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Interview – Inventivity in a Balance between Training and Imagination

Glashow, Sheldon

1. How you define inventivity and creativity?

Inventivity, of course is the ability to invent as creativity is the ability to create, but that is not the intent of your question. Both have two prerequisites; training and imagination. Artists must learn to draw, composers must study music, engineers or scientists must spent many years developing their skills, but imagination is more difficult to acquire, if indeed it can be acquired. However, imagination is often and easily destroyed by improper or inadequate education.

2. What was the major catalyst which enabled the inventivity to happen in the case of invention that brought the Nobel Prize to you?

It could be attained having encouraging parents, attending excellent public schools and research universities, choosing inspiring mentors.

3. For small nations (like Montenegro or Serbia), what are the things to do to induce inventivity and creativity among young people?

I suggest them to provide excellent schooling to as many citizens as possible, especially to those who are evidently gifted. Encourage them to attend world-class universities (possibly abroad) and provide them career opportunities within their countries. Take the risk that some of those educated abroad may not return.

About the Author

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The Unintended Consequences of Technological Innovation: Bluetooth Technology and Cultural Change

Naimi, Linda L.; French, Richard Mark

Abstract – As our knowledge and understanding of our natural world have increased, so has our desire to explore, manipulate and change the world around us. A prime example is our drive for technological innovation. We seek to harness new and emerging technologies to improve the quality of life, to increase efficiency, lower costs, and overcome the barriers of time, distance, geography and other physical limitations. We believe technological innovations will improve the way we live, work, play, and learn, and enhance the quality of human life. We move forward with our inventions, creations and innovations, anticipating the positive benefits innovations will have for us all. But there are unintended consequences as well and this has become an emerging area of policy making and research. This paper examines the unintended consequences of Bluetooth technology and how it has hastened both desirable and undesirable cultural change.

Introduction

In the late 17th century, Sir Isaac Newton rocked the scientific world on its heels with the publication of one of the most influential scientific books ever written, the *Philosophiae Naturalis Principia Mathematica* (Newton, 1687). In this seminal work, Newton distills the complex principles and interactions of motion and gravity, laying the foundation for the laws of physics as we know them today. In the elegant axioms that follow from his analysis, Newton revealed the intricate relationships between force and motion, cause and effect, matter and energy, and action and reaction.

Newton's First Law of Motion states that "every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it." (Newton, 1687). Thus, in the last two centuries, some societies – particularly those isolated by geography, custom, language or politics - experienced relatively stable social cultures with little substantive social change, while other nations, subscribing to Newton's Second Law of Motion experienced rapid social change with the advent of the Industrial Revolution and its aftermath, the Technology and Post-Technology Eras, and more recently, the Information Age (Friedman, 2005).

Newton's Second Law of Motion says that "The relationship between an object's mass *m*, its acceleration a, and the applied force *F* is $F = ma$. Acceleration and force are vectors (as indicated by their symbols being displayed in slant bold font); in this law the direction of the force vector is the same as the direction of the acceleration vector" (Newton, 1687). One could argue by analogy that the introduction and rapid adoption of mass production technologies tended to speed up the economy and spur not only new market growth, but the development of new technologies and businesses.

Newton's Third Law states that "for every action there is an opposite and equal reaction" (Newton, 1687). Similarly, when technology innovation and modernization efforts are introduced into society, these automatically trigger pockets of resistance to change. Following Newton's logic, the more people are forced to accept change, the greater the resistance. Whether innovations are accepted, tolerated, desired or resisted, their introduction into society will be accompanied by unanticipated and unintended consequences.

As our knowledge and understanding of our natural world have increased, so has our desire to explore, manipulate and change the world around us. A prime example is our drive for technological innovation and implementation. We seek to harness new and emerging technologies to improve the quality of life, to increase efficiency, lower costs, and overcome the barriers of time, distance, geography, and other physical limitations. But the

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consequences we intend are not always the consequences we realize. For example, drugs intended to cure or treat a particular medical condition may inadvertently cause other problems. Side effects may range from mildly uncomfortable symptoms to harmful, and in some instances, fatal consequences. Technologies, such as nuclear energy, intended to produce cheaper, more abundant electrical power have also been used to create weapons of mass destruction. Robots intended to improve assembly line efficiency eventually replaced many workers.

Should we be surprised that innovations may have unintended consequences? Of course not; they always have. Technological innovation brings both new opportunities and new problems. They generate public support and resistance. And inevitably, adoption of technological innovations leads to adaptation and uses not envisioned by the inventor. For every intended consequence, there will be an opposite and equal unintended consequence. And this fact triggers the ethical, legal and political controversies surrounding technological innovations.

Innovation is one of the most frequently cited concepts in social science and STEM research. Yet, only one in a thousand studies address the unintended consequences of innovation, making this one of the most talked about and least studied phenomena in both the soft and hard sciences (Sveiby et. al., 2009). This paper examines the unintended consequences of Bluetooth technology and how it has hastened both desirable and undesirable cultural change.

Science and Innovation: A Brief Historical Perspective

Since the dawn of recorded history, man's progress has been measured in part by the diffusion and adoption of new ideas and inventions. Resistance to new ideas, fueled by fear, lack of knowledge, religious and cultural beliefs and traditional practices, has often been strong and thus, knowledge and information accumulated slowly. In some societies, traditional practices and strongly held cultural values remained virtually unchanged for centuries. Communication across borders and distances was accomplished by the use of couriers on foot and on horseback, carrier pigeons, smoke signals, trade caravans, immigrants, and publicly posted signs, such as totems, clay tablets, papyrus rolls, etchings, stone, copper and wood carvings, and hieroglyphics.

But the modern era of science and innovation is considered to have started in the 1400-1600s during what is known in the west as the Renaissance period (Windlespecht, 2002).
The printed word is but one example. Until the 1400s, books and manuscripts were painstakingly copied by hand for distribution among the elite of the time. But in 1440, Johannes Gutenberg developed a printing press that used molds, moveable type and an oil-based ink for mass production of books and other printed material which made the printed word available to the masses for the first time. The Gutenberg press remained in use into the twentieth century (Rees, 2006).

In the 1500s, Leonardo da Vinci sketched many marvelous inventions, including an airplane, helicopter, armored car, submarine, parachute, and centrifugal pump. Centuries later, devices like those in da Vinci's drawings were realized and helped to dramatically change transportation, warfare, and land reclamation (Berkun, 2007). Zacharias Janssen,a Dutch lens crafter, developed the first compound microscope and Martin Behaim, a German mapmaker, made the first globe called the Nurnberg Terrestrial Globe (Berkun, 2007).

