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MODERN PHYSICS IN A GLOBAL SOCIETY

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Dedicated to Professor Boran Leontić on the occasion of his 70th birthday

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Successes of modern physics and consequent technologies have enabled humanity to create our global village. However, despite their thorough training and proven, useful knowledge, physicists are nowadays often treated as a relatively inexpensive 'commodity'. Encouraged by experience of several former students, and by using selected examples, I argue that as a community we should better 'market' our physics profession that, in addition to its primary role – rational understanding of nature – provides: i) the most versatile undergraduate degree, also for those who want to continue studies in management, economy or bio-medicine; ii) fascinating creative opportunities in advanced research and new interdisciplinary technologies and iii) often more relevant insight into workings of the global economy than the 'conventional' economic approach, and especially into smart venture-investments. All these themes are equally relevant for the Croatian society and its welfare in the early 21st century.

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1. Introduction: perception of modern physics

In this paper, I do not present modern physics as we usually discuss it among physicists. Instead, I begin with the perception of modern physics by the pragmatic (and sometimes greedy) money-making fraction of our present global society. Personally, I think that contemporary physics, as an academic discipline, is in a great shape and as challenging as ever, and I emphasize that the primary role of physics remains the deep insight and rational understanding of measurable, natu-

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ral phenomena. As such, our curiosity-driven discipline requires and deserves stable funding from usual government sources, yet for various reasons (mainly negative influence of the mass-media) this is often not a priori granted. Therefore, my main objective here is to share some of the inner struggle that we all feel (in Europe, in the USA, in Switzerland as well as in Croatia) that could help us to better 'market' our science and our arduously won understanding in a rather fast evolving cost-effective, global (and local) society of the 21st century. Namely, whether we like it or not, and despite their excellent professional training and relevant contemporary skills, physicists are nowadays often treated as relatively inexpensive 'commodity', partly due to a collapse of the 'iron curtain' and the partial end of the arms race. Ideas similar to these discussed here are already seriously considered by our professional bodies (EPS, APS, MRS, . . .) and many colleagues are taking an active part in these discussions: how to 'market' physics-profession, how to attract the best talent, how to maintain our intellectual impact (and leadership) and, in some cases, how to simply survive in the tough restructuring of the fast evolving global village, in a jungle of new ideas and rather weak (or sometimes abundant) funding.

I want to emphasize that, although this article provides an 'easy reading' even for non-physicists (that is one of my aims), several thought-provoking examples and some generally unknown facts are often 'hidden' in the text or within the context of the paper. Also, many facts that seem trivial to physicists are often perceived as striking by, say, bankers. For example, the businessmen are always amazed when they see the range of numbers used in modern physics (see Table 1). They probably somehow believe that we treat those numbers in a way they make conventional business deals (with a profit ranging from 1- 50%). Moreover, management consultants often admit to me privately that, given our skills, we are generally poorly paid, yet that it is our responsibility (of the physics community) to 'market' achievements of our own profession and of our own specific know-how. So, this paper does offer some 'marketing' tips for those who want to actively promote our profession.

It is the modern physics (for example, our understanding of electrodynamics) that has created our present global technological society yet, we have to make certain that all the young people in our society are aware that our profession provides (at the very least): i) the best undergraduate degree (and certainly the very best universal, intellectual package), for students who want to continue their postgraduate studies in engineering, economy, management or even bio-medical professions; ii) the best qualification for any advanced research, interdisciplinary development or strategic analysis, and iii) profound insights into the workings of the complex global economy and venture investments. I will not discuss all these claims in detail but I will provide some examples. Each member of our professional community should find his/her way of presenting our profession to other segments of the society. No longer can we expect to work in 'closed', elite ivory towers, so we better learn fast how to integrate into the new global framework. I will also argue that all these 'global' themes are equally relevant to the Croatian society of the early 21st century.

Modern physics uses a set of experimentally verified models that enable us to describe the observed, measurable natural phenomena [1–20]. As physicists, we know that these are not dogmatic ideas and it is very plausible that some future generation will drastically modify or, at best, gradually update our present understanding [19]. My 'popular' view of modern physics was published elsewhere [21] and I have deliberately cited literature for non-specialists who are looking for some additional reading. Here I will drastically oversimplify the perception of physicists. I will use an image that I know, from my own experience, roughly represents how some financial managers perceive us. Note that they consider us a 'commodity': you can hire a physicist when you have some need for modeling of a specific financial problem. To avoid any misinterpretations, I emphasize that this is not our own image of ourselves; it is how decision- and money-makers often perceive our 'usefulness'.

