EDUCATION FOR ENGINEERING STUDENTS: THE CASE OF LOGIC

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***Abstract* – Logic is one of the common denominators of philosophy, mathematics and computer science. As such, it is one of the basic ingredients of engineering education. This paper is a case study: the case of logic, from school pupils, up to advanced engineering students. We end with concluding remarks on the current place of the logic studies background in engineering schools.**

Keywords: *logic, education, engineering, methods of reasoning.*

1. INTRODUCTION

Logic has been defined as the study of the rules of correct thinking. It concentrates on the principles that guide rational thought and discussion. The most fundamental concept in logic is that of an argument. An argument must be distinguished from "arguing", which is a debate or disagreement between different people. The logical concept of an argument is: a set of statements, one of which is the conclusion, the others are premises, and the premises support the conclusion. In other words, it is a statement along with the evidence that supports it [11].

When we discuss about logic, we have to refer to the different domains of logic, and understand how they relate to our field of interest and expertise. Logic encompasses a number of sub-topics: arguments; methods and patterns of reasoning; attributes and classification; propositional logic; predicate logic; higher-order logic; deductive vs. inductive logic; multivalued logic; modal logic; formal logic.

Logic plays a key role in sciences, as it is one of the underlying concepts that transcend the domain of discourse of each particular science. If there is going to be any rational discussion of different positions, the discussion must use the rules of logic. While logic will not specify what the content of the statements are, it will tell you how to arrange the statements in a logical fashion [12].

For example, in exact sciences, all the new knowledge is obtained using logical deductions and logical reasoning. In experimental sciences, a lot of accent is put on classifications of concepts and information. In advanced sciences, equally important is the use of higher order logics, meta-logics, etc., that actually generalize different aspects of binary logic.

We are also mentioning here the fuzzy logic, developed in 1965 by Lotfi A. Zadeh, which generalizes the concept of truth value, allowing statements to be not only strictly true and strictly false. Fuzzy logic is currently used not only in theoretical developments, but as well in scientific and industrial applications.

Traditionally, logic is studied as a branch of philosophy, together with grammar and rhetoric. Since the mid-nineteenth century, formal logic has been studied as the foundation of mathematics. This relationship has been established in 1903 by Bertrand Russell and Alfred North Whitehead in their book, Principia Mathematica [13]. On the other side, the development of formal logic and its implementation in computing machinery is considered as the foundation of Computer Science.

We argue that Engineering, together with Mathematics and Computer Science, form a triangle of disciplines that, today, live and act interdependently. From an engineering point of view, we remark that Mathematics provide underlying theoretical methods and methodologies, while Computer Science provide, among others, the necessary modeling and simulation tools to help with engineering design.

The main points of this paper are that logic, with many of its branches, is an ancestor of engineering; that logical thinking is fundamental to a successful engineering education; that accurate logical thinking is formed during years, slowly by slowly, but consistently, with the classes of logic taught to elementary and high school pupils, with the logical and mathematical reasoning taught to undergraduate students.

A good understanding of logic and a good formation of logical thinking depends, as well, on the horizontal connections learned and understood by pupils and students: you do not (or, better, you *should not*) learn logic because you have to, because you were told to. You learn logic because this is the one and only fundamental topic you actually use in your everyday life. Whatever you do, you use some logic. Even the lack of logic denotes some kind of logic. Everything else is built on top of logic.

This paper is organized as follows: section 2 covers teaching of logic in elementary (section 2.1), secondary (section 2.2) and high-schools (section 2.3). Section 3 covers teaching of logic in undergraduate education: section 3.1 approaches the specialization of Mathematics, section 3.2 approaches the specialization of Computer Science, section 3.3 approaches the specializations of Physics and Chemistry, and section 3.4 approaches different specializations of Engineering. Section 4 deals with the impact of logic and logic thinking to engineering. The paper ends with a section on concluding remarks.