The pace of innovation quickened as human civilization entered what many historians consider to be the dawn of the Modern Era. From the 1600s to the 1900s, innovations in science, medicine, astronomy, communications, transportation, agriculture, printing and mass production brought about waves of social, cultural, economic and environmental change, resulting in both intended and unintended consequences. For example, refinements to the telescope in the early 1600s enabled Galileo Galilei to make astounding astronomical observations which advanced the field of science and added to our understanding of our solar system. However, his remarkable findings were met with skepticism from some academic corners and cries of heresy by religious leaders who condemned him during the infamous Inquisition trials. Despite these setbacks, scientific discoveries continued to be made, driving the development of more sophisticated technology such as the reflecting telescope invented by James Gregory in 1663 and more powerful telescope lenses by Christian Huygens in 1654.

The 1700s witnessed a host of new inventions, including the hot air balloon, Benjamin Franklin's lightning rod, thermometer, Celsius, the metric system, steam engine, cotton gin, parachute, and light bulb. In 1800, Count Alessandro Volta invented the battery in 1800 which introduced the first generators of continuous electrical current and revolutionized business and communications over night (www.enchantedlearning.com/inventors). The inventions of the telegraph in the1830s in Europe led Samuel Morse to invent the first American telegraph in 1835. Alexander Graham Bell (assisted by Thomas Watson) invented the first American telephone in 1876 along with a number of other inventions, including the multiple telegraph (1875), the hydroairplane (now called a hydrofoil), the photo-sensitive selenium cell (the photophone, a wireless phone, developed with Sumner Tainter), and new techniques for teaching the deaf to speak (www.enchantedearning.com/inventors). With newer devices, more power was needed, which led to improvements in battery generators and alternative energy sources. In the 1850s, Gaston Plante invented rechargeable lead-based batteries followed by Georges Leclanche's dry cell batteries and Edison's alkaline batteries. Lewis Waterman invented the first leak-proof fountain pen in 1884, a tool which revolutionized writing.

As we approached the twentieth century, the pace of innovations quickened. Thomas Edison made numerous contributions to science and innovation in the late 1800s and early 1900s, including, the telephone transmitter, the phonograph (and records), motion picture projector, and improvements to the incandescent electric light bulb. Edison patented more than one thousand inventions during his lifetime. He was quoted as saying, "Genius is one percent inspiration and 99 percent perspiration" (Hargadon, 2000)

During this time, Nikola Tesla was quietly transforming life and work through his numerous inventions. Among his most influential inventions are his work in electromagnetism, the radio, fluorescent lights, and the famous Tesla coil which generated huge voltages from high frequency alternating current. He demonstrated wireless communications through the radio by transmitting broadcasts overseas. For many years, he was engaged in a bitter dispute with Edison over direct current (DC) versus alternating current (AC) electrical circuits.

Working with Westinghouse, Tesla developed and promoted the alternating current and the AC motor, which generated far more voltage with greater sustainability, consistency and over greater distances than was possible with direct current technologies and are credited with ushering in the Second Industrial Revolution. Today, Tesla's alternating current is the world standard. In 1960 the unit measuring magnetic fields (International System of Units) was named the *tesla* in his honor. In addition, he is known for the *Tesla effect* of wireless energy transmission system which combined electrical power transmissions with broadcasting and wireless telecommunications systems. His disputes with Edison and others may have contributed to his being shunned by the American scientific community. But he is highly revered in Europe and is credited as one of the most important contributors in the fields of commercial electricity and electromagnetism.

The twentieth century was witness to some amazing inventions. Olds and Ford used assembly lines to mass produce the Model T and other early electric motor cars. The Wright Brother's airplane took to the air in 1903. John Baird invented the first mechanical television in 1924 and six years later, made the first public broadcast of a television program. Lazlo and Georg Biro invented the first non-leaking ball point pen in 1935, another improvement in writing.

In 1932, Karl Janksy pioneered the use of radio telescopes to track radio waves in space. The first practical radar system was developed by Sir Robert Watson-Watt in 1935 and became an invaluable tool during WWII. Alan Turing is widely regarded as the father of the computational computer, with his invention of the Turing Machine in 1936, but George Stibitz is internationally recognized as the father of the modern digital computer in 1937. This was followed by Konrad Zuse in 1941 with the first working computer and later developed magnetic storage for computers. In 1945, John Mauchly and John Eckert from the University of Pennsylvania unveiled the first all purpose, digital computer. Called ENIAC (Electronic Numerical Integrator and Computer), it filled an entire room.

Television and radio and electric appliances became household staples by the 1950s. The automobile, railroad transportation and buses had greatly improved in the post war boom. Telephone lines crisscrossed the countryside connecting people, government and businesses as never before. Information and communication were now just the press of a button away. The government and military were busily harnessing the new computer technology and connecting computers over networks that formed the foundation for the Internet. The Technology Age had arrived.

In 1959, Jack Kilby and Robert Noyce developed an integrated circuit or chip which revolutionized the computer industry. For the first time, information could be stored or processed on tiny transistors, making it possible to build small and inexpensive devices, such as computers. Office and business computers soon gave way to personal computers and the High Technology Age burst onto the scene. Today, more than one billion personal computers are in use worldwide. The number is estimated to double by the year 2015 (http://www.science-portal.org/in/71).

The first cellular phone was invented in the 1960s and after twenty years of testing and refinements, it was introduced into the world marketplace in the 1980s, primarily to commercial customers and, subsequently, to consumers. Edwin Armstrong invented the frequency modulation radio (FM) back in 1935, but their functionality was limited. Only a few calls could be made at the same time in the same area. So to solve this problem, the decision was made to develop many small areas or cells which would share the same frequencies. This worked well as long as users stayed within a given area. But when they left that area, the call would drop. Bell Labs developed a method for switching the calls to a cell tower in the new area as the user moved about. But implementation was stymied because there were no computers at the time capable of handling the automatic switching. By the 1980s, the personal computer helped to jumpstart the cell phone industry. Today, it is virtually inconceivable in many parts of the world to consider going without access to a cell phone or computer. They have become as common a cultural icon as bottled water.

