

## ETHICAL ASPECTS OF MEASUREMENT-RELATED RESEARCH AND ENGINEERING PRACTICE

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**Abstract** – The paper contains an overview of ethical dilemmas that appear in measurement-related research and engineering practice. They are presented in a broader context of ethical issues that have been currently discussed in empirical sciences and engineering in general.

**Keywords** professional ethics, scientific misconduct, falsification of measurement data

### PREFACE

This paper does not contain any scientific novelty. It is an essay-type compilation of the author's views and of the opinions of others, selected among those consistent with the author's views. It covers ethical concerns which are common for measurement-relying sciences and branches of engineering. Special emphasis is put on ethical issues related to practice of measuring.

### 1. INTRODUCTION

"Money is just money. Ethics does not apply to it. Ethics is about our relations with family and friends."  
(a Canadian patent attorney)

#### 1.1. Ethics today

Ethics is a branch of philosophy or a philosophical science dealing with the moral principles and rules of human activity. The term "ethics" is also used as a synonym for ordinary morality or the name for a set of special standards of conduct (e.g. "engineering ethics"). In its principal meaning, ethics is an applied science: it is a science because it yields knowledge, and it is applied because it is concerned with the application of abstract principles to concrete problems of human action [1]. Not every type of human conduct is the proper object of ethics since morality is concerned only with free conduct. More precisely, the object of ethics is determined by the scope of our moral responsibility:

- we are responsible only for the fully conscious, free and voluntary actions;
- we are responsible for right and wrong actions if we know that they are right or wrong;
- we become responsible for our actions from the very moment of their planning, not only after they have been accomplished;

- we are responsible not only for the actions themselves but also for their future consequences.

Since the times of the Sophists, scepticism about ethics has been returning in waves. In the fourth century BC in Athens, the Sophists were teaching that morality was a set of rules invented by the rulers to keep the ruled under control, thus a matter regulated by social convention. Conventions may differ from society to society, or even from community to community; thus, morality is relative [2]. There are numerous varieties of ethical relativism, but what they all share is the central dogma that moral propositions, instead of having objective truth – truth for all people in all places at all times – are true relative to one standard but not another [1]. After the Second World War, Western society once again entered into a period of moral and ethical relativism due to significant philosophical shift that can be characterised as a movement from asking what knowledge is – to what knowledge means. Knowledge in postmodern world is a product available for consumers who may select any kind of knowledge they wish. Theories, especially "great" theories, are very much out of fashion. In the internet, knowledge on the same subject is available in many variants and forms for the choosing. Similarly, we are now free to choose our own ethical base, our own values. Ethics in a postmodern world is local, temporary, and without a logical base [2].

#### 1.2. Why are scientists now expected to be more ethically sensitive than they used to be?

The positivists postulated the axiological neutrality of science, but the experience of the twentieth-century science clearly demonstrated that such a constraint of science understanding may be very dangerous for our civilisation as a whole, and for our science in particular. Already in the early seventies, Karl-Otto Apel and Jürgen Habermas started the debate on the ethical aspects of social communication, and showed that the objectivity of science requires a community of argumentation, and argumentation may be meaningful only if some ethical principles are assumed: the respect of truth, responsibility for information, and the respect for others.

John Ziman is trying to answer the title question by referring to the transformation of traditional aca-

democratic science and industrial science into an integrated hybrid institution whose employees, scientists, have to perform new roles in which ethical considerations can no longer be swept aside [3]. In the past – he argues – science was insulated from ethics for two reasons: academic scientists were supposed to be indifferent to the potential consequences of their work, and industrial scientists did work whose consequences were considered too serious to be left in their hands. Applied simultaneously to the new hybrid institution of science, those reasons do not reinforce each other but tend to cancel each other out [3]. Taking into account that the hybrid institution of science creates new incentives for misconduct, the traditional barriers between science and ethics must be questioned.

The increasing concern about ethical aspects of research has been constantly stimulated by the observation made by many researchers, attorneys, and university administrators that the scientific misconduct is getting epidemic [4]. The research community's ability to develop and support ethical standards and expectations has not kept pace with the substantial developments in research. Consequently, a disturbing number of researchers are today negligent and unwilling to acknowledge their mistakes; by their actions, the ability of the research community to govern itself is frequently called into question [5]. There are diverging opinions on the incidence of scientific misconduct, but "it's unscientific to make repeated assertions that scientific misconduct is an extremely small or non-existent problem when we have few or no reliable data supporting those claims" [6]. The author of this statement is referring to a 1987 editorial in *Science* which asserts that: "99.9999% of all published reports are truthful and accurate, often in rapidly advancing frontiers where accurate data are difficult to collect." In fact, there is no basis for this claim, despite the air of scientific precision conferred by the four digits following the decimal point [6].