Table 1. Numbers used in our daily life and global finances, compared to numbers used in modern physics.

Numbers that we use in our daily life, presented in an 'unusual' form (for consumers):	$\approx 10^3 = 1\,000$
Numbers that by now use most financial institutions and (big) bank managers - billions:	$\approx 10^9 = 1\,000\,000\,000$

Very large numbers in physics:

Number of electrons in a cm^3 of a metal	$\approx 10^{22} = 10\,000\,000\,000\,000\,000\,000\,000$
Estimated number of atoms in human body:	$\approx 10^{28}$
Estimated number of atoms in the Universe:	$\approx 10^{80}$

Very small numbers in physics:

Diameter of an atom in meters:	$\approx 10^{-10}$ m
Planck's constant:	$h = 10^{-34}$ J s= 0.000 000 000 000 000 000 000 000 000 000 000 1 J s

So, try to think of a (computational) physicist as a 'big-bank-manager' of energy quanta ('money units'). While the true bank manager distributes the monetary units across the Planet and tries to satisfy interests of his bank and his clients, the physicist studies the distributions (by using the laws he understands) of quanta of energy that he skillfully distributes within a 'sample' (or available states). While the former tries to make a financial profit by intelligently re-distributing money-units and investing some of it into the fast growing profitable enterprises, the latter measures energy distributions in various systems and tries to model how nature 'uses' energy quanta (or vibrations) in it's numerous (strange) phenomena and achieves some form of equilibrium or, in some cases, fast, exponential growth. In such a picture, an applied physicist (or chemist), appears almost as an alchemist, (s)he successfully creates artificial phenomena and/or states of matter (for example: new artificial materials) and is indeed very much an active co-creator of the contemporary technology; certainly not just a 'passive', smart observer of the Universe.

Such an image of a physicist is evidently very naive, incomplete and certainly does not give justice to our profession or our true science. Most physicists dislike it, yet I know from my numerous popular lectures that it helps create a communication bridge and ultimately high degree of appreciation from a pragmatic, money-oriented members of the society (usually not interested in laws of nature or any non-profitable 'understanding'). Therefore, it is useful to be aware of such a perception, when we try to communicate with power-centers that nowadays may (or may not) be interested to support our noble science. Namely, ever more rarely can we get 'normal' grants from usual sources (mostly government-related budgets) for our curiosity driven research or even advanced applied concepts. The present society likes to perceive our work as 'useful'. This is fairly general trend, visible in developed western countries, as well as in societies in transition, like Croatia. And it is with such an image in mind that the financial community hires our bright students and uses them in numerous financial centers around the Globe. Physicist's skills are essentially used to apply fairly well established models and equations and use them in a financial context. Specifically, at my home-institution the EPFL, the trend in the past 15 years is fairly evident. The number of graduates who continue doctoral studies in physics is roughly constant. While in the early eighties most physics graduates were hired for some form of R & D in the industry, in the late eighties it was the US electronics companies that seemed to dominate the job scene (especially Intel, Santa Clara). Nowadays, at the close of the century, the job offers to our graduates abound from (inter)national financial institutions and/or management consultants. And in most post-industrial societies we have difficulties to attract domestic students to complete physics doctorates; they tend to pursue postgraduate studies in other disciplines, notably managment.

In what follows I will try to discuss various 'skills' and 'ideas' that global society finds attractive about physicists and that so far have not entered into our University curricula or into our mainstream professional thinking. Firstly, I note that, given the fact that global economy is almost fully integrated and has reached an estimated volume of the order of several tens of trillions of dollars (almost \$ 10^{14}, hence an acceptable number of 'particles' even for physicists), global money distribution changes, fluctuations and chaotic (or in some cases strongly correlated) behaviour are far beyond the understanding of conventionally educated economists or bank managers. The Wall Street certainly does not resemble La Bourse in Paris of the 19th century so problem solving ability and the insights and mathematical ability of trained physicists are more and more appreciated.