The World Wide Web grew out of the pioneering efforts of Tim Berners-Lee who wrote the first browser and HTML language protocol in the 1990s. The growth of the WWW has been nothing short of phenomenal and has changed culture and practice through innovations in graphic interfaces, email, virtual communities, streaming audio/video, real time and asynchronous communications, services, information services, advertising and marketing, financial management, purchasing, business transactions, recreation and entertainment.

Unintended Consequences of the Technology Revolution

Innovation has been part of man's attempt to adapt to and modify his environment. Whether we look at the wheel, "the printing press, the light bulb, penicillin, the transistor, and every other great human invention, discovery, or social advance" they all began with a simple idea – how to do something better (Foster, 1996, p. 24). Emerging technologies are "science-based innovations that have the potential to create a new industry or transform an existing one" (Day and Schoemaker, 2000, p. 30). Recent books tout titles like Innovate or Die by Jack & Matson (1996) frequently cite quotes by great thinkers such as Drucker (1985a) who once wrote that a 'company has two functions - innovation and marketing - everything else is just expenses'. But innovation is based upon prior knowledge and attainment. As Berkun (2007) asserts: the "World Wide Web, the web browser, the computer mouse, and the search engine – four pivotal developments in the history of business and technology – all involved long sequences of innovation, experimentation, and discovery" (Berkun, 2007, 14).

From the telegraph to the telephone, from radio to television, from cameras to deep space telescopes, from room-sized computational computers to personal computers, the past hundred years have ushered in an explosion of new information and communication technologies and innovations that have changed life as we now know it. The development of personal computers in the 1970s and 1980s spurred public interest in the potential of new technologies to transform learning, recreation, communication and work. The development of robots and artificial intelligence systems promised a new wave of "thinking" machines that would enhance efficiency and production. It also created fear that people would be replaced by technology and take a backseat to the new marvels (Wise, 1997).

Micro cassettes and the tape recorder were initially intended to provide affordable and portable copies of recorded information, such as music, lectures, books and self-help guides. But cassette tapes and tape recorders became essential tools in fueling the Islamic Revolution in Iran in the 1970s. The tape recorder played a significant role in toppling the late Shah of Iran. From exile in France, Ayatollah Khomeini and his supporters launched a barrage of taped messages at the Iranian people, inciting riots that eventually led to the overthrow of the Reza Shah Pahlavi in 1979 (Jones,1990; Word Review Press, 1998).

The popular rise of the Internet and cyberspace in the 1990s was touted as an important advancement in the world of warfare, governance and business. For many, the digital world represented power and freedom and flexibility that allowed someone to reach beyond traditional barriers and boundaries and connect with a greater world community (Berkun, 2007).

The proliferation of computer networks has made it possible for government, military, educational and business organizations to process and store vast amounts of information more efficiently. But it also led to hacking, security breaches, theft of intellectual property, invasions of privacy and identity theft. And it has led to social, political and cultural changes that have had a sweeping impact on the global community. Western music and radio broadcasts are credited with helping to bring down the Soviet Union. Radio broadcasts and smuggled tape cassettes throughout the 1960s, 1970s, and 1980s, are said to have created a counterculture in Soviet society that became virtually unstoppable (Wasserman, 2004). Technologies have been charged not only with liberating us from our physical constraints, boring routines, and tedious activities, but also with changing our cultural values and social norms. Let us take the example of Bluetooth technologies.

Bluetooth and Cultural Change

Ericsson is credited with developing Bluetooth technologies back in 1994 in an attempt to allow for greater flexibility and connection among technology users. Bluetooth is simply a short range radio link between devices. It has gone through several iterations with each one being more capable than the previous. Really, Bluetooth is a technical specification that manufacturers use when developing hardware and software. At this writing, the most recent version of the specification is called Bluetooth 3.0 + HS and supports theoretical data transfer rates of 24 Megabits/seconds (Mbit/s) – a 30 fold increase over version 1.2,

Bluetooth was named after the famous Viking hero and leader, Harald “Bluetooth” Blatand, who united Norway and Denmark under his reign. IBM, Intel, Nokia, Toshiba and Ericsson formed a Special Interest Group (SIG) in 1998 to refine, enhance and promote Bluetooth. In 1999, Microsoft, Agee Systems, 3Com, and Motorola joined the SIG. UPS poured $120 million into a groundbreaking mix of Bluetooth and Wi-Fi technology that has transformed their global business activities (Technology Review, 2005). Today, Bluetooth technologies have enabled consumers, business professionals and government officials to adapt to a fast paced, mobile world.

So far, the wireless Bluetooth headset seems to be the most popular device, with wireless keyboards and mice also selling well. It is common to see people who appear to be talking to themselves, but who are really conversing on a small, Bluetooth headset. Indeed, these headsets are sometimes worn as fashion accessories, even when not in use.

Despite its proliferation, Bluetooth technology has been attacked on a number of fronts because of failures in security and connectivity. Identity thieves can obtain confidential data, numbers, download complete contents stored in the memory chips in mobile phones and eavesdrop on all data and voice messaging. Some of the more familiar attacks on Bluetooth technology include:

- Snarf - the attacker connects to the Bluetooth device without alerting the user
- Backdoor - establish a trust relationship through the use of the “pairing’ mechanism that acts as a passkey to the device
- Bluebug - authorization to make premium priced phone calls or have a connection to the internet
- Bluejack - attackers can send messages to strangers via the Bluetooth and gains access to data
- Warnibbling - software called Redfang allows hackers to locate Bluetooth devices in the area and access corporate or sensitive information

  (http://hubpages.com/hub/Types-Of-Bluetooth-Hacks-And-Its-Security-Issues).

Although many would say that risk is the most important concern in developing and marketing new technologies, Shoemaker (2000) believes the challenges lie in three unlikely areas: uncertainty, complexity and paradigm shift. Uncertainty refers to the extent to which the proposed technology will be adopted into and by society at large. Complexity refers to the various social, political, economic and cultural forces that may color how the technology is viewed by the public. And paradigm shift refers to widespread adoption and adaptation of a technological innovation that alters the way we think, the way we interact, the way we live or play and the way we work or conduct business.

The intended consequences of innovation tend to focus on three outcomes: (1) they become desired and preferred, (2) they lead to adaptation and common uses, and (3) they may be unlikely to succeed in the marketplace, but it is possible. Unintended consequences of innovation usually involve three potential unanticipated outcomes: (1) society finds them desirable, (2) society finds them acceptable, and (3) society finds them undesirable.

Problems often occur when those who believe in the technology as an end in and of itself ignore the social and cultural norms of the society in which the technology is being introduced.