Not having reliable statistics, let's mention some blatant examples of scientific and academic misconduct:

- The anthropologist Derek Freeman has demonstrated that the famous Margaret Mead's research on Samoan culture was shoddy, ill-informed and far from accurate picture of Samoan life [1].
- At the National Centre for Human Genome Research, its director found that for two years one of his graduate students had published data that were systematically manufactured [6].
- At the Bell Labs research centre in Murray Hill, N.J., one of the centre's brightest stars, Dr. Jan Hendrick Schön, fabricated results in what many considered to be groundbreaking experiments [7].
- At the Lawrence Berkeley Laboratory in Berkeley, California, Dr. Victor Ninov, an expert on the nuclei of heavy elements, fabricated the results of a highly publicized 1999 experiment which supposedly led to the discovery of two new chemical elements [7].
- At the Academy of Pedagogy in Słupsk, Poland, 11 out of *ca.* 100 theses prepared in 2000/2001 under the tutorship of Dr. Elżbieta Gaweł-Luty, Professor of Social Pedagogy, turned out to be almost identical [8].
- At the Silesian University of Technology, Poland, a handbook for students was published which contained pictures copied without permission from handbooks published earlier at Warsaw University of Technology, Poland [9].

Despite growing incidence of similar instances of misconduct, the society still tends to hold the scientific and engineering professions to an elevated standard, and expects scientists and engineers to perform on a higher ethical plane. This justifiable expectation is creating a dilemma for students, young scientists and young engineers, since most of the enduring bulwarks of moral and ethical decision making are being abandoned, and young people are not being equipped with the intellectual instruments required to distinguish right from wrong [10]. Numerous initiatives have recently appeared in various professional and academic milieus to remediate this situation. In particular, the codes of professional ethics have been issued by the professional societies, and the courses of professional ethics have been introduced into academic curricula. The experience related to the latter ones has made possible more precise diagnosis of the state of minds of the young generation. Ronald E. Bucknam reported when the first version of such a course was developed: "it was assumed that students in engineering schools today know and understand the differences between right and wrong, as part of their primary and secondary education, family upbringing and religious training; unfortunately, experience in teaching the course and reports from other instructors at various institutions around the country appear to indicate that this basic premise was unfounded" [10]. Preliminary results of research on the factors affecting the behaviour of young people in the present societal environment point to the deterioration of the family unit, decreasing focus on religious values, abdication of responsibility, over-liberalized education programmes, and increased emphasis on self-gratification and personal aggrandizement – as the primary causes – and the distortion of reality in news media, lack of truth in advertising, unethical practices in business, increased emphasis on litigation to solve differences of opinion – as the secondary causes [11].

These are the premises underlying the motivation behind this paper. With the advancement of science and engineering in the postmodern society, the ethical problems are getting more and more important. Many every-day situations seem to prove that their solution is a *sine qua non* condition of the further progress. One may even risk a statement that their solution is in many cases more important than the theoretical and technical developments.

## 2. ETHICAL ASPECTS OF SCIENTIFIC RESEARCH

"The secret to creativity is knowing how to hide your sources" [13]  
(Albert Einstein)

### 2.1. Unpopularity of truth

Science is an important method of getting knowledge, but it is a limited and far less perfect method than often supposed. The proper understanding of this methodological constraint is necessary to use science for knowledge gain, without limiting the progress. All ways of knowing have their limits and advantages, and all should be used as a unit to best insure progress [4]. An important aspect of science, not often sufficiently stressed, is that its findings should be treated as provisional, never revealing the final truth [4]. For the sake of simplicity, let's avoid sophisticate discussion over the definition of truth and remain with its traditional understanding as the coherence or correspondence of thoughts and things. Of course, we do not experience things directly; consequently, we grasp the truth as a coherence of the common-sense experience of a thing with its mental image or – in a scientific situation – of the methodologically acceptable experience of a thing with its theoretical representation.

For many reasons, the concept of truth is escaped in the context of today's culture:

- The direct personal experience of truth is shrinking in our every-day life. There is a very limited class of situations that we undertake the task of testing the truth of statements we are exposed to. In the majority of cases, we accept those statements without any analysis or reasoning – based on a more or less justified confidence in the source of information.
- We face today an overproduction of ideas. Growing insensitivity, boredom and disorientation is our defence reaction to every-day bombardment of pieces of information, theories, hypotheses and views.
- The elements of interpretation of the reality that are proposed to us are inconsistent: we are exposed to the contradictory thoughts on the same things, all presented as true. To avoid the pain of contradiction, we are choosing to reject the concept of truth.
- Our advanced-technology-based civilisation is highly robust to the untruth. Its functioning seems to be not perturbed by irrational consequences of false pieces of information circulating in it.

The unpopularity of truth, accompanying the transition from modern to postmodern culture, is implying the loss of the confidence in the reason. This is a paradox of the postmodern era that the rapid development of science-based technology is accompanied by decreasing interest of the societies in science and their increasing distrust in its achievements. This phenomenon, together with the progressing specialization of science, has made possible the takeover of the science control by the centres of political power. As a rule,

those centres are not interested in the truth aspect of science but in its practical applicability.

### 2.2. What is scientific misconduct?

Any scientific misconduct has its roots in a transgression against truth. Although what the definition of scientific misconduct should include is a matter of some controversy, all proposed definitions [11], [12] comprise:

- fabrication, *i.e.* making up data or experiments or other significant information in proposing, conducting, or reporting research;
- falsification, *i.e.* changing or misrepresenting data or experiments or other significant information such as the investigator's qualifications and credentials;
- plagiarism, *i.e.* representing the work or ideas of another person as one's own.