2. LOGIC IN ELEMENTARY, SECONDARY AND HIGH-SCHOOL EDUCATION

The purpose of this section is to discuss the topics of logic relevant for an elementary school pupil, based on the degree of understanding of a human being aged 6-10 (primary school children) and 10-14 (gymnasium children), and we are going to continue with an analysis of logic education for high-school students, i.e. people aged 14-18.

We are considering the applicability of the logic background to different disciplines studied in school. We underline that this is the most difficult part of a logic teacher: to make the pupils see that whatever they learn in class they actually use in different other classes, or in their everyday life.

2.1. Elementary school

Children at the level of elementary school have evolved around their genetic background, and developed with the help and support of their parents. It is our belief that children inherently reason, act and react in a ‘logic’ manner. The logic behind their actions may not, however, be obvious. Consequently, all our actions and activities towards children have to be logic, and consistent. The whole relation cause-action-effect has to be transparent to the child, and no actions should be taken and enforced based on the reasoning “you do this because I am telling you this”. The child should be created a framework where he should feel that he is making the judgment and the decision, that he is receiving proper feed-back on his reasoning process, that his parents and tutors are eager to contribute to developing his reasoning independence, and not to force him into reasoning with the mind of others.

If the children see a logical pattern in the actions of the people surrounding them, the children are most likely to evolve in a positive manner, because they are going to make one step behind simply understanding the logic. At some point they will make their own deductions and generate their own rules and patterns based on the logic they learn from their parents and educators.

On the other side, an illogic behavior from their tutors, or a behavior based on the argument of force, and not reason, will most likely lead to a reverse effect in the child mind. The child may withdraw, and may get wrong conclusions about him, his performance, and the particular issues that are required from him.

2.2. Secondary school

At age 10-14, pupils are still too young for a full course of logic. There is still a lot to be done to make the pupils understand the relevance of logic.

The main task rests with professors of most of the disciplines the children are studying. One of the main issues with children learning is that they tend to learn and prepare for each subject in an isolated manner. They tend to ignore the relationship between study objects.

While the different subjects may not be actually related to each other, it is the sensitive task of the teacher to stress the rationale, the methods of reasoning and all the logic background without which the whole subject of study would become nonsensical.

The students will definitely notice that similar reasoning patterns are applied with more than one subject, and will start to make connections based on this common background. They will use the learning experience from one subject in order to gain efficiency with a different subject.

2.3. High school

This is the proper place for the first course of logic. We believe that this course of logic should allow the students to start from their previous background, i.e. use of logic and reasoning patterns to learn with different subjects.

A logic course for high schools should as well include some logic formalisms. Full understanding of propositional logic, as well as of different patterns of formal and real world reasoning is necessary. Of course, at every place examples from the real world and from the studied subjects should be provided.

It is our opinion that at this point the teacher of logic should have a strong orientation towards exact sciences. Experiences in Romanian high schools show that a teacher of logic with a humanistic background tends to ignore the interdependencies of the course with other disciplines, and teach the course as a separate entity.

High-school children would definitely benefit of practical sessions of adversarial reasoning, where the class splits in teams reasoning for and against certain topics. Periodically, the teams would change sides, and the new positions should be reasoned using other arguments than those used by preceding teams.

3. LOGIC IN UNDERGRADUATE EDUCATION

At this point, of undergraduate studies, formal logic may be approached in its full elegance. The logic foundation set in high-school is solidified at this level, as undergraduate students already have a formal mind. Of course, such a course should have a specific orientation based on the different specialization domains of the undergraduate students.

We discuss the relationship between (formal) logic and exact sciences. We will uncover logical thinking and logical concepts in different aspects of exact sciences. We will remark that many issues in such sciences, familiar to different degrees to non-professionals, are good examples of logical reasoning.

We are commenting on the coverage of logic with the undergraduate programs available at the two major universities in Cluj: the Babeş-Bolyai University and the Technical University of Cluj-Napoca.