In Table 1 we can see some very large and some very small numbers that are part of our professional knowledge and that we use in our description of nature. When we try to think of them within the aforementioned 'banker-physicist' analogy, some novel insights begin to emerge. Firstly, by now billions have clearly become financial numbers, and, if present trends continue (plus some inevitable inflation), the stock-exchange will soon use trillions in their anual financial dealings. This is partly unavoidable, as the human mind is the same in physicists and economists, so ultimately in any analysis there is a finite number of archetype-models to follow. These archetypes are, in most cases, the models used in physics. Therefore, most other groups in the society tend to come to us (or to applied mathematicians) for guidance in complex data analysis. However, rather comfortingly, I note that extremely large or truly small numbers remain firmly in the domain of physics. Nevertheless, when we also learn that every day the Swiss banks win or loose close to $ 30 million just in daily fluctuations of various currency rates, we begin to grasp that, at least to global society's financial decision-makers (who manage distributions of billions of dollars) some of our established modeling techniques (often boring to us) appear rather useful. Alas, applied to a rather banal pursuit of money making.

2. 20^{th} century physics and technological society

In the March 29 (1999) issue, the TIME magazine [22] summarizes remarkable achievements of some two dozen of the greatest minds of the 20^{th} century. Discoveries of Einstein (theory of relativity), Bohr (quantum physics), Watson and Crick (DNA structure), and Berners-Lee (world wide web) are discussed, together with Shockleys's co-discovery of transistor, or his co-creation of the remarkable Silicon Valley. What immediately strikes any reader of such a review is the fact that most of these discoveries have already made tremendous impact on our world-view and produced huge technological changes. The use of electricity in the beginning of the century, the radio after the World War I, the TV after the WW II, or more recently, the silicon chip, the personal computing or the Internet had a tremendous impact on our productivity. We now live in the computer-assisted information-society global-village era.

Most of these technological revolutions can be directly traced to the discoveries of modern physics [1]. But, what I want to emphasize here and what is not well known, is that most of these remarkable creators received their first degree in physics. To physicists this is not surprising, as we know that physics is conceptually the richest scientific discipline, yet to a layperson it is not immediately evident and it is not known by the society in general. It can be shown that the discoveries of modern physics (and subsequently related technologies) have ultimately altered our lives with a typical 'technological' delay of about one generation. Political personalities, wars and revolutions, different social schemes and philosophies did somewhat modulate these trends, but overall, and on a global scale, couldn't stop any of them. The telephone, the telefax and personal computers are used on all continents. A young physicist, trained during the frightening war years in Sarajevo, was subsequently able to complete advanced D. Sci. studies in Switzerland [24]. Physics is more universal than music. The teaching of the deterministic chaos is similar in Kyoto, Rio, New York, Delhi or Zagreb (and the equations are the same) so we can easily integrate physicists from any of the respective universities. Yet a graduate of classical music will need an additional training in Hindu microtonal music. So, our first task when doing the 'marketing' of physics is to emphasize the positive role of physics as a basic science, a discipline that deserves continuing support from the society, as the most universal 'language' and a profound 'eye-opener' for any inquiring human.

In addition to the strengths of the physics education, I will now argue that physicists, active in the front-line research, are often aware of enormous technological changes some 10-15 years before the enterpreneurs and venture capitalists even notice them. Let me use an example as an illustration. Consider currently dominating Si-electronic technology, i.e., the ultra large scale integration in chips for fast computers. Our colleagues at Intel or NEC tell us that around 2010 the Si-technology reaches its limit: the size of an individual transistor in the chip can no longer provide the necessary functionality. Namely, the insulating oxide layer, SiO_2 becomes leaky at required thickensses < 2 nm at ambient temperature. Furthermore, the 'processing and fabrication' of such Si-based chips (it is all on nano-scale) is also a formidable challenge. Obviously, these nano-scale physics problems (ultra-thin insulators) have to be solved before we could meaningfully discuss Si nano-technology or any of the alternatives. Yet, this is precisely what is now being researched in the physics laboratories worldwide. It is conceivable that some of our colleagues have a viable alternative in, say, superconductor cryo-cooled Josephson technology of layered high-T_c oxides [26-28]. If, with roughly equal production costs, the switching speed of an array of Josephson junctions could beat the cooled semiconductor chips by a factor of 100 (and/or reach the quantum limit), some venture company (let's call it TerraFlop Inc.), formed along these lines, would have a potential market of up to \$ 1 tn (\$ 10^{12}) beyond 2010! Such TerraFlop Inc. may appear in the next few years (or perhaps exists already?) and everyone, including you and me, could potentially participate in the initial investment. We can become it's co-owners, and if it grows, our financial share will also grow. But, let us test our insight. Will TerraFlop type of technology be the one used globally beyond 2010? That type of expert 'know-how' and insight in the market, technology, financies and people involved is needed to evaluate such opportunities and make informed decisions on venture investments.