This is often the perspective taken by those who subscribe to technological determinism – that is, that technology innovation and progress drive social and cultural change and that this is a good thing. But they often ignore deeply-rooted cultural patterns, religious values and traditional practices that people hold sacred and they may underestimate the negative impact innovations have on work, family, and social relationships. The fear factor cannot be ignored. But at the same time, cultural values and norms cannot keep out innovations or prevent change from occurring.

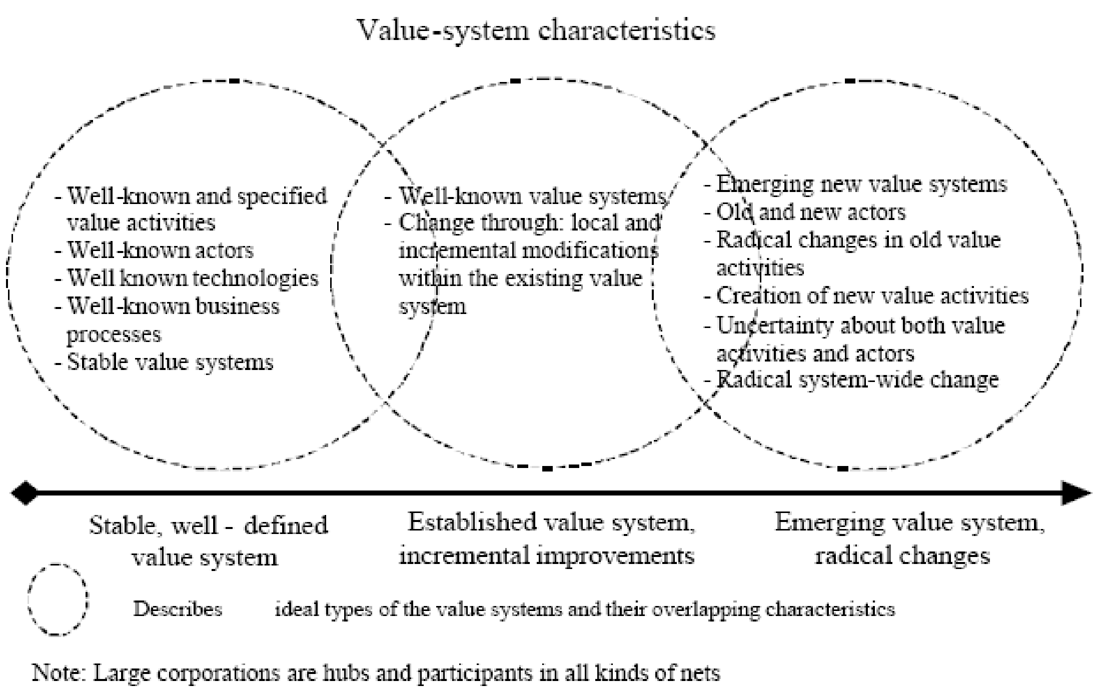

Figure 1. The value - system continuum

Source: Möller, Rajala, Svahn 2002)

As Moller et al (2002) point out in their values-system model, change comes from within cultures as well as outside cultural systems and most societies. This means that change is inevitable. But how the change occurs is important. In stable systems, change is slowly accepted when it is introduced by familiar, well known and respected sources. In established systems with some degree of flux, change occurs incrementally usually at the grass roots or local levels and filters across and up the social strata. In less stable systems, change is usually spontaneous, radical, emergent and often systemic. Societies adapt differently to innovations and by understanding the underlying social/political/cultural dynamics of a given social order, those who wish to introduce innovations can reduce the number of unintended consequences as well as resistance to change.

For people on the go, cell phones, laptops and PDAs have proven indispensable. In 2000 alone, the market for PDA in the US had grown to $1.03 billion, more than twice the $436.5 million in 1999 (Tam 2001). The number of internet capable mobile devices exceeded 1 billion in 2003, and the US alone has well over 300 million Bluetooth capable devices (Whitehouse, 2004). How many cell phones are in use on a daily basis? The Washington Post estimated that there are 2.4 billion cell phone users with more than one thousand new cell phone customers added each minute (http://www.theglobalist.com/globalicons/syndication/sample.htm). Now, PDAs, cell phones and a few other devices have essentially merged into what we now call the smart phone. People are now often carrying around a single device they use for several different purposes. For example, a typical smart phone includes a phone, camera, mobile internet connection and a pocket computer running a variety of software. The software typically includes scheduling and office software recently found in PDAs and music software that had been found only in dedicated players. Of course, they incude Bluetooth wireless capability. It seems likely that they will also soon become popular as book readers.

Bluetooth and other wireless technologies are changing our personal and professional lives. And in the process, they are introducing new problems into society. We all know that talking on a cell phone or text messaging while driving dramatically increases the risk of having an accident. Yet we continue to use cell phones while driving, shopping, working, exercising, and on vacation. We also know that security weaknesses inherent in wireless technologies have enabled criminals to listen in on private conversations, steal phone numbers and other critical information, and eavesdrop. However, this has not curbed cell phone use or transactions and information exchanges that take place via cell phone. Recent studies have shown another adaptation of cell phones - helping students cheat on exams (Callahan, 2004).

In traditional societies, where men and women are not permitted to interact in public, Bluetooth technology has enabled the young generation to bypass traditional customs and social barriers. They chat, arrange meetings and share photos of themselves without others being aware. In countries such as Saudi Arabia and Yemen, the situation has become so troubling that their respective governments tried to ban cell phones, PDAs and Cyber Cafes on the basis that they were corrupting the morals of the young. However, recent estimates suggest that more than twenty-four million cell phones are currently in use in the Arab world. Clearly cell phones are becoming infused into daily life and work and eventually into the culture.

Understanding that they could not ban cell phones in their country without a severe backlash from the public and protests from businessmen, more than half of the Moslem countries have passed laws banning cameras in cell phones, but not cell phones themselves. The premise was that cameras invite mischief and may compromise the reputation of females in society. This represents something of a compromise for the fundamentalist clergy who recognize that society is changing around them.

(Arab Lounge, at http://www.arablounge.com/?gclid=CLu2kpXtr4wCFQGPWAodt0RGRQ).

