to pool their financial resources for carrying out large, costly, and often risky projects without the burden of individual responsibility for the outcome, physically and financially, beyond possible lack of return on investments. A corporation is treated as if it were an individual itself, taking the blame for the real individual investors. Such an arrangement, so common in our modern economy, raises many questions of accountability and responsibility, particularly shared responsibility.

"preventive ethics": ethical reflection and action aimed at preventing moral harm and unnecessary ethical problems. The main emphasis in ethics should be supporting responsible conduct. In fact, the vast majority of engineers are morally committed. So too are most corporations. Reinforcing the connection between ethics and excellence, individuals and corporations should primarily be "value-driven," rather than simply preoccupied with "compliance-based" procedures, to invoke terms used in management theory. More recently, Charles Harris and his colleagues have suggested that engineering ethics education needs to pay closer attention to the more positive aspects or the "aspirational ethics" of engineering.[10] Most articles in engineering codes of ethics often focus on preventative ethics and they do not provide much clear guidance on how engineering work can promote human well-being. Practicing aspirational ethics often requires engineers to go beyond what is obligatory for them. Nevertheless, we argue that advocating aspirational ethics is beneficial for building positive public images of engineering, cultivating ethical culture of the engineering profession, enhancing the mutual trust between engineers and the public, and generating positive impacts of technological change.

(5) MYRIAD MORAL REASONS GENERATE ETHICAL DILEMMAS. A chemical engineer working in the environmental division of a computer manufacturing firm learns that their company might be discharging unlawful amounts of lead and arsenic into the city sewer.[11] The city processes the sludge into a fertilizer used by local farmers. To ensure safety, it imposes restrictive laws on the discharge of lead and arsenic. Preliminary investigations convince the engineer that the company should implement stronger pollution controls, but their manager insists the cost of doing so is prohibitive and that technically the company is in compliance with the law. The engineer is responsible for doing what promotes the success of their company, but they also have responsibilities to the local community that might be harmed by the effluent. In addition, they have responsibilities to their family, and rights to pursue their career. What should they do?

Ethical dilemmas, or *moral dilemmas,* are situations in which moral reasons come into conflict, or in which the applications of moral values are problematic, and it is not immediately obvious what should be done. The moral reasons might be obligations, rights, goods, ideals, or other moral considerations. In engineering as elsewhere, moral values are myriad and they can come into conflict, requiring good judgment about how to reconcile and integrate them. Beginning in chapter 2 we discuss resources for understanding and resolving ethical dilemmas, including codes of ethics and ethical theories. We emphasize that ethical dilemmas need not be a sign that something has gone wrong; instead, they indicate the presence of moral complexity. That complexity would exist even if we could eliminate all preventable problems, such as the corporate scandals.

(6) MICRO AND MACRO ISSUES. *Micro issues* consider individuals and internal relations of the engineering profession. *Macro issues* concern much broader issues, such as the directions in technological development, the laws that should or should not be passed, and the collective responsibilities of groups such as engineering professional societies and consumer groups.[12] Both micro and macro issues are important in engineering ethics, and often they are interwoven.[13]

As an illustration, consider debates about sport utility vehicles (SUVs). Micro issues arose, for example, concerning the Ford Explorer and also Bridgestone/Firestone, who provided tires for the Explorer. During the late 1990s, reports began to multiply about the tread on Explorer tires separating from the rest of the tire, leading to blowouts and rollovers. By 2002, estimates were that 300 people had died and another thousand were injured and more recent estimates place the numbers much higher since then.[14] Ford and Bridgestone/Firestone blamed each other for the problem, leading to the breakup of a century-old business partnership. As it turned out, the hazard had multiple sources. Bridgestone/Firestone used a flawed tire design and poor quality control at a major manufacturing facility. Ford chose tires with a poor safety margin, relied on drivers to maintain proper inflation within a very narrow range, and then dragged its feet in admitting the problem and recalling dangerous tires.

In contrast, macro issues center on charges that SUVs are among the most harmful vehicles on the road, even *the* most harmful, given their numbers. The problems are many: instability because of their height that leads to rollovers, far greater "kill rate" of other drivers during accidents, reducing the vision of drivers in shorter cars behind them on freeways, blinding other drivers' vision because of high-set lights, gas-guzzling, and excessively polluting. Keith Bradsher estimates that SUVs are causing about 3,000 deaths in excess of what cars would have caused: "Roughly 1,000 extra deaths occur each year in SUVs that roll over, compared to the expected rollover death rate if these motorists had been driving cars. About 1,000 more people die each year in cars hit by SUVs than would occur if the cars had been hit by other cars. And up to 1,000 additional people succumb each year to respiratory problems because of the extra smog caused by SUVs."[15] Bradsher believes these numbers will continue to increase as more SUVs are added to the road each year and as older vehicles are resold to younger and more dangerous drivers.

Should "the SUV issue" be examined within engineering as a whole, or at least by representative professional and technical societies? If so, what should be done? Or, in a democratic and capitalistic society, should engineers play a role only as individuals, but not as organized groups? Should engineers remain uninvolved, leaving the issue entirely to consumer groups and lawmakers? Even larger macro issues surround public transportation issues, in relation to all automobiles and SUVs, as we look to the future with a dramatically increasing population and a shrinking of our traditional resources.