Sometimes "other serious deviations" are included in the definition of scientific misconduct, such as cases of theft of, or damage to, research equipment, sabotage of experiments, misuse of funds, gross negligence in a person's professional activities, and setting up a training programme as a means for coercing sexual favours from trainees. Funding agencies explicitly include deception in proposing research in their definition of misconduct [12], [13]. Furthermore, the cover-ups of misconduct in science, reprisals against whistleblowers, malicious allegations of misconduct in science, and violations of due process in handling complaints of misconduct in science are also considered to be instances of misconduct [14, p. 26].

The scientific misconduct should be differentiated from the honest mistakes being a necessary by-product of scientific progress [12]. On the other hand, the heavy instance of scientific misconduct, called fraud in science, should be differentiated from civil fraud because it not necessarily satisfies the legal requirement that there be a party who has been injured by the fraud; there remain, however, other three elements: the perpetrator makes a false representation; the perpetrator knows the representation is false or recklessly disregards whether it is true or false; and the perpetrator intends to deceive others into believing the representation [15]. When it does occur, it is almost always found in the biomedical sciences, never in the fields like physics or astronomy or geology, although other kinds of misconduct do occur in these other fields [16]. The public and the scientific community have both been shocked in recent years by an increasing number of cases of fraud committed by scientists [13]. What are the causes of this phenomenon inside the structure of the institution called science? The answer given recently by Gottfried Schatz seems to get the point: "... we scientists are also contributing to the mess. We want to be smart and forget to be warm. We think too much about competition, and not enough about generosity. We go for power, and forget that power and science don't mix. We are so anxious to become famous that we have no time to

think about what science is all about. There are too many congresses, committees, evaluations, prizes, honours, and elections to academies. There is just too much noise." [17].

### 2.3. Choosing research goals and methodology

The most evident ethical concern, related to the choice of research goals, appears if the study is aimed at creating something morally wrong (destructive or demoralizing). Less evident is the expectation that we use money allotted for research in an ethically irreproachable way. Within the constraints imposed by the quantity of that money and available research infrastructure and personnel, we should define the research subject in a way as to maximize the targeted good. This process of constrained optimization requires, of course, a criterion that should be agreed with the "client" providing finances.

The other class of ethical concerns related to the choice of research goals has appeared in the second half of the twentieth century, during the exponential growth of research institutions, when those institutions started to generate enormous amounts of useless knowledge – scientific banality. The criterion of research originality has been trivialized by being separated from the criterion of significance. The inflow of papers containing new information without any significance for science or practice has contaminated the infosphere making impossible its proper use by modern societies [18]. The most common mechanism generating the infopollution is the system of research evaluation based on the quantitative criteria of published contributions. A simple recipe for success in this system is: avoid authentic originality, stick to the well established areas of study, and publish frequently small pieces of the research results.

There are also numerous ethical concerns related to the research methodology. They are evident in medical or biological studies where the experiments on human beings or animals are subject to well-known restrictions. Less evident are ethical concerns related to the justified use of research money, such as, for example, a classical dilemma concerning the use of synthetic and real-world data. The acquisition of latter ones is usually (much) more expensive, but they yield more reliable results. Thus, the question arises: what is the justified minimum of real-world data to be used?

All scientific results must be treated as susceptible to error. Since scientists do not have limitless working time or access to unlimited resources, even the most responsible among them can make an honest mistake. When it is discovered, it should be acknowledged, preferably in the same journal where the mistaken information was published [14, p. 24]. Mistakes made through negligent work – haste, carelessness, inattention – should be treated more harshly. If scientists "cut corners" for whatever reason, they are placing their reputation, the work of their colleagues, and the public's confidence in science at risk [14, p. 24]. A third category of errors are those that involve deception

(fabrication, falsification or plagiarism); they hit the fundamental values of science [14, p. 26].

When speaking about ethical concerns related to the research methodology, we need to discriminate between reliable and unreliable research or more and less reliable research, as interpreted by Stephen Cole, a distinguished sociologist of science [19]. Richard Feynman, a famous physicist, used the *cargo-cult* parable to characterize ill research methodologies. He made a very accurate observation that many scientists imitate research rituals rather than do science: they employ expensive instrumentation and write journal papers, but an examination of their work may lead to the conclusion that they have been really fooling themselves. They have set out to produce a certain result, or they forget to ask certain critical questions about what they are doing or why. One may even find that questions about the premises underlying their research are forbidden by those who pay for it, and that certain results are deemed unacceptable in advance [13]. This happens more frequently in the today's system of science integrating academic and industrial science than it used to happen in the past in any of those branches of science. This system – being focused on the final result of research rather than on the research process, on the knowledge directly applicable in practice rather than on cognition – has created a favourable environment for scientists who are talented enough to master the research methodology but not necessarily motivated by curiosity, intellectual fascination or scientific dreams. Those people follow the opportunity: easy financing, attractive place of conferencing, prospects for professional promotion. They have no personal interest in the subject of study, neither in its scientific significance; they simply produce knowledge for money [18, p. 69].

During the last 20 years, the evolution of research ethics has followed the lines drawn by Karl R. Popper: from the traditional ethics, based on the idea of individual authority and certain knowledge, towards a new ethics, based on the idea of collective authority and uncertain knowledge. In both cases, the term "authority" is used in the sense of "epistemic authority" as meant by Józef M. Bocheński [20]. The most significant change is related to the problem of epistemic errors. In the past they were excluded from consideration. The new ethics is based on the following reasoning [21]:

- The quantity of knowledge, even that accumulated within a single speciality, is too vast to be mastered and controlled by a single person.
- It is impossible to avoid all errors, even those that potentially can be avoided; they may appear even in the most established and verified theories.
- Discovering of errors is an important task and duty of the researchers. They should be, therefore, open to them, should look for them, analyze them, and learn from them.
- Self-criticism and gratitude for external criticism is thus their moral obligation.

- *Ergo*, the organized methods and mechanisms of critics are a systemic necessity of science.

Although there is no one standard scientific methodology, four steps are generally included [4]:

- the observation of the research object and its environment with respect to its features related to the purpose of study;
- the construction of hypotheses on possible relationships among those features;
- the experimentation aimed at testing the hypotheses;
- the development of some type of statements which generalize the relationships found, *i.e.* confirmed by experimentation.

The critical part of this methodology is acquisition of objective empirical data, obtained by measurement and summarized by statistical methods [4]. Replication under slightly different circumstances is a primary means to reduce the influence of the environmental factors. Unfortunately, because of time, money, interest, *etc.*, this ideal is actually often not implemented.

#### 2.4. Survival in research

Good science tends to be defined as "science that someone will pay for" [13]. There is an overwhelming tendency to apply the free-market paradigms to research and engineering. It means in many cases that if somebody is going to pay you for a scientific or engineering idea you will be tempted to sell it – at the highest possible price – regardless whether it is true or not, whether it may be used against human beings or not, whether it is your fully original idea or not.

Another major concern related to this systemic arrangement is a potential conflict of interest in the process of reviewing manuscripts and grant proposals. Reviewers are advised to be sensitive to such a possibility, and – if in doubt – to return the paper advising the editor of the potential conflict of interest or – alternatively – to furnish a signed review stating the reviewer's interest in the work, with the understanding that the editor may pass this signed review to the author [5]. The reviewers of grant proposals submitted to funding agencies see others' ideas before they have been published. The related abuse consists in plagiarism of ideas, and occasionally of words, formulas, and diagrams from grant proposals. To make the theft from a reviewed grant proposal effective, the reviewer assigns this proposal so low a score that it is not funded. Plagiarism by a grant reviewer is thus a double offence: theft of intellectual property and unfair evaluation [5], [14, p. 17].

Fabricating data for a grant proposal is another example of scientific misconduct related to financing research: what we commonly find is a situation in which an investigator has some scientific evidence for a conclusion but seeks to deceive others about the strength of that evidence [12]. The kind of misconduct seems to be particularly frequent in biomedical sciences which have become "expensive, busy, manipu-

lative, political, and harshly competitive" [17]. Their practitioners are being forced to fiddle with the truth: "if they apply for grants, they must make wild claims, or they won't get funded" [17].

The scarcity of science funding and competitive atmosphere among scientists discourages traditional scientific openness and cooperation. Scientists are hunting for free data and information to put into their proposals, while at the same time withholding information about their own discoveries. Scientific meetings have turned into cautious discussions of where the money is. Many scientists are spending more time on writing proposals than on research [13]. "Today's science is too much dominated by efficient people with cold eyes" [17]. They are intelligent enough to quickly learn how to effectively approach granting institutions, how to choose the research subject to warrant a positive outcome, how to approach scientific gurus to get a positive evaluation, a review or a recommendation. They know the rules of the game, and apply them in practice in a scruples-free way [18, pp. 144-145].

The climate of the "factory of knowledge", dominating over contemporary science, is depriving the researchers of the will and desire to pursue the truth. They have to adapt, *i.e.* become efficient in the above-described sense, in order to survive in the institution [18, p. 147]. Productive scientists complain that they are plagued with administrative work and committees, the paperwork required by granting agencies and foundations, *etc.*; complain but have no choice ... This is an additional risk factor of scientific misconduct: in many recently reported cases, the perpetrators were under career pressure or thought they knew what the answer would turn out to be if they went to all the trouble of doing the research work properly [16]. Researchers often use the term "cutting corners" to refer to such departures from good research practice that endanger research integrity. Being overtired or in a rush to meet a deadline are often given as explanations for negligence in performing tasks or fulfilling responsibilities. Thus, pressure to prove the value of one's work by publishing is a common element in the many cases of reckless research [12].

#### 2.5. Publish or perish

When reading a scientific paper, we are free to agree or disagree with its conclusions, but we want to be confident that we can trust its account of the procedures that were used and the results produced by those procedures [16]. Thus, the deliberate misrepresentation of a conclusion as true when the perpetrator knows it to be false is a cardinal instance of scientific misconduct related to publishing research results. Much more frequent, however, is the exaggeration of what the researcher has done or of the strength of the evidence for some conclusion in which the researcher firmly believes; such exaggeration may be disregard of counter-evidence rather than fabrication or falsification of data or experiments [15].

According to the reports of the office of the Inspector General of the US National Science Foundation, the most common accusation of scientific misconduct is plagiarism [5]. Like falsification, plagiarism is a fundamental betrayal of trust. Plagiarism fails to credit another's contribution. Credit may be given in three different ways, appropriate in different circumstances: inclusion as an author of the article, listing of one's contribution to the work in a formal acknowledgment or citation of a work in the "References" section of the paper [5], [14, p. 20]. An author should cite those publications that have been influential in determining the nature of the reported work and that will guide the reader quickly to the earlier work that is essential for understanding the present investigation. An author is obligated to perform a literature search to find, and then cite, the original publications that describe closely related work [5]. Citations acknowledge the work of other scientists, direct the reader toward additional sources of information, acknowledge conflicts with other results, and provide support for the views expressed in the paper. Thus, citations place a paper within its scientific context, relating it to the present state of scientific knowledge [14, p. 20].

The attribution of undeserved credit qualifies also as a scientific misconduct. Quite frequently, the name of a person is included in a list of authors even though that person had little or nothing to do with the contents of a paper. Such "honorary authors" dilute the credit due the people who actually did the work, while inflating the credentials of those so "honoured". Several scientific journals now state that a person should be listed as the author of a paper only if that person made a direct and substantial contribution to the paper [14, p. 22]. According to the highest ethical standards, one should withdraw one's name from the list of authors if one does not agree with all the statements of the paper or does not consider the subject of the paper significant enough to be published. A strict observance to this rule would considerably reduce the quantity of scientific banality [18, p. 169]. One of the mechanisms generating the number of insignificant papers is fragmentation of research results. It has increased when investigators perceived that the number of their publications was of overriding significance [5].

The banality, and sometimes lack of veracity, is effectively hidden in numerous papers by a fence of language. The Orwell's opinions on the language of English literature, published in 1946, apply to this case directly: "(...) prose consists less and less of *words* chosen for the sake of their meaning, and more and more of *phrases* tacked together like the sections of a prefabricated henhouse. (...) banal statements are given an appearance of profundity by means of the *not un-*formation. (...) if thought corrupts language, language can also corrupt thought." [22]. The last observation is especially true if the authors, consciously or unconsciously, make use of fallacious arguments [23].

The most frequently met logical misconstructions of this type are the following:

- excluded middle (assuming that there are only two alternatives when in fact there are more);
- appeal to anonymous authority ("experts agree that ..", "scientists say ..");
- false causation (assuming that because two things happened in a sequence, the first one caused the second one);
- confusing correlation and causation;
- causal reductionism (trying to use one cause to explain something, when in fact it had several causes);
- argument by selective observation (the enumeration of favourable circumstances and forgetting others);
- misunderstanding of the nature of statistics;
- *non sequitur* inference (something that just does not follow);
- ambiguous assertion (a statement sufficiently unclear to leave some sort of leeway).

A journal space is a precious resource created at considerable cost; an author, therefore, has an obligation to use it wisely and economically. By failing to meet this obligation, one is wasting the time of reviewers and editors [5].

After publication, an author is expected to share data and other research materials with qualified colleagues upon their request. A scientist who is unwilling to meet this expectation runs the risk of not being trusted or respected [14, p. 17].

The institution of peer review, closely related both to publishing research results and to the mechanisms of funding research, is endangered by the recent evolution of the institution of science. The referee, usually one of the few experts in the field, has an obvious conflict of interest. It requires very high ethical standards to not use anonymity for one's own advantage. Unfortunately, as time goes on, more and more referees have their ethical standards eroded by receiving unfair reviews when they are authors [16]. Another related problem is simple dereliction of duty by reviewers who "have no time" to read and carefully evaluate the work of other researchers. According to James R. Wilson, "the problem of non-performance by referees has reached epidemic proportions, and (...) it is urgently necessary for the scientific community to address this scandalous state of affairs" [24]. Peer review is thus one among many examples of practices that were well suited to the time of exponential growth of science, but will become increasingly dysfunctional in the nearest future [13].

### 3. ETHICAL ASPECTS OF ENGINEERING PRACTICE

*"Primum non nocere"*  
(Hippokrates, ancient father of moderne medicine)

Engineering ethics includes standards of ordinary morality, such as those related to honesty, and – on

top of that – some specific additional moral requirements [25]. Engineering ethics is more mature as a topic of discussion than research ethics [12]. This is partly due to an important difference between research and the engineering creation: the engineers – in contrast to investigators – receive independent feedback on the performance or failure of technical objects they create [12].

The capacity of engineering milieus for full moral discourse is currently hampered by several factors. One is that engineers cannot avoid the fact that they deal in a marketplace economy, where competition, cost, and profit motives seem to be the bottom line: they are frequently under pressure to please the boss, the stockholders, the client, rather than follow the guidance of conscience. Consequently, a lot of indifference and even cynicism can be found in the engineering professions. When lines become blurred and difficult to draw, then moral standards seem out of reach [26].

In contrast to research, practicing beyond one's competence in engineering is recognized to be irresponsible since grave harm to others may result from incompetent practice [12]. In general, the consequences of engineering activity split into two broad categories: anticipated (intended and desired, not desired but common or probable, not desired and improbable) and unanticipated (desirable, undesirable) [27]. The unpredictability in engineering is related – on the one hand – to the complexity, dynamics and intransparency of technical systems, and to ignorance and mistaken hypotheses of engineers – on the other [27]. One of the less recognized factors that limit our ability to anticipate consequences of engineering actions is our concern with the immediate foreseen consequences that excludes consideration of longer-term consequences: one's actions may be rational in terms of immediate results, but irrational in terms of long-term interests or goals [27].

Ethics is about what we ought to do. But how we can decide what we ought to do when the outcomes of our actions are uncertain? There are no simple answers to this very important question, but there are some general principles which may or may not be applicable in a particular situation. In general, we can decrease uncertainty in four ways: increase knowledge, combine uncertainties through large scale organization, increase control of the situation, and slow the progress [27]. We should take advantage of those ways to reduce uncertainty to the extent that the costs permit. We are not obliged to exhaust all of our resources or money to reduce uncertainty because this could easily outweigh the good to be gained from the action [27].

A good example of technical objects provoking recently ethical debates are nanocomputers or nanomachines which could be used as molecular assemblers and disassemblers to build, repair, or tear down any physical or biological object. On the one hand, numerous potential benefits of their use are

exposed [28]: in manufacturing (precision manufacturing, material reuse, miniaturization), in medicine (pharmaceutical creation, disease treatment, nanomachine-assisted surgery), and in environment protection (toxin cleanup, recycling, resource consumption reduction). On the other, however, serious concerns are raised if the consequences of nanomachines application are considered since it is clear that they may be used for the development of new terrible weapons of mass destruction or for electronic surveillance [28].

#### 4. ETHICAL ASPECTS OF MEASUREMENT PRACTICE

"It is wrong always, everywhere, and for anyone, to believe anything upon insufficient evidence." [29]  
(William K. Clifford)

##### 4.1. General considerations

Measurement is a source of evidence in science and engineering. It is a key element of any research in natural sciences, medicine and technology, and a fundamental tool of engineering design and testing. The ethical misconduct related to the methodology of measurement, to the execution of measurements or to the interpretation of measurement results may have, therefore, a significant negative impact on the quality of research and quality of engineering creations. By using incorrect or unsubstantiated measurement data provided by others, one infects one's own research; and the chain of consequences can be lengthy and very serious. This is as true of honest or careless mistakes as it is of the intentional distortion of data, which is what the scientific or engineering misconduct is usually restricted to [11]. In many prominent cases of pathological science, the root of the problem was data selection that may have been subconscious but was nonetheless grossly misleading [24].

Measurement is an operation aimed at acquiring information. Measurement science and technology is thus a part of a broad super-discipline called Information and Communication Technology (ICT). The ethical problems, characteristic of ICT in general, apply – at least partially – to measurement science and practice. The most mature branch of ICT ethics is computer ethics which traditionally deals with such problems as privacy, accuracy, intellectual property and access, security and reliability [30]. ICT, however, by transforming in a profound way the context in which traditional ethical issues arise, adds new dimensions to old problems [30]. The networking of society, based on computers and telecommunication links, implies a depersonalisation and an increasing sense of the practical anonymity of actions, in a context where an individual agent's behaviour is often perceived as only a marginal and microscopic component of wider and more complex courses of action. The diffusion of responsibility brings with it a diminished ethical sense in the agent and a corresponding lack of perceived accountability [30]. On the other hand, qualitatively new phenomena related to infosphere, encourage the

formulation of new ethical requirements, such as: entropy ought not to be caused in the infosphere; entropy ought to be prevented in the infosphere; entropy ought to be removed from the infosphere; or information welfare ought to be promoted by extending, improving and enriching the infosphere [30].

The logical, mathematical and practical links between measurement and mathematical modelling of physical objects have been profoundly explained during last 30 years. It is thus evident that the ethical problems related to measurement are inherent for modelling and *vice versa*. The engineers working on modelling for simulation applications are sometimes exposed to considerable pressure from commercial management or customers to "adjust" their models in order to provide desired results [24]. The only effective guard against such practices is an honest validation of models as accurate representation of the corresponding target systems, by means of appropriately designed measurement experiments [24].

#### 4.2. Measurement methodology

It is clear since publication of the Kurt Gödel's incompleteness theorem (1931) that even mathematics is unable to prove that some its statements are true or false. Most philosophers of science agree that science is unable to prove the veracity of some basic assumptions (paradigms) it is for centuries based upon. Measurement science is unable to prove that the results of measurement contain any truth about physical reality; thus, the discourse between realists and instrumentalists is continued. Methodological relativism, inspired by this situation, implies sometimes ethical relativism in studying and doing measurements being a source of serious ethical concerns. The measurement people have to be extremely clear about the methods they use to gather and analyse data. They should be aware that not only the validity of the data but also the validity and precision of the methods used for acquisition of those data are subject to evaluation. The development of a new method can be a controversial process; its reliability as a source of information is always under scrutiny. If someone is not clear and exact about the procedures used to derive a new result, the validation of that result by others will be hampered [14, p. 10].