3.1. Study of Logic in Mathematics

The undergraduate curriculum in Mathematics at Babeş-Bolyai University [15] includes a fundamental course in Logic, taught in the first semester: *Logic, Set Theory and Arithmetic*. The course deals with elements of mathematical logic (propositional calculus, the decision problem, predicate calculus and quantifiers), sets, relations, functions (operations with sets, binary relations, functions, injective, surjective, bijective functions, equivalence relations and factor sets; the kernel of a function, factorization theorems, ordered sets, lattices, homeomorphisms, Boole algebras. applications to Logic and Computer Science), cardinal numbers (direct product and exponentiation of sets and functions, operations with cardinals, ordering of cardinal numbers, infinite and finite sets, elements of combinatorics), numbers (axiomatic set theory, natural numbers, the Frege-Russell construction and Peano's axioms, construction of integer, rational, real numbers), arithmetic (divisibility, greatest common divisor, the division algorithm, Euclidean algorithm, prime numbers, unique factorization theorem).

Because of the nature of the specialization, the entire curriculum shows a strong dependence on logic, logical thinking and logic habits. There is a strong accent placed on setting hypotheses, proving or disproving conclusions, reasoning, producing new knowledge, consistent with the past knowledge.

3.2. Study of Logic in Computer Science

The undergraduate curriculum in Computer Science at Babeş-Bolyai University [15] includes three courses relevant to Logic: *Mathematical Foundations of Computer Science*, taught in the first semester; *Functional and Logic Programming*, taught in the third semester; *Formal Languages and Compiler Design Methods*, taught in the fifth semester.

The course *Mathematical Foundations of Computer Science* deals with the presentation of logic foundations for computer science: propositional and predicate calculus, Boolean algebra and Boolean functions. The connection with logic programming and logical circuits is presented. Additionally, the codes of information representation are introduced. The following concepts are covered: the propositional and predicate calculus, from algebraic point of view and as deductive systems; normal forms; decidability problem in predicate calculus: direct and by refutation methods of theorem proving (Herbrand method, resolution method); Boolean algebra, Boolean functions and applications; canonic and maximal monomials; simplification of Boolean functions by Veitch, Mc. Quine and Moisil methods; Boolean equations; combinational and sequential circuits; systems of numeration, conversions; the direct, inverse, and complementary codes; theorems of addition; representation of numeric information.

The course *Functional and Logic Programming* aims to get the student accustomed with new programming paradigms (functional and logic programming); to introduce a programming language for each of these paradigms (Common Lisp and Prolog); to induce the idea of using these programming paradigms based on the applications' necessities; to assure the necessary base for approaching certain advanced courses. The following topics are covered: Functional programming and the Lisp programming language (programming and programming languages; imperative programming vs. declarative programming; the importance of functional programming as a new programming methodology; history and presentation of Lisp; basic elements in Lisp; symbols management; definitional mechanisms; data structures, macro definitions and optional arguments); Logic programming and the Prolog programming language (basic elements of Prolog; facts and rules in Prolog; goals; the control strategy in Prolog; variables and composed propositions; anonymous variables; rules for matching; the flow model; examples; the Prolog program; backtracking; composed objects and functors; recursive data structures); Other functional and logic languages; Examples of applications; Programs presented comparatively in Lisp, Prolog and in imperative languages; Specific applications.

The course *Formal Languages and Compiler Design Methods* deals with grammars and languages; Chomsky hierarchy; regular grammars, finite automata and their equivalence; context-free grammars, push-down automata and their equivalence. Compiler construction fundamentals: compiling phases, scanning, parsing and code generation.

The considerations of the logic background of curriculum, mentioned for the mathematics specialization are valid, as well, with computer science. A mention is worth, however, the more pragmatic character of computer science. Computer scientists not only deal with theoretical reasoning, but they have, as well, a strong tendency towards the practical impact and usefulness of knowledge, practical applications based on such knowledge. Even if all the mathematical background is important for unlocking different reasoning patterns, a few particular mathematical areas are essential for a good preparation in computer science. We are considering here algebra, statistics, probability theory, discrete and continuous systems

Because of the nature of the specialization, the entire curriculum shows a strong dependence on logic, logical thinking and logic habits. There is a strong accent placed on setting hypotheses, proving or disproving conclusions, reasoning, producing new knowledge, consistent with the past knowledge.