(7) CAUTIOUS OPTIMISM ABOUT TECHNOLOGY. The most general macro issues pertain to technology in its entirety, including its overall promise and perils, an issue taken up in chapter 10. Pessimists view advanced technology as ominous and often out of our control. They point to pollution, depletion of natural resources, fears of biological and chemical weapons, and the lingering threat of robotics taking human jobs. Optimists highlight how technology profoundly improves all our lives. Each of us benefits in some ways from the top 20 engineering achievements of the twentieth century, as identified by the National Academy of Engineering: electrification, automobiles, airplanes, water supply and distribution, electronics, radio and television, agricultural mechanization, computers, telephones, air-conditioning and refrigeration, highways, spacecrafts, Internet, imaging technologies in medicine and elsewhere, household appliances, health technologies, petrochemical technologies, laser and fiber optics, nuclear technologies, and high-performance materials.[16]

As authors, we are cautiously optimistic about technology. Nothing is more central to human progress than sound technology, and no aspect of creative human achievement is less appreciated by the public than engineers' ingenuity. At the same time, consistent with the social experimentation model, the exuberant confidence and hope—so essential to technological progress—needs to be accompanied by sober realism about dangers.

Such a cautiously optimistic attitude is even more critical in the age of AI. Given the huge potential of AI-enabled technologies in improving human well-being and production efficiency, it is unlikely that humans will completely terminate or abandon the development of these technologies. As philosopher Peter-Paul Verbeek has suggested, we as humans need to learn how to morally accompany technology. We are required to thoroughly engage with designers and engineers and "look for points of application for moral reflection and anticipate the social impact of technology-in-design."[17]

1.1.2 What Is Engineering Ethics?

With this overview of themes and sampling of issues in mind, we can now define engineering ethics. The word *ethics* has several meanings. In the sense used in the title of this book, ethics is synonymous with morality. It refers to moral values that are sound, actions that are morally required (right) or morally permissible (all right), policies and laws that are desirable. Accordingly, *engineering ethics consists of the responsibilities and rights that ought to be endorsed by those engaged in engineering, and also of desirable ideals and personal commitments in engineering.*

In a second sense, ethics is the study of morality; it is an inquiry into ethics in the first sense. It studies which actions, goals, principles, policies, and laws are morally justified. Using this meaning, which also names the field of study of this book, *engineering ethics is the study of the decisions, policies, and values that are morally desirable in engineering practice and research.*

These two senses are *normative:* They refer to justified values and choices, to things that are desirable (not merely desired). Normative senses differ from *descriptive* senses of ethics. In one descriptive sense, we speak of Henry Ford's ethics or the ethics of American engineers, referring thereby to what specific individuals or groups believe and how they act, without implying that their beliefs and actions are justified. In another descriptive sense, social scientists study ethics when they describe and explain what people believe and how they act; they conduct opinion polls, observe behavior, examine documents written by professional societies, and uncover the social forces shaping engineering ethics.

As it turns out, morality is not easy to define. Of course, we can all give examples of moral values, but the moment we try to provide a comprehensive definition of morality we are drawn into at least rudimentary ethical theory—a normative theory about morality. For example, if we say that morality consists in promoting the most good, we are invoking an ethical theory called utilitarianism. If we say that morality is about human rights, we invoke rights ethics. And if we say that morality is essentially about good character, we might be invoking virtue ethics.

These and other ethical theories are discussed in chapter 3. For now, let us simply say that morality concerns respect for persons, both others and ourselves. It involves being fair and just, meeting obligations and respecting rights, and not causing unnecessary harm by dishonesty and cruelty or by hubris. In addition, it involves ideals of character, such as integrity, gratitude, and willingness to help people in severe distress.[18] And it implies minimizing suffering to animals and damage to the environment.

1.1.3 Why Study Engineering Ethics?

Engineering ethics should be studied because it is *important,* both in contributing to safe and useful technological products and in giving meaning to engineers' endeavors. It is also *complex,* in ways that call for serious reflection throughout a career, beginning with earning a degree. But beyond these general observations, what specific aims should guide the study of engineering ethics?

In our view, the direct aim is to increase one's ability to deal effectively with moral complexity in engineering. Accordingly, the study of engineering ethics strengthens one's ability to reason clearly and carefully about moral questions. To invoke a term widely used in ethics, the unifying goal is to increase moral autonomy.

Autonomy means "self-determining" or "independent." But not just any kind of independent reflection about ethics amounts to moral autonomy. Moral autonomy can be viewed as the skill and habit of thinking rationally about ethical issues on the basis of moral concern. This foundation of moral concern, or general responsiveness to moral values, derives primarily from the training we receive as children in being sensitive to the needs and rights of others, as well as of ourselves. When such training is absent, as it often is with seriously abused children, the tragic result can be an adult sociopath who lacks any sense of moral right and wrong.[19] Sociopaths (or psychopaths) are not morally autonomous, regardless of how "independent" their intellectual reasoning about ethics might be.

Improving the ability to reflect carefully on moral issues can be accomplished by improving various practical skills that will help produce autonomous