In Saudi Arabia, for example, the highest religious (Sunni) authority issued a ruling that called for the banning of cell phones with built-in cameras because they are being used to spread obscenity and encourage unIslamic behavior. This came after a government ban on the sale and importation of cell phones into the country failed. The black market in cell phones rose almost over night. Religious authorities in this traditional Moslem nation accused men and women of using the cell phones to flirt, exchange phone numbers, send messages over Twitter, create Facebook and MySpace web pages, create blogs, obtain access to forbidden materials (such as dating services, pornography sites, etc.), exchange virtual kisses and share photos (http://www.msnbc.msn.com/id/8916890/).

Nevertheless, camera-cell phones have caught on fast throughout Asia, Europe and the Middle East, prompting concerns about privacy, unethical conduct and impropriety. Critics of camera-cell phones said they have been used to take pictures of women exercising or even photos of women in public baths and post these to the web or circulate them among other cell phone users. Some have charged camera-cell phones as contributing to heightened corporate espionage and with higher incidences of student cheating in school and college. As a result, these devices have been banned in public places. In the United States, "there is a bill in Congress that would make the taking of illicit photos on federal property a crime punishable by up to a year in prison and fines' (Associated Press, September 29, 2004).

In India the problem is not so much the camera as it is the ring tone. Muslim clerics objected to the use of verses from the Quran, religious recitations and even the Muslim call to prayer as ringtones on cell phones. They banned these ringtones as being unIslamic and blasphemous. (CBS News website at http://networks.org/?src=cbs:2006:11:22:world:main2205417).

Of course, the practice of banning the use of cell phones or technology is not all that surprising. Headlines from various news agencies round the world reveal the extent of concern about the invasions of privacy afforded by Bluetooth and other emerging technologies that enhance mobility and connectivity at the expense of privacy and social mores. A search of online sources using a Google search engine revealed thousands of headlines and news articles regarding Bluetooth, privacy and social change, such as:

- Arab countries ban cameras in cell phones
- US Secretary of Defense bans camera phones in Iraq
- Japan bans cell phones in public baths
- South Korea requires "clicking sound and bright red lights" on all camera cell phones
- US Judge bans the use of cell phones to take images in courthouses except in designated media areas.
- Professors ban cell phones from examination rooms
- Arrests are up for men who surreptitiously use a camera phone to photograph up women's skirts (Japan Times)
- Muslim Clerics in India ban use of Quran as religious ring tones

(Sample obtained from a Google search on keywords: Bluetooth, Cell phones, privacy, social change).

In Africa, despite high rates of poverty, infant mortality and illiteracy, the cell phone industry has been booming in recent years. It has opened new markets in low-cost banking, created new products, and encouraged entrepreneurial activities. It has also spawned a huge underground network of identity thieves who trade on personal information they obtain from other cell phone users and those who use cell phones to check financial information (http://www.airtightinteractive.com/projects/related_tag_browser/app/).

In Japan, it is estimated that more than 70 million Japanese (nearly 60% of the population) use cell phones with web access on a daily basis. This represents a 300% increase in the use of cell phones since 2000 (Faiola, 2004). Today that number has doubled. Cell phones (called *keitai* in Japanese) are fast becoming the preferred choice for web surfers and have ushered in a *keitai culture.* It is not uncommon to see Japanese men and women watching television on their cell phones or personal digital assistants (PDAs) or using the built-in GPS system to obtain city maps. They download music and movies, browse the web, order things online, scan bar codes, pay bills, play games and even engage in the Japanese famous past time of Karaoke. At Bukkyo University in Kyoto, students in more than fifty different courses rarely speak aloud in class. Instead, they send emails or text message their professors who respond orally. (http://www.japanvisitor.com/index.php?cID=359&pID=1099).

In a more anecdotal example, one of us (MF) has posted a series of short videos on YouTube showing how to do example calculations for a sophomore level engineering technology class. Students are using smartphones to view these video clips when doing homework. Moreover, posted comments show suggest that a large percentage of viewers are at other insitutions and that at least some are in other countries.

What to do with Old Technology

Other unintended consequences concern what to do with aging or obsolete technology. Landfills and dump sites are quickly filling up with non-biodegradable plastics and materials. To this we add the concern of batteries, CRTs, disks, chips, laptops, monitors, cell phones, etc. Some organizations have recycled technology for many years. They gather older technology equipment, refurbish them and give them away to charitable organizations, senior citizens or to impoverished nations. But eventually, the recipients find themselves stuck with aged technologies and must decide how to dispose of them. And so the problem just passes from one hand to another.

Some enterprising entrepreneurs have started a different form of technology recycling. Outdated cell phones have been stripped of their internal circuitry and transformed into *objets d'art*. Cell phone casings have been transformed into makeup compacts, cigarette holders, coin holders, mouse traps, and other cute and entertaining whimsical art. Computers have become flower containers or toy boxes, pencil/pen holders, office bins, and so on. Laptops have become mirror and makeup sets or paint kits. The fact is that these novelties are catching on in the Far East and may soon hit the American market.

BlueDating

New concerns have arisen around the phenomenon known as BlueDating. Men and women who have joined a dating service enter what is called the vicinity (or calling area) and their cell phones instantly update their address book with the name and contact information of other subscribers in that area. They can review the information that has been exchanged between the cell phone devices, and if interested, engage in Bluechat or text messaging.

In Europe and Asia, where mobile phone use far exceeds that of personal computers, mobile dating services are attracting millions of single men and women. In Great Britain, services such as Enpocket's Speed Dater Mobile allow tens of thousands of British users to post and search personal profiles and then anonymously "chat" with others using short text messaging services (SMS). Online dating services have gained in popularity. But mobile dating services are slowly making inroads among those engaged in the dating game. Popular online dating sites such as Match.com, eHarmony.com and LavaLife.com offer mobile versions of their Web service through nearly all of the major cellular services providers in the United States (Eng, 2005).

In the United States, about 6 million people (roughly fifteen percent of the online Web dating population) used mobile matchmaking services in 2004. Mobile dating services generated roughly $31.4 million in revenue. Today, the number of online daters had nearly tripled and revenues are estimated to top $215 million this year (Eng, 2005).

The demand for wireless dating has also spawned new businesses and new open source software for use with iPhones, cell phones, iPods and other PDAs. For example, MIT is pioneering an application called *Serendipity* (Reported in *New Scientist Magazine* March 20, 2004.). Other open source applications include Speck, Spontact, Jambo, Enpresence, 6th Sense, and Easy Jack, to name a few. Researchers at the Swiss Federal Institute of Technology in Zurich are developing dating applications designed to run on mobile phones. The new protocols are appropriately named "Bluedating".