3.3. Study of Logic in Physics and Chemistry

The undergraduate curriculum in Physics [16] and Chemistry [17] at Babeş-Bolyai University includes an elective course in Logic: *History and logic of science*, taught in the third semester.

Other than this elective course, the whole background of logic is made available through specific courses of mathematics. As well, in an indirect manner, different concepts and behaviors of logic inspiration are used and formed throughout the learning activity. Students with majors of Physics and Chemistry use logic when needing to form hypotheses with their experimentations, when proving the validity or invalidity of these hypotheses, when reasoning about theoretical results based on past knowledge.

3.4. Study of Logic in Engineering

The undergraduate curriculum in Automation at the Technical University of Cluj-Napoca [18] includes a number of courses with contents relevant to Logic: *Mathematical Analysis I*, *Mechanical Engineering*, *Knowledge-Based Systems*. Other than these courses, an elective course of *Logic* is available, taught by the Department of Socio-Human sciences.

The course *Mathematical Analysis I* includes elements of Logic: statement calculus, sentential connectives, predicate calculus.

The course *Mechanical Engineering* includes an introduction to logic mechanisms with mechanical parts, and the analysis and design thereof).

The course *Knowledge-Based Systems* refers to logic programming, knowledge base, expert system, man-machine interface, fuzzy logic, interfaces for fuzzy logic controller (FLC), fuzzy logic controller, fuzzy logic controller adjustment, fuzzy logic modeling, fuzzy modeling, neural network, identification using neural networks).

The undergraduate curriculum in Computer Engineering at the Technical University of Cluj-Napoca [18] includes a number of courses with contents relevant to Logic: *Introduction to System and Computer Science*, *Analysis and synthesis of numeric devices*, *Numeric circuits*, *Logic programming*, *Logic Foundations of Artificial Intelligence*. Other than these courses, an elective course of *Logic* is available, taught by the Department of Socio-Human Sciences.

The course *Introduction to System and Computer Science* includes an introduction to logic machines, logic transformations, information representations in computers, numeration systems and base conversions, errors in computer arithmetic.

The course *Analysis and synthesis of numeric devices* refers to Boolean algebra; analysis and synthesis of combinational circuits; analysis and synthesis of sequential logic circuits; design of numeric systems with programmable devices.

The course *Numeric circuits* includes coverage of different types of integrated logic circuits, their parameters, design and use.

The course *Logic programming* covers the foundations of logic programming; declarative semantics in first order logic; the minimal Herbrand model; procedural semantics; correctness and completion; negation as failure; undecidability in logic; programming techniques in Prolog; expressiveness of pure Prolog; meta-logic predicates; extra-logic predicates; non-determinist programming; incomplete data structures; lists and difference structures; search techniques; meta-interpretation.

The course *Logic Foundations of Artificial Intelligence* covers the following topics: introduction to AI; intelligent agents; problem solving by search; informed search and exploration; problems of constraints satisfaction; adversarial search; logic agents; first order logic; inference in first order logic; knowledge representation; planning; planning and action in the real world.

Other technical specializations offer general and special courses of *Mathematics*, partly oriented towards mathematical logic, partly oriented towards the high mathematical knowledge required for these particular specializations. As well, elective courses are provided, including *Logic*, by the Department of Socio-Human Sciences.

4. IMPACT OF LOGIC TO ENGINEERING

This section concentrates, using different case studies, on the impact of logic and logical thinking to engineering.

4.1. Logical thinking ability

The importance of cultivating logical thinking ability has been strongly emphasized. In addition, logical aptitude tests are included in entrance and employment exams, and logical thinking ability is used as a criterion in admission and hiring decisions. The study [10] develops material for cultivating logical thinking ability in the form of a confrontational (two-player) game learning system. The programs constructed by students combat each other, and are then analyzed and improved as a means of supporting the cultivation of logical thinking ability. The paper [10] describes a case study of cultivating logical thinking ability in teaching high school students.