What is currently being researched in most advanced physics laboratories may become commercial technology beyond 2010. Research in 1999 on nano-scale condensed matter becomes eventually nano-electronics, nano-engineering or cryotronics. Therefore, it is fair to say that physicists involved in truly front-line research 'see' the potentially relevant technologies some $5 - 10$ years earlier than production technologists, and often up to $10 - 15$ years before the venture capital investors. This is very relevant for creative wealth creation (also by participating physicists) in a global as well as in the local society.

3. Physicists in global (and local) economy

Let us first see the overall global context. Three most globally spread multinational companies, General Electric, Shell and Ford have all together about 1 million employees (roughly the total number of employed people in Croatia), yet their annual turnover is $2 tn, two orders of magnitude higher than the Croatian GNP, or one and half times GNP of France. It is not surprising that the French are concerned [23]. Economists also tell us that Croatia has per capita income of $ 4000, and most developed countries (with highly developed science and technology) have $ 15 000 or more (Switzerland is close to $ 30 000).

Even with a high growth rate of the Croatian economy (say 3 – 5% per year), it will be difficult to reach the per capita income of the developed Western countries. However, the global schemes available through the Internet offer new opportunities that are not yet fully accepted by conventional economy nor our society. Evidently, physicists understand other functions and schemes, beyond the 'conventional' economic growth (that is usually around 2 – 3% in European economies). For example, the exponential growth is a part of the physics training, an established fact in cellular biology and it has already been clearly demonstrated in the Internet economy. The www.amazon.com was formed by two enthusiasts [25] with a computer and several hundred dollars in 1994 when our homeland Croatia already existed as a souvereign state. In 1999 it's market value is some $ 27 bn (and is still growing), more than the Croatian GNP. The Internet was actually created for physicists 30 years ago and even the world wide web was introduced by a trained physicist [22]. As most physicists use computers on the Net as a part of an open, global scientific exchange, one cannot but wonder how many attractive research, development or investment opportunities are just a mouse-click away.

For example, one can easily envisage a formation of the venture investment taskforce, formed either privately or by the goverment. An experienced international lawyer, a financial expert and a physicist, who has hands-on experience in novel technologies, could easily integrate their know-how with two young Internet-hackers whose task would be to search for promising new ventures that have exponential growth potential. If they would buy, say, one hundred risk-ventures for $ 100k each, the total cost would amount to $ 10M; a small droplet even within the Croatian economy. Surely, 90 – 99% of these companies will collapse, but if only one survives and grows truly exponentially, it's value would become greater than the present Croatian GNP: remember amazon.com. Of course, this would not change all other economic parameters of the Croatian society that will still have to go through the more conventional 2 to 5% growth and evolution. Such new creative schemes are not forbidden or even morally unacceptable, as one always uses $< 1\%$ of the total budget for these bold, yet informed, risk investments. On a global scene there exist visionary governments, investment groups and enterpreneuring individuals who use similar schemes.

But why do we need a 'seasoned' physicist in such an investment team? Well, physicists can and do see potentially relevant technologies much before anyone else (see the previous section). Physicists often know personally some of the people who are involved in techno-ventures or have read their key papers and can figure out some 'hidden' facts. If one simply buys such venture investments without knowing a lot about them, it's like buying the lottery: the odds are very small. However, physicists-techno-experts have the insight into promising trends and technologies, the understanding of what works and what doesn't. Moreover, open-minded physicists easily communicate with other talented professionals. And if you are still not convinced: imagine if Tesla signed a contract with Westinghouse for only 1μ\$ (\$ 10^{-6}) per Watt of produced electricity, or if Shockley posessed rights for only 1n\$ (\$ 10^{-9}) per working transistor used nowadays in integrated circuits in our global village!

We have already discussed our fictitious TerraFlop Inc. that may become relevant in the huge post-Si nano-electronics market. Here we have to solve some really tough nano-physics or find alternative nano-scale electronic materials, before we can even begin to contemplate investment options. Nevertheless, no law stops Croatian physicists to participate in such a challenge, either as creative researchers or as a part of a task-team that may eventually have to decide into which alternative post-Si electronics technology to invest.