Final Thoughts

Bluetooth technologies are transforming or challenging social customs and cultural values around the world. Today, Leeds University is developing a mobile phone that will measure a patient's vital signs and deliver the results immediately to a GPS. 3G mobile phones and global positioning systems (GPS) will support remote mobility at a global scale and increase the awareness of our movement through physical space. Cell phones are being used to help law enforcement officers handle emergency situations and locate missing children.

Bluetooth enabled devices are inexpensive and ubiquitous. It is almost certain that innovative uses, perhaps unintended by the original developers, will evolve. As the popularity of Bluetooth enabled devices increases, they begin to resemble a distributed array of small computers equipped with sensors. They could, for example, be programmed to report their locations (determined precisely by integrated GPS receivers) in order to track movements of crowds, thus offering a valuable tool for urban planners. This same capability could be used to track visitors to a store or mall in order to determine traffic patterns. Since the processors in these devices aren't doing anything much of the time, a 'cloud' of Bluetooth enabled smart phones (sitting otherwise idle in the pockets of their users) could be treated as a distributed computing network and be put to work perfoming some useful, complex calculation. They would, through the two-way wireless connection, be able to both receive data and instructions from a central server and to report results.

Ten years ago, new technologies hit the market, on average, about every eighteen months. Today, emerging technologies and innovative adaptations of existing technology have shortened that timeline to less than six months. With the introduction of new technologies or adaptations of existing technologies occurring so rapidly, law and security measures appear to be moving at a much slower pace. Traditional values are being challenged as the Information Age brings the world community together in an unprecedented way. Innovations pose challenges to existing social attitudes and cultural norms, and legislation and policies continue to lag far behind. Whatever we may intend as the consequences of innovation, we must find better ways of anticipating or addressing the unintended consequences of innovation. This is an emerging field of study in the social, behavioral, and natural sciences which brings to mind, a number of unanswered questions:

- Does technology innovation drive cultural change? Should it?
- Is "imported technology" a form of cultural invasion?
- How do we address ethical and legal issues more effectively and responsibly?
- How is the Information Age affecting our children?
- As responsible global citizens, how do we address the unintended consequences of technology innovation and its impact on society and culture?

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The Dumbing Down Effect of American Public Education

Felix T. Hong

***Abstract*—The year 2008 marked the 25th anniversary of the appearance of an important document, *A Nation At Risk*, which castigated the American public education. All subsequent educational reforms resulted in either modest improvement or further deterioration. This article traces the major reasons of failure to excessive emphasis on domain-specific knowledge and logical reasoning. As a consequence, students were overwhelmed with a huge amount of knowledge to be memorized. Their grade performance was achieved at the expense of critical thinking. An indirect reason was the failure of the mainstream psychologists in elucidating factors, which distinguish creative individuals from their less privileged counterparts. In our quest for demystifying the enigma of human's high creativity, we have identified visual thinking as the major missing link in educational reforms. Visual thinking was also the hidden factor in deciding the success or failure of a number of popular educational approaches, which include small group teaching, cooperative learning and constructivism, and a popular corporate technique called brainstorming. In search of historical evidence, it was found that most of the clues to our present solutions had appeared in the 1908 book of Henri Poincaré and the 1908 discovery of Robert M. Yerkes and John D. Dodson. This article revisited their insights in the light of modern cognitive science and computer science, in lieu of a formal commemoration of the 100th anniversary of their discoveries. In the eve of the 400th anniversary of Galileo's epoch-making discovery of Jupiter's moons, it was found that his 1610 book *Sidereus Nuncius* (*The Starry Messenger*) provided a convenient platform to debate the merits and the shortcomings of different learning approaches.**

***Index Terms*—Creativity theory, critical thinking, educational reform.**

I. Introduction

ABOUT twenty-five years ago, the [U.S.] National Commission on Excellence in Education published a scathing document, *A Nation at Risk* [1]. In its opening section, the document indicated that the educational foundation was being eroded by "a rising tide of mediocrity." Subsequent reforms had only dubious effects, at best, and often led to further deterioration, at worst. Those repeated forms incorporated the then-latest advances in educational psychology. It appeared that some crucial factors might have been omitted. It took a radically different approach to uncover these missing factors but the clues had been available a hundred years ago.

On a parallel and independent path while I investigated biological information processing, I was intrigued by the mystery of human high creativity, as practiced by scientific geniuses. Gradually, I became more and more involved, thus transforming a hobby into an obsession. I drew inspiration from introspections of scientific giants, such as Henri Poincaré [2], Albert Einstein [3], and Nikola Tesla [4]. These introspections revealed that geniuses had a penchant for what I called *picture-based reasoning* [5]. Consultations of the music literature revealed something similar. For example, Mozart used a picture metaphor to describe his composing activities [6]. Of course, the thinking style in music is the tonal equivalent of visual thinking. These introspections seemed to point to a common mental faculty in creativity [7], contrary to the popular view of a multitude of different talents [8]. The common denominator is the exceptional capability of *parallel processing* of information, which reminisces the paradigm once preached by *Gestalt* psychologists. In other words, geniuses all had a multi-track mind. However, a multi-track mind is not the monopoly of geniuses. Many ordinary intelligent folks also have a multi-track mind, with perhaps lesser proficiency.

A turning point was my encounter, in the late 1990s, with a new breed of medical students, whom I referred to as *dumb high-achievers*: students who commanded high grades but exhibited poor problem-solving ability. Their thinking style appeared to be diametrically opposite to that of scientific geniuses. I called it *rule-based reasoning*, because they had a tendency to learn science as a collection of well-established rules, much like cookbook recipes or computer algorithm [5]. In other words, dumb high-achievers think like a conventional digital computer; they have a one-track mind and they processed information *sequentially*. On the other hand, students who were instructed to emulate geniuses' preferred thinking style — picture-based reasoning — often showed surprising improvement. At that point, I started to look into the literature of psychology and cognitive science.

It did not take me long to realize that what I referred to as

Dedicated to Professor Tsu-pei Hung of National Taiwan University, whose reasoning process reminded me of Sherlock Holmes.