4.2. Applications of fuzzy logic

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth, i.e. truth values between “completely true” and “completely false”. The concept was introduced by Dr. Lotfi Zadeh in 1965 as a means to model the uncertainty of natural language.

Zadeh originally devised the technique as a means for solving problems in the soft sciences, particularly those that involved interactions between humans, and/or between humans and machines. Within the United States, with some exceptions, the technique has remained mainly of basic research interest.

The situation in Japan is quite different [4]. Because of a Japanese cultural view of the vagueness of human nature (all concepts belonging partially to contradictory sets), there was almost immediate enthusiasm for the idea. This led to active research and a host of commercial applications, almost entirely in the area of physical systems control. The currently fielded applications range from large-scale electro-mechanical processes, like subway systems and elevators, to mass market consumer applications like camcorder focus or smooth operation of automobile cruise controls.

4.3. The Saligny brige

The King Carol I Bridge (later renamed Anghel Saligny Bridge) was built between 1890 and 1895 in Romania over the Danube and Borcea and when it was completed it then became the longest bridge in Europe and the third in the world [14].

The two cities on the banks of the river which was built were Feteşti on the left side and Cernavodă on the right side. The bridge was used for almost a century, until it was replaced in 1987 with new bridge built next to it.

As it is demonstrated by one century of uninterrupted use (1895-1995), the system of bridges of Cernavodă is a real work of engineering art. The bridge has a length of 4,037 meters of which 1662 meters over the Danube and 920 meters over Borcea and was designed by the Romanian engineer Anghel Saligny. It is 30 meters above the water, allowing tall ships to pass under it. The bridge has four spans of 140 meters and one of 190 meters.

Among the numerous original solutions successfully used at the building of the Cernavodă bridge, we only mention here the use of soft steel, that contributed to the extended durability of this construction.

The bridge was inaugurated on 26 September 1895 and as a test on the opening, a first train of 15 locomotives sped at 60 km/h, followed by a second train, speeding at 80 km/h. Meanwile, Anghel Saligny, together with the heads of the construction teams, waited confidently under the bridge, in a small boat.

The reader will agree that this is a good example of logic thinking in engineering. Instead of building repeated versions of the bridge, based on trial and error, the designer carefully analyzed the task, considered the relevant variables and attributes, and realized mathematical models, used scientific research, worked on these models in such a manner that the final work satisfied all the constraints. Thus, with logic thinking and engineering knowledge, Saligny was confident that the bridge, when built, was up to its task.

5. CONCLUSIONS

We have analyzed logic from the point of view of its impact to philosophy, mathematics and computer science. We have considered the impact of these different fields to engineering.

We have discussed the approaches to logic at different moments in a student's education. We have approached logic for elementary school children, for secondary and high schools. We have discussed about the curricula of logic for a few specializations, considered relevant for the engineering education: mathematics, computer science, physics, chemistry, automation, computer engineering. We have approached, as well, the impact of logic and logical thinking to engineering.

This paper brings an important point. A good understanding of logic and a good formation of logical thinking depends, as well, on the horizontal connections learned and understood by pupils and students: you do not (or, better, you *should not*) learn logic because you have to, because you were told to.

You learn logic because this is the one and only fundamental topic you actually use in your everyday life, and in our specific specialty studies. When learning, studying, and reasoning about knowledge, facts, hypotheses, deduction rules, you actually use logic. Whatever you do, you use some logic. Even the lack of logic denotes some kind of logic. Everything else is built on top of logic.

Mankind, before being formed by *human* beings, is formed by *logical* beings. Logic is our friend. The study of logic from different perspectives has originated the domains of Philosophy, Mathematics and Computer Science. We use logic in our everyday life. We use logic as an important tool in our research. We use logic to reason, to teach others, to learn from others.

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