In my view it also means that we shall give our young people excellent physics and science training (I believe that science education is still comparatively good in Croatia) and possibly even envisage some changes in the University curriculum. I also believe that for Croatian wellfare it would be much better that 2000 students of the Faculty of Economics first study some slightly 'easier' (bolje bi bilo 'easier') physics under-graduate curriculum. Subsequently, armed with versatile physics models and insights, they could continue in economics or managment, by doing additional year of advanced post-graduate MBA (master of business administration) courses. That has already been acomplished by several of my former Diploma students. They have since completed the MBA, and they still consider physics (as a first degree) an optimal educational background. But can we convince our media, our administrators and above all our young Croatian people to study physics first and opt for economy, managment or bio-medicine only for the post-graduate studies? I emphasize that this is clearly the trend and choice made by some of the brightest students in the very best Universities in the West.

4. *Concluding remarks*

There is clearly an important place for modern physics and for us, physicists, in the global society, yet we have to fight for more prominent role than an inexpensive 'commodity' image. The contemporary physics is as challenging as ever, and the primary role of physics remains the deep insight and rational understanding of measurable, natural phenomena. As such, our curiosity driven discipline requires and deserves a stable funding from usual governmental sources. Yet, if the planetary ecosystem doesn't collapse due to the fast growing polution, the 21^{st} century will in general favour all forms of integrated knowledge [29] and physics is an archetype example of a discipline with an established, experimentally verified 'know-how'. However, we have to make sure that the young people, and the public in general, are fully aware that, in addition to a valid intellectual curiosity and fundamental enquiry, physics also provides: i) the most versatile, globally recognized, undergraduate degree, usefull in further studies of economy, management or bio-medicine; ii) creative opportunities in advanced research and new technologies, and iii) better insights into workings of the global economy than 'conventional' economic approach, useful even in smart venture-risk investments. And there are many other opportunities for physics: in school teaching, in strategic research, in industrial development, in communications or in bio-sciences. It is up to every individual to choose in which exciting domain (s)he will participate and make creative contributions [29].

Last but not least, all my arguments are based on our present knowledge of modern physics. But let me remind you that a century ago, in 1899, when the electron was confirmed, Lord Kelvin claimed in the Royal Society (London) that all major physics laws are known. So, I cannot but wonder how many surprises wait for us only one generation from now, even within our own discipline, let alone within a cross-disciplinary framework of the global science. No law of nature forbids creative (Croatian) physicists to produce scientific milestones and no human law forbids daring physicists and engineers to create novel technologies, join new ventures or find other forms of creative association of their professional skills and ideas, and in the process, produce more wealth and well-being for the global as well as Croatian society in the 21st century.

Dedication

I dedicate this article to Professor Boran Leontić. He introduced me to Feynman Lectures, he helped me when I was most insecure and he provided wise, selfless advice in all crucial stages of my carreer. I also thank my numerous professors in Croatia who have greatly contributed to my survival in the global society. Finally, I thank Dr. Eduard Tutiš for many stimulating discussions and critical reading of the manuscript.

NOTE added in proof: After the completion of this manuscript I have discovered a rather thought-provoking editorial by the distinguished condensed matter theorist P. W. Anderson (Princeton). In the September 1999 Physics Today (page 9) he challenges our academic establishments and some conformist ideas about the future of physics in our global village.

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MODERNA FIZIKA U GLOBALNOM DRUŠTVU

Uspjesi moderne fizike i proizašlih tehnologija su stvorili naše sadašnje globalno društvo. Međutim, unatoč vrlo solidnom obrazovanju i dokazanih, korisnih znanja, fizičari su često tretirani poput relativno jeftine 'robe'. Ohrabren iskustvima nekolicine bivših studenata, pokazujem odabranim primjerima da svi zajedno moramo poboljšati 'promidžbu' fizike koja, uz svoju osnovnu ulogu - racionalno razumijevanje prirode - nudi: 1) najbolju dodiplomsku naobrazbu, također studentima koji žele nastaviti studije ekonomije, poslovodstva ili biomedicine; 2) kreativne izazove u najnaprednijim istraživanjima i novim interdisciplinarnim tehnologijama, te 3) često relevantniji uvid u ponašanje globalne ekonomije, nego konvencionalni ekonomski pristup, a i bolji uvid u riskantne tehnoinvestiticije. Također pokazujem da su sve te teme podjednako važne i za naše hrvatsko društvo te njegov prosperitet u ranom 21-om stoljeću.