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picture-based and rule-based reasoning, respectively, have long been known as visual and verbal thinking, respectively, in the psychology literature [9,10]. These two distinct styles of thinking stemmed from the concept of *cerebral lateralization*. The concept was derived from Roger Sperry's split-brain research [11,12]. In its earlier versions, the concept stipulated that the left cerebral hemisphere specializes in linguistic function and the right hemisphere specializes in visuo-spatial and nonverbal cognition. This concept has undergone significant revisions over the past few decades. Generalizations to include other cognitive functions lead to the following interpretation. The left hemisphere specializes in analytic cognition: its function is therefore algorithmic in nature. In contrast, the right hemisphere specializes in the perception of holistic and synthetic relations: its function stresses Gestalt synthesis and pattern recognition. However, this simple dichotomy was dismissed by subsequent investigations as over-simplified. An improved interpretation of hemispheric specialization advanced by Goldberg and coworkers [13], called the *novelty-routinization theory*, eventually elucidated the puzzle and expelled the doubt. According to this revised interpretation, the right hemisphere is critical for the exploratory processing of novel cognitive situations. The left hemisphere is critical for information processing based on preexisting representations and routinized cognitive strategies. The traditional verbal/nonverbal dichotomy of lateralization thus becomes a special case.

It appeared that the right hemisphere governs the preferred thinking style of geniuses, whereas the left hemisphere governs that of dumb high-achievers. It has long been suspected in the literature that creativity may be associated with the right hemisphere activity. However, the so-called "right brain movement," which advocated strengthening the use of the right hemisphere in education, was eventually discredited by mainstream psychologists. Even Einstein's introspection was openly ridiculed in the psychology literature. Among Einstein's detractors, Harris [14] presented an exceptionally harsh criticism with an objective of silencing the "right-brain" movement.

Confusions regarding the role of hemispheres in creativity could be avoided if one recognizes that a scientific report seldom reproduces how the discovery has been made. About 100 years ago, Poincaré said, "It is by logic that we prove, but by intuition that we discover" (p. 274 of [9], p. 2 of [10]**)**. By identifying intuition and logic with picture-based reasoning and rule-based reasoning, respectively, what Poincaré said is tantamount to: it is by picture-based reasoning that geniuses discover, but by rule-based reasoning geniuses prove. By the same token, dumb high-achievers invoked only logic (rule-based reasoning) in generating and verifying solutions. However, there is nothing wrong about rule-based reasoning, if it is used along with picture-based reasoning alternatingly, if not simultaneously. In point of fact, geniuses also used it during the solution-verifying phase. However, dumb high-achievers practiced logical reasoning to the complete exclusion of visual thinking. Thus, dumb high-achievers can be equated to practitioners of *exclusively* rule-based reasoning. It was a horrifying shock to me to find that some experts had actually endorsed and even advocated this deviant thinking style (see below). Detailed evidence in support of my present interpretation of human creativity has been published elsewhere [15–18].

Whereas the terms, verbal thinking and visual thinking, are readily linked to the concept of cerebral lateralization, the synonymous terms, rule-based reasoning and picture-based based reasoning, were retained because they serve as convenient reminders of the equivalent concepts of sequential and parallel processing, respectively. Incidentally, Mozart was probably the first to recognize the essence of the difference of these two distinct styles of information processing, in spite of the fact that he was born about two hundred years prior to the advent of computer science and artificial intelligence. In his letter to Baron von P (see p. 268 of [6]), Mozart wrote, "Nor do I hear in my imagination the parts *successively*, but I hear them, as it were, all at once (*gleich alles zusammen*)." The identification of the word "successively" and the phrase "all at once" with sequential processing and parallel processing, respectively, appear to be unambiguous.

The concept of cerebral lateralization helped demystify the enigma of human creativity. However, it also bred major misconceptions. The general public and even some scientists held the view that scientists and engineers are good at left-brain-based thinking whereas artists and experts in social scientists and in humanities are good at right-brain-based thinking (see [19] for a general survey of various views). A similar view attributed rational and logical reasoning to scientists and engineers whereas it attributed sensible thinking to artists and humanities experts (rationality vs. sensibility dichotomy). The dichotomy seems to be perfectly in line with Gardner's theory multiple intelligences. The erroneous views had a far-reaching consequence in shaping science education. In particular, it spawned the popular approach of custom-tailoring instructions to students' diverse learning styles. There was no lack of individuals advocating the use of both cerebral hemispheres. However, their view could only grace the pages of popular press (e.g., [20]).

A rare exception was the first-hand account of the subjective inner feeling about the separate function of the two hemispheres [21]. Jill Taylor, Ph.D., a Harvard-trained brain scientist, had a rare form of stroke, which completely obliterated her left hemisphere function for an extended period, and she then fully recovered to tell the true story. Anyone, who is interested in the topic of cerebral lateralization, should not miss this rare gift to mankind. It is beyond reasonable doubt that the left and the right hemisphere function as a sequential (serial) and a parallel processor, respectively. Taylor's introspection clearly indicated the separation of tasks in temporal and spatial processing in the two respective hemispheres. However, the identification of recognizable spatial patterns and their meaning requires the left hemisphere's participation in terms of contour delineation; the function of the right hemisphere alone reveals a single spatial image *in continuum* without clearly defined boundaries of its subunits, so-to-speak, and, therefore, without a clear meaning. Taylor's report indeed makes sense in terms of the novelty-routinization theory, mentioned above. Whereas detection of novel spatial images is a task of the right hemisphere, classification of these images into recognizable patterns (possibly with a name tag) is a left-hemisphere task.

Contrary to common belief, cerebral lateralization also exists in lower vertebrates, including fish and birds. MacNeilage, Rogers and Vallortigara, along with their colleagues [22], found that a consistent interpretation could be achieved if they assumed that the right hemisphere evolved to detect changes in the environment (novelty detector), whereas the left hemisphere evolved to increase the dexterity of self-motivated routine motor skills of the right side of body (the beak in birds and the right hand in primates, for example) and the ability to see details with the right eye so as to assist the execution of routine tasks (routine executor). This interpretation is consistent with the novelty-routinization theory. They further presented experimental evidence showing the enhanced efficiency of a lateralized brain as compared to a non-lateralized brain, which must perform both types of mental tasks with a compromised efficiency. Previously, we pointed out that creative problem solving requires a "mood swing" between meticulous rule-based reasoning, on the one hand, and permissive picture-based reasoning, on the other hand (p. 528 of [15]). Again, it is not difficult to understand the advantage of cerebral lateralization in the context of creativity.

A two-month stint in the National Changhua University of Education, located in central Taiwan, afforded me a first-hand opportunity to witness how much inroad educational psychologists had made into shaping the education of future teachers for the public educational system (from kindergarten, through primary school to junior high school in Taiwan, or, kindergarten, first grade through 12th grade in the U.S., i.e., the K-12 system). A treatise with a major following in the educational community was recommended to me: *The Neurological Basis of Learning, Development and Discovery: Implications for Science and Mathematics Instruction*, authored by Anton E. Lawson [23]. Strangely, this book managed to concentrate all misconceptions in a single source. However, Lawson's view was by no means unique. Daniel Willingham, whose "Ask the Cognitive Scientist" column frequently appeared in *American Educator* (an official publication of American Federation of Teachers), essentially held the same view [24]. Lawson's treatise thus represented the prevailing view of the mainstream educational psychology. I therefore could conveniently evaluate Lawson's book in lieu of an actual field survey in the U.S. public school system.

A special feature in Lawson's book was his attempt to reconstruct Galileo's thought process, which led to the 1610 discovery of Jupiter's four largest moons. He used Galileo's book, *Sidereus Nuncius* (*The Sidereal Messenger* or *The Starry Messenger*) [25], as the source material for the reconstruction. Lawson then claimed that the reconstructed thought process of Galileo was exactly as his new theory had predicted. He also cited numerous scientific discoveries in the past as collateral supports. In the present article, we shall attempt an alternative reconstruction by analyzing Galileo's report from the perceptive of a practitioner of picture-based reasoning.

The validity of a reconstructed thought process is difficult to authenticate without the benefit of the original discoverer's personal approval. Although direct proof is impossible, a comparison of my reconstruction and that of Lawson may shed some light on Galileo's actual thinking process; the merit of each version can be evaluated on basis of the strength of evidence so uncovered. Furthermore, such attempts of reconstruction could be construed as student reports on assigned reading of Galileo's book. A comparison of the two "student reports" could be used as a basis to evaluate the effectiveness of two different styles of student learning. The comparison may give us relevant insights into why the American educational system continued to deteriorate in the past decades. It turned out that the clues so uncovered could also be found in the 1908 book of Poincaré [2] and in an article of Yerkes and Dodson, published in the same year [26]. It was therefore fitting to commemorate the centennial anniversary of these epoch-making discoveries by revisiting these authors' insights and by pondering what could have been different had their words been heeded. It is also fitting to pay tributes to Galileo's 1610 discovery in the eve of its 400th anniversary.

II. The Lure of Logical Deduction

Students who first became a novice in scientific research were often told to begin by formulating a working hypothesis prior to performing an experiment. The student is then expected to make predictions based on the working hypothesis and to design experiments to test the predictions. If subsequent experimental observations agree with the hypothesis, the student can conclude that the hypothesis is a valid one. This doctrine is essentially what Lawson advocated in his book. However, a valid hypothesis implies that the investigator knew the correct answer before any experiment had been done. The hypothesis must be either a) a trivial one, b) a corollary of a powerful theory, or c) a product of an exceptionally superior mind. The third possibility was an unlikely one since most, if not all, highly creative scientists indicated that they had had no idea about the correct answer to begin with, and they, by their own admission, were, therefore, incapable of formulating a viable hypothesis in a single leap.

Lawson claimed that his *hypothetico-predictive theory* provides a cognitive foundation of numerous novel scientific discoveries in the past and of students' learning in science education. Specifically, he presented numerous examples to demonstrate that reasoning in major scientific discoveries fits the "*if … and … then … but … therefore …*" format; Galileo's revolutionary discovery of Jupiter's moons was no exception. Readers readily recognize that this format is one of the most common instructions in a number of high-level computer languages. Furthermore, the construction of this particular type of computer algorithm conforms to the Greek practice of syllogism. Essentially, Lawson claimed that novel scientific discoveries were made by means of logical deductions. Superficially, this claim sounded innocuous. However, Lawson also made a heroic effort to prove that Francis Bacon's induction method is not qualified to be a valid scientific method. By default, the *hypothetico-predictive method* — that is, deductive reasoning — became the *one and only one* scientific method of investigations. Since every educated individual is expected to learn deductive reasoning in school and every competent investigator is expected to have a good command of the skill, what can possibly make a difference in problem-solving ability is the amount of acquired knowledge. This reasoning allowed Lawson to further conclude that the only source of creativity is a broad and deep knowledge base. Previously, Hayes and Weisberg also made essentially the same claim (A detailed critique of Hayes' and Weisberg's work can be found in Sec. 4.21 and Sec. 4.22 of [16]). A direct consequence of such a view was: students should be loaded with a vast amount of relevant knowledge. In the age of ever-accelerating information explosion, this educational view became a nightmare of modern students.

Logic is such a seductive word and, at the same time, such an oppressive word that few educated people would dare to oppose Lawson's claim. Why did Poincaré then claim that discoveries must be made by means of intuition? To understand the latter point, we must go back to a number of creativity models formulated in the previous century. Most of these creativity theories or models separated the creative process into two phases: the solution-generating phase and the solution-verifying phase [27]. Thus, Poincaré's remark implies that intuitive reasoning predominates in the solution-generating phase, whereas, according to Lawson, the generation of a solution to a novel problem is attributed to deductive reasoning alone. Poincaré did point out the crucial role of logical reasoning in the solution-verification phase. Few people would dispute the importance of logical reasoning in the solution-verifying phase. However, it takes more than just logic to make a novel discovery. Two questions arise. Why did so many scientists mention logical reasoning instead of intuition in their quest for the unknowns? But then what is intuition?

Intuition is a strange concept. Almost everyone knows how to use the term "intuition" and a related term "insight," but experts found it difficult to define these terms explicitly [28]. In addition, highly creative individuals often had no clues about their source of inspiration even after the fact, as if it were "out of nothing." In referring to a long-standing problem that he had just solved, German mathematician Carl Friedrich Gauss said, "The riddle solved itself as lighting strikes, and I myself could not tell or show the connection between what I knew before, what I last used to experiment with, and what produced the final success" (pp. 308-309 of [29]). Incidentally, Tesla also used the lightning metaphor to describe the suddenness of a novel discovery, whereas Archimedes had no time to put on his clothes when he suddenly exclaimed "*Eureka!*" Suddenness is a common feature of many major scientific discoveries but it is seldom, if any, a feature of pure deductive reasoning. This is just another puzzle that befuddled psychologists of the past century.

To make a long story short, we have identified intuition with picture-based reasoning [15,16]. In practicing picture-based reasoning, inspiration arises from a picture or part of a picture rather than from words or equations. Since the hint from a picture or part of a picture is non-verbal in nature, it is difficult to recall in words afterwards. Picture-based reasoning explains why creators, such as Gauss, had no recollection