The uncertainty of measurement results may imply the uncertainty of the decisions or actions based on those results. This becomes a delicate ethical issue if those decisions or actions touch welfare or lives of human beings. Taking into account that the cost of measuring is usually growing quickly with the required accuracy, one may ask: what is an ethically justified level of uncertainty in such situations? Let's consider a typical example. Because it is impossible to deterministically test an aircraft controller, probabilistic testers are used for this purpose. It is estimated at 99% confidence level that after 100-day testing, the undetected bugs remaining in the aircraft controller may cause a crash of the host airplane after  $10^5$  years

on average. It is proposed, for the reason of savings, to reduce the time of testing to 10 days which would imply the corresponding reduction of the average time to fault to 100 years. Is it ethically justifiable to place money on human life? If so, how should it be computed? If not, how should engineers and society determine the acceptable risk of a particular technology? The software version of this example, with a corresponding numerical illustration may be found in the internet [31].

#### 4.3. Acquisition and analysis of measurement data

Fabrication of data and falsification of data are two among three generally recognized forms of scientific misconduct, condemned also by engineering milieus. Several factors can encourage the publication of fudged measurement data: academic researchers are under pressure "publish or perish"; prominent scientists may be tempted to "cut corners" because they feel that nobody will challenge their results; busy peer reviewers are inclined to scrutinize papers only for obvious flaws [7]. The subject of fabrication and falsification of data is not entirely new: in 1830, Charles Babbage, father of computing, wrote a book on dishonesty in research [32] where he introduced the term that is still very much in use: "cooking the data." To cook the data is to select only those data that fit one's hypothesis and to discard those that do not. Selecting data solely because they support one's hypothesis is misconduct, now called "falsification" of data. It should be noted, however, that "data selection," when made according to legitimate criteria, is an indispensable part of science. It is legitimate to discard some data if they are evidently contaminated or if statistical methods applicable to those data warrant discarding some "outliers." An essential feature of legitimate data selection is disclosure of the methods of selection [12]. In the context of ethical discussion on falsification of data, a case of Robert A. Millikan is largely analysed by the authors of many papers and books on research ethics.

Robert A. Millikan won the Nobel Prize in 1924, mainly due to his important and innovative measurement, carried out around 1910, of the charge of the electron. His method involved watching the behaviour of oil drops in an electrically charged field. Ionized by passage through an atomizer, they have an extra electron or electrons riding on them. A drop was allowed to fall between two plates, and then an electric field was created which pulled it upwards. The speed of the drop depended on the charge riding on it; thus, the rise time was measured. Millikan published tables of measured rise times which indicated that the charges on the drops were multiples of the same number – the charge of the electron. A confrontation of Millikan's papers with laboratory notebooks has revealed, however, that he selected his drops for publication purpose. Sometimes he mentioned this fact in his publications, and sometimes he did not. Of particular concern is the fact that in his 1913 paper, presenting the most

complete account of his measurements, he stated "It is to be remarked that this is not a selected group of drops but represents all of the drops experimented upon during 60 consecutive days." Some authors, analysing his case from an ethical point of view, condemn him because his published statement is at odds with what can be concluded from an uncritical examination of his notebooks. Others defend him on the basis of a careful analysis and interpretation of comments on the data that appear in those notebooks: they find that the assertion that all drops were presented in the paper refers to all of the data taken under those conditions when the apparatus was working properly [11].

In the information era, the era of abundance of measurement data generated by complex scientific and engineering institutions, one may legitimately ask about the distribution of moral responsibility for the quality of the data in the hierarchies of experts involved in the process of their acquisition. Laboratory heads frequently candidly admit that the volume of data collected in their laboratories makes it impossible for them to personally check even their own graduate students research results; and that they would attempt to do so only if some reason were presented to doubt a result [15]. Trust is thus necessary where the trusting party cannot control or monitor the trusted party's performance. Limits on the efficacy of monitoring are especially clear where research collaborators come from different disciplines [15].

#### 4.4. Presentation of final measurement results

The uncertainty of measurement data should be assessed and disclosed to make those data meaningful. In many practical cases, however, this means the disclosure of technical or medical risk. Even when this risk may have been demonstrated to be extremely small, it is non-zero and it means a negative message very likely to be eliminated by people of marketing... The codes of ethics of engineering societies, such as IEEE, demand "...to disclose promptly factors that might endanger the public or the environment," and "...to be honest and realistic in stating claims or estimates based on available data ..." [33]. Airlines, however, rarely mention safety in their advertisements, though it is implied and it is a reasonable expectation [31].

Sometimes the quantitative expression of measurement uncertainty is impossible. This applies, in particular, to complex experiments of partially qualitative nature. In such cases, circumstances that might make the experiment invalid should be reported – not only what one thinks is right about it: other causes that could possibly explain the results, factors whose influence has been eliminated by some other experiments, *etc.* [34]. In contrast to advertising, one should give all of the information to help others to judge the value of one's contribution; not just the information that leads to judgement in one particular direction or another [34].

The validity of the procedure used for obtaining the raw data has been always a primary responsibility of measurement people. Today, it should be complemented with the secondary responsibility for the interpretation of those data, *viz.* for the validity of the procedure of inference underlying this interpretation, because it is getting to be, more and more, an integral part of the measurement process since the advent of computerised techniques of measurement. To realize how this issue delicate may be, let's follow an analysis of the inference about the existence of hydrogen in the sun based on certain observations made with the spectroscope, the analysis provided by William K. Clifford more than 120 years ago: "By looking into the spectroscope when the sun is shining on its slit, we see certain definite bright lines: and experiments made upon bodies on the earth have taught us that when these bright lines are seen hydrogen is the source of them. We assume, then, that the unknown bright lines in the sun are like the known bright lines of the laboratory, and that hydrogen in the sun behaves as hydrogen under similar circumstances would behave on the earth. But are we not trusting our spectroscope too much? Surely, having found it to be trustworthy for terrestrial substances, where its statements can be verified by man, we are justified in accepting its testimony in other like cases; but not when it gives us information about things in the sun, where its testimony cannot be directly verified by man? Certainly, we want to know a little more before this inference can be justified; and fortunately we do know this. The spectroscope testifies to exactly the same thing in the two cases; namely, that light-vibrations of a certain rate are being sent through it. Its construction is such that if it were wrong about this in one case, it would be wrong in the other. When we come to look into the matter, we find that we have really assumed the matter of the sun to be like the matter of the earth, made up of a certain number of distinct substances; and that each of these, when very hot, has a distinct rate of vibration, by which it may be recognised and singled out from the rest. But this is the kind of assumption which we are justified in using when we add to our experience. It is an assumption of uniformity in nature, and can only be checked by comparison with many similar assumptions which we have to make in other such cases" [29].

## 5. CONCLUSIONS

On many occasions, it has been indicated in this paper that numerous ethical concerns of scientists and engineers, in particular those involved in measurement activities, are by-products of our postmodern civilisation or get importance due to some peculiarities of this civilisation. Global industrialisation and the phenomenon of consumer society are two principal mechanisms of this civilisation that produce forces destructive with respect to the traditional systems of values. One of such values in science is trust. The level of

trust that has characterized science and its relationship with society has contributed to a period of unprecedented scientific productivity. The scientific research enterprise is built on a foundation of trust: trust that the results reported by others are valid and trust that the source of novel ideas will be appropriately acknowledged in the scientific literature. To maintain this trust in the current climate of research, much more attention must be given by the scientific community to the mechanisms that sustain and transmit the values that are associated with ethical scientific conduct [15].

Throughout most of its recent history, science was constrained only by the limits of imagination and creativity of its scientists. In the recent decades that state of affairs has changed dramatically. Science is now constrained primarily by the number of research posts, and the amount of research funds available. What had previously been a purely intellectual competition has now become an intense competition for scarce resources. This change is likely to have an undesirable effect in the long run on ethical behaviour among scientists [16]. Such and similar opinions are expressed by many intellectuals, but there is no signs of systemic reaction. This seems to confirm an entomologist's observation that we humans are in some sense opposite of social insects who individually may look very stupid, but collectively always behave in such a way as to secure survival. We, humans, have enough wise people among us, but collectively...[35] Two remedies already implemented by academic and engineering milieus – introduction of special courses of professional ethics to the academic curricula, and promulgation of codes of professional ethics – are of limited effectiveness.

Numerous examples of ethics courses for students of engineering may be found in the proceedings of annual conferences of the American Society for Engineering Education, published in 1995-2003 [36]. Those courses are usually aimed at increasing ethical sensitivity of students, providing them with knowledge of relevant standards of conduct, enhancing their capacity of ethical judgment, and improving their ethical will-power [25]. Unfortunately, as a rule, they are treated by a prevalent majority of students as a politically correct decoration of the curriculum, without any practical significance – thus unnecessary.

Numerous codes of professional ethics, issued by learned societies and professional associations – the codes differing in the literary form and the level of generality – may be found in the internet [33], [37-41]. The development of professional codes of ethics is resulting from the lack of understanding of the fundamental difference between ethics, meaning a set of standards of moral conduct, and law. In modern societies, law is imposed and implemented (executed) by political authority; it is codified and it applies to strictly predefined issues, not necessarily concerning morality. Ethics is a set of moral standards freely accepted by a person or a social group; it is a product of free, individual or collective, reflection over the

dialectics of good and bad aspects of all human relations; it applies to both recurrent and completely new situations that are not morally neutral. The professional codes of ethics seem to imitate law. Consequently, they can serve to excuse us from personal morality and can be used as a tool for avoiding moral considerations. In some cases, codes of ethics are designed merely to avoid outside regulation of a profession [26]. Even blind devotion to ethical codes cannot enable us to adequately respond to the ethical concerns of scientific vocation or engineering profession; the final burden is always upon our conscience and values [26].

Genuine ethical autonomy is the product of reflective and honest choice. It is the freedom to gauge meaning, to browse among one's meditations, to change one's perspective. To be morally alert is to be conscious of the complexities that ethical dilemmas impose [26]. The engineer's or researcher's sense of identity and ethical responsibility demands critical reflection upon the multiple avenues of professional conduct rather than blind adherence to codes [26]. This ability should be developed at home, at school, and at academe; it should be enhanced by positive examples of public life and creations of art; it should be practised in every-day life. Unfortunately, this list of wishful thoughts is very likely to be mocked by the avantgarde of modern "engineers of souls"...

Swallowing this grain of bitterness, let's conclude this paper with a quotation from the famous Richard Feynman's essay "Cargo Cult Science": "So I have just one wish for you – the good luck to be somewhere where you are free to maintain the kind of integrity I have described, and where you do not feel forced by a need to maintain your position in the organization, or financial support, or so on, to lose your integrity. May you have that freedom" [34].

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