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ENGINEERING LITERACY

Abstract. *The UN project "17 Sustainable Development Goals" pursues the goal of a guaranteed solution to the problem of hunger, providing clean water and the like for the entire population of the Earth. The brief terms of this project (only 15 years) reinforce the responsibility of the main team, namely engineers. The qualification of any engineer will increase if he/she acquires additional knowledge in other technical areas in addition to the main profession. A compulsory educational program called "Engineering Literacy" (EL) is offered. It is planned that the EL will describe the main sectors of modern engineering. The same format is provided for the description of each technical sector under the heading, for example, the Space Industry Section, or the Nuclear Energy Section, or the Construction Sector Section, etc. The difficulty of each of the sections should be at the level of a high school graduate. Other requirements for each section are discussed in more detail in the article. As a demonstration, the article presents a preliminary short version of the Section "Nuclear Energy. Lessons from the past to avoid mistakes in the future".*

Keywords: *UN SDG, Engineering Literacy, Science Literacy, Space Industry, Construction Sector, Brief description of the Section.*

INTRODUCTION

Human beings moved slower compare to animals almost in all periods of their presence on Earth. In ancient times large groups of people, e.g., the armies of Alexander the Great or Roman cohorts even with access to the best technologies of their time had the same speed as our present walking tours. Most likely, this fact will be considered as obvious. Therefore, let's make a mental jump "closer" to our time. We will be surprised but the motion of armies saved the same "walking" speed after 2 thousand years. This statement is correct for Napoleon's army; for the battles of World War I and even for the main part of World War II.

Unique machines, which helped to outstrip the fastest animals [1–3], appeared quite recently, only about 100 years ago [4–6]. These references demonstrate the results of fair competition. Trains appeared earlier, in the 19th Century, but train requires rails for its motion.

It took about 50 years more for the implementation of the "records" into regular life. As the result, today, any inhabitant of the Earth can move faster than animals on the ground, in the sky and in the sea[1]. Technical progress didn't stop there. The artificial "brain" demonstrated its advantages compare to the human being one after the victory over the chess champion in 2000. More and more artificial assistants were being created in parallel. Almost every human being has a cell phone — a pocket device for communication with the whole world with the "library" with unlimited amount of information as a bonus (access to the Internet). The list can be continued.

Statement #1:
Exactly last 30–50 years are the period of triumph of technical progress after investments into science for thousands of years

The UN program "17 Sustainable Development Goals" for 2015–2030 [7] was created for fixing key problems of mankind, such as the exclusion of hunger; the provision of every inhabitant of the Earth with clean water and enough amounts of energy, etc. Moreover, the UN stated that SDGs should be implemented within 15 years. Such a short period for the program means that SDGs can be achieved by using the existing technical base only. Implementation of new (significant) inventions looks unrealistic within 15 years. Thus, the most qualified expert community confirms the author's Statement #1.

Statement #1 doesn't against scientific research. Indeed, this is the confirmation that investment in science is the correct decision. But for the purposes of this article the main objective of Statement # 1 is to stress of increasing role of engineers today.

This article is the continuation of the previous author's research related to Science Literacy in general [8–10]. Based on Statement #1 one can speak about separate and PRIORITY element within Science Literacy, namely Engineering Literacy (EL). EL also can be the pilot initiative for mandatory training. The arguments, which explain above, are in the first and the second chapters of this article.

[1] E. g., AWD cars; Water scoopers and Airliners.

The third chapter proposes the general format for EL. The key proposal is to have separate Divisions for each area of engineering. Thus, the last chapter demonstrates the first draft of such Division by using nuclear energy as an example.

SCIENCE LITERACY, SCIENCE POPULARIZATION AND STEM

WHY DO WE NEED ENGINEERING LITERACY AS ADDITIONAL ELEMENT?

The different areas that compliment "classic" education and increase the level of scientific knowledge were analyzed in previous publications [8–10]. More specifically, Science Literacy and Science Popularization related to natural sciences as well as "Science + Technology + Engineering + + Math" (STEM) were discussed. The following conclusions were made from this analysis:

1) Science Literacy is the component, which integrates all three listed ones: Science Literacy; Science Popularization and STEM. The function of Science Literacy is similar to the function of the elementary school if one builds a "hierarchy" of Science Literacy; Science Popularization and STEM. This is exactly Science Literacy, which can help any human being to identify correctly the challenges of technical progress (both positive and negative ones);
2) Science Literacy training similar to the study in elementary school should be MANDATORY for everybody. Science Literacy training in contradiction to elementary school study should be extended for the whole life to follow the progress in technique.

Declaration (about mandatory training) and implementation (of mandatory training) have totally different content. It is impossible to overcome the "distance" between declaration and implementation in one jump. The step-by-step approach is more acceptable. And engineers are the most suitable audience for the start. First of all they are "inside the subject" because of their profession. Secondly, they already use post-graduate courses, thus the new training can be considered as the extension. Additional arguments are listed below.

THE ESSENCE OF ENGINEERING LITERACY

The story, which was described in Jules Verne's novel "The Mysterious Island" [11], is related to the second part of the 19th Century. The heroes of this novel were landed on a deserted island as the result of the damage the balloon. Despite of shortage of initial tools they could create a metallurgical plant, build a boat, design and install telegraph communication lines and did other useful things. These results were achieved by using a comprehensive knowledge of engineer Cyrus Smith and his correct management. The prototype of the "universal" engineer Cyrus Smith was based on real people in Jules Verne's science fiction 150 years ago. The universal engineer in the 21st Century is real science fiction.

The majority of modern engineers are high-skilled experts. This statement is correct for the knowledge and skills in the only area of their professional expertise. Unfortunately, (very often) the engineer doesn't differ too much from humanitarian in case of discussions about other technical fields.

The union of scientific and engineering associations of Ukraine (USEAU) receives proposals, which can "change the world" very often. In most cases even elementary expertise shows useless of such proposals. One of the latest proposals was about the following. The "inventor" suggested to create powerful solar plants on the Earth's poles and to connect this power stations with the fridges for ice production. New ice would stop the global temperature increasing according to the inventor's thoughts. The absurdity of this idea is absolutely clear for anyone, who remembers physics from secondary / high school. The school task asks: what would be with the temperature in the room in case one opens the door of the working fridge? It is evident that the school task and above invention are the same in nature and have only scale difference. The limited survey was conducted among engineers about the correct answer to school task during preparing of this article. Unfortunately, only a few engineers gave the right answer[2].

Let's use the soft definition "forgetfulness of modern engineers" for the knowledge quality of school physics / chemistry. There are (at least) two reasons for such forgetfulness. The first reason is related to the explosive increasing in the amount of information. "Beautiful packaging" helps for better memorization of new information without verification of its trustfulness. At the same time proven (but boring) info is transferred to the periphery of our memory. The second reason for forgetfulness (author's vision) is the permanent increasing in friendliness of the modern machines and devices. Once upon a time we measured room size by a measuring tape. It was impossible to get correct data without refreshing of the theory of mistakes [12]

[2] Indeed, there are no needs in deep knowledge in thermodynamic. One also doesn't need to study of the components of the fridge and their relationship. The only one fact is needed: the efficiency of any device is always lower than 100 %. And also remember that efficiency has a useless part (missing part to 100 %), which always **heats the environment**. Thus, a fridge with an open door would heat the room, and very expensive complexes (solar panels plus fridge) on the poles would increase (!!!) the temperature of the planet.

in our memory. Almost all cell phones today have electronic/ laser measuring tape. Thus, one can measure office size without leaving a chair and without a theory of mistakes. The classic thermometer reminded us about the expansion of the liquid with increasing of temperature. The changes of atmosphere pressure were clear from the deformations of the "box" in the old barometer and their connections with the arrow. Alas, modern electronic devices exclude the opportunity to remind physical laws. The majority of us have forgotten numeracy skills, preferring to use Excel of phone calculator. As the result, the technical knowledge, which engineer has acquired on the lessons of physics, chemistry, biology and mathematics in school, are firmly forgotten in "adult life".

Although forgetfulness is caused by objective reasons, it leads to (at least) three negative consequences specifically for engineers.

Firstly, an engineer with wider knowledge has added value in its profession. The credibility of his / her project will increase in case the engineer compares own solutions with best practice in other branches. Such additional knowledge can be used by both: or engineer-researcher, or technician. The forgetful engineer has no such advantage.

Secondly, and it is natural, that exactly the engineer can provide his / her relatives by fair knowledge about the influence of modern and future technologies on family life. The noise from the construction of a new building nearby in combination with breaking news about earthquake initiate natural question. What about the safety of our own building? Can IT-engineer answer on this question? What about the harm from a multi-hour talk by use cell phone? The powerful source of electromagnetic waves is very close to the brain. Does a chemical engineer know the right answer?

There were very prestigious to be the officer in the bank for many centuries. Modern online banking followed to fast firing of human beings in the banks. AI will enhance the trend. There is an opinion that unmanned vehicles can kill the profession of taxi driver. What is about my own profession in the future?

The discussions about many global challenges today, like climate changes or Mars colonization are similar to Agora — meetings in Ancient Greece or revolutionary crowds. In both cases participants are guided primary by emotions[3] instead of analysis. Who, if not engineers, should act as independent experts for increasing analysis value? This is the third reason for fighting with forgetfulness.

The above arguments can be undoubtedly rewritten into the following:

Statement No. 2:
The program Engineering Literacy is needed, which will describe modern level of S&T and link this knowledge to the basic laws of nature

What is the novelty of Engineering Literacy compare to "ordinary" post-graduate training? Post graduate training is already used worldwide and confirmed its efficiency. It is also mandatory for civil engineers in many countries.

Engineering Literacy as a new program should be the addendum to regular post-graduate study. The objective of "classic" training is updating knowledge for the specific profession periodically. The proposed objective of Engineering Literacy is to get extra knowledge. It is assumed that the new program will consist of "Divisions" with the specific description about, e. g., space industry, or construction, or green energy in each of them. The list of proposed divisions is the below **table 1**.

The list of Divisions for mandatory study should be complimentary to the main profession of the specific engineer. By other worlds, Engineering

[3] his statement doesn't mean that author is against the emotions. There were exactly the emotions, which saved our Motherland — Ukraine several times in recent history. However, the author is strictly against such emotions, which are in contradictions with the laws of nature.

Table 1

Proposed list of Divisions

No.	Division title	No.	Division title
1.	Nuclear energy	8.	Artificial intelligence
2.	Space industry	9.	Metallurgy and chemical technologies
3.	Construction	10.	Roads and ground transportation
4.	Green energy	11.	Helicopters and aircrafts
5.	Traditional energy	12.	Nano- and other advanced materials
6.	Microelectronics	13	Communication and GPS
7.	Clean water	14.	Bioengineering

Literacy is an additional study for NON-PROFILE engineers.

GENERAL REQUIREMENTS FOR THE FUTURE PROGRAM

The general approach for the study of natural sciences in high and secondary schools, despite of some negative / inefficient elements, can be used as the base for Engineering Literacy. The author was a member of the team for preparing of the chain of textbooks in physics for secondary and high school, e. g. [13]. This experience allows getting sight of the main feature of studying natural sciences in schools. It is impossible to create a full chain of proofs, similar to university course, because of limited knowledge of schoolchildren in mathematics. This conclusion is valid for 90 % (?) of cases. Instead, the authors of any textbook provide more or less free description. The trustfulness of such description is supported by the high reputation of school education.

A similar approach can be used for Engineering Literacy. The author does believe that the scientific complexity of Engineering Literacy should be on the similar level of the complexity of the natural science programs in high school. This is only the chance to save interest to the subject for the future students. And world class authors and the umbrella of international engineering federations will ensure the credibility of the information in the Engineering Literacy Divisions.

The free presentation style in the Division allows to include of three mutually supported parts in the whole description. The first one is the history of this area of technique. This part should be limited by the framework: Past experience for the elimination of the mistakes in the future. The second part is for demonstration of the best technical results in this area. And finally, the text description should be supplemented by a large number of qualitative problems for increasing the creativity component.

Each Division should be prepared in the format of E-brochure (for decreasing expenses and increasing opportunities for distribution). The content should be updated periodically and E-format is the most suitable for this purpose. Similar to the best school manuals the description should have an Internet extension. Based on this feature, the limited size of the main E-brochure (probably around 50 pages) can be extended by: a) an exercise book with the task of different level of complexity; b) science popularization in various formats; c) movies related to the subject for family watching.

As the summary, proposed Engineering Literacy is the flexible system, which:

- Includes periodically updated package of knowledge needed for the engineer for improvement of his / her professional skills;
- Use the same package for the needs of the engineer's family or public activities;
- Is created in the framework of the similar amount of knowledge as in high / secondary schools and is synchronized with school programs;
- Is available for free;
- Is formed in the format for potential use by the whole family;
- Can be used itself as technical dictionary;
- Provides links to other technical databases.

NUCLEAR ENERGY; LESSONS FROM THE PAST TO EXCLUDE MISTAKES IN THE FUTURE

In parallel to this article, the author is preparing E-brochure with the same, as this chapter name. It is assumed that this E-brochure will be the draft of the first Engineering Literacy Division (see Table above). The limited size of the article size doesn't allow to include of all information into this chapter. Therefore, this chapter can be considered as "a movie trailer".

Nuclear reactions are much more powerful source of energy compare to fossil fuels or conventional explosives. Such understanding appeared long before the exact values of nuclear reactions were measured. There is one copy of the engineering journal, which was issued in the regional branch of the Ukrainian engineering organization and which is stored in the archive of USEAU [14]. The name of the Ukrainian city Mykolaiv, where this journal was issued, is known mainly for the engineering community because of as a shipbuilding plant. Nevertheless, one can find the article about engineering aspects of nuclear energy use, which was written by the almost modern language. Please, note that the first nuclear reactor was built only after 40(!) years after the Ukrainian publication [15]. Impact from the nuclear device on the globe level was demonstrated even later, in 1961 [16][4].

"Nuclear world" is absolutely unusual for the classic engineer. The first difference is the sizes. The next comparison demonstrates this difference clearly. One of the thinnest artificial items in our everyday life is aluminum foil in our kitchen. Its thickness is 20 mkm. Let's mentally increase the microscopic nucleus of an atom up to a more "ordinary" size, say to the size of an orange. A proportionally enlarged thin foil will transfer into giant

[4] It was the test of so-called the Tsar Bomb with a nuclear yield of 58.6 Mt. The seismic wave generated by the explosion circled the globe three times. More details one can find by himself.

plate with equal to the Earth's diameter thickness. The measuring "device" in the micro world has the similar size as the object of measurement, therefore, the measurement procedures are differed from regular ones. The interaction between particles has a non-linear (also unusual) nature. All listed phenomena require new theoretical description, namely quantum physics instead of classic one. Interested engineers can expand their knowledge in math and learn quantum theory by themselves.

Here is the continuation of the engineering aspects of nuclear energy use. Despite of the specific features of the micro world, the engineering solutions were very similar to those in the classic world. The size of the journal article doesn't allow to describe the details. The only two features are underlined here: a) the key engineering solutions are the examples of masterpieces; b) the scale of production facilities for nuclear energy use exceeded previous cases in tens and more times. The only one example is shown below for decoding of above statements. The technologies and equipment for the separation of uranium isotopes should be created. Every family uses separation of the substances with different masses a few times a week while switching on the centrifuge of the washing machine. The task with uranium is more complicated because: a) the masses of isotopes are almost the same; b) the quantity of needed isotope is less than 0,1 % in the mixture. By use analogy, one should obtain, say 10 liters of water from almost dry clothes. Let's continue this analogy. One should gather all washing machines from the large city, like Paris and Rome. He also should gather all the clothes and, maybe, all linen from the city. The next step is to rent a stadium for these washing machines and to build an electric power plant for the supply of the new facility by electricity. Indeed, previous description is almost the right picture for uranium separation. The only one correction is much more precise centrifuge use.

The history of nuclear energy contained not only engineering masterpieces, but also the engineering mistakes. E. g., the accidents on Chernobyl [17] and Fukushima [18] atomic power plants are well-known. The engineering mistake is the most popular explanation for both of these accidents. An alternative version can be formulated as: the reason is the shortage of scientific and engineering literacy. The proof package will be in the full version of this Division[5]. Both terrible accidents defined the trends: a) to close nuclear energy programs (e. g., Germany) and b) to use more safe solutions. International Atomic Energy Agency recommends one of a such safe solution, namely the module reactor [19].

It should be mentioned thermonuclear reactors, which are using fusion nuclear reactions, for complete the picture. Natural examples of such reaction one can see every day (Sun or other stars on the sky). The example of military application was mentioned above [16]. But there is a long delay with the creation of a fusion reactor for electricity / heat production. Scientists from many countries are trying to obtain "artificial Sun" in the labs for 70+ years. The only last information demonstrates certain progress [20].

The links to the movies related to the subject will be provided in the last part of the chapter. These movies can be recommended for watching together with the families. After completion of Engineering Literacy the engineer can be the family guide with the explanation of complicated scientific / engineering items. There are stories about heroism, e. g. [21]; spy stories, e. g. [22; 23]; tragedies, e. g., [24]; and human dramas, e. g. [25]. This list can be continued.

CONCLUSIONS

1. The mandatory Engineering Literacy course as the addendum to the standard post-graduate education is proposed;

2. Engineering Literacy should include the study of those areas of technique that compliment the main profession of an engineer. The list of such areas has been proposed, in particular, Space industry; Nuclear energy; Construction sector, etc.;

3. The same format is proposed for each description (Division). The main components of this format are: a) lessons learned from the history of the development of the specific area of technique; b) modern level; c) the set of qualitative problems for increasing creativity component. More specific criteria were also formulated as addendum to the main ones;

4. The draft / pilot description for the Division "Nuclear energy" with the title "Nuclear energy; Lessons from the past to exclude mistakes in the future" is presented.

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[5] If shortly, there were two faults: a) unprofessional experiment at the beginning and b) operator mistake at the end. Both ones were because engineers ignored the technical difference between a nuclear reactor and ordinary thermal reactor.

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ІНЖЕНЕРНА ГРАМОТНІСТЬ

Резюме. *Проєкт ООН "17 Цілей Сталого Розвитку" має на меті гарантоване розв'язання проблеми голоду, забезпечення чистою водою для всього населення Землі тощо. Стислі терміни цього проєкту (лише 15 років) посилюють відповідальність команди ключових виконавців, а саме — інженерів. Кваліфікація будь-якого інженера буде зростати в разі набуття додаткових знань в інших технічних сферах, які є додатковими до основної професії. До уваги читачів пропонується обов'язкова освітня програма "Інженерна грамотність", що має на меті описати основні сектори сучасного інжинірингу. У програмі передбачено однаковий формат для опису кожного технічного сектору: наприклад, розділ "Космічна промисловість", розділ "Ядерна Енергія", розділ "Сектор Будівництва" тощо. Складність кожного розділу має бути на рівні випускника середньої школи. Інші вимоги до кожного розділу окреслено в статті більш детально. У статті наведено попередню коротку версію розділу "Ядерна енергія. Уроки з минулого для виключення помилок у майбутньому".*

Ключові слова: *ЦСР ООН, інженерна грамотність, наукова грамотність, космічна промисловість, сектор будівництва, стислий опис розділу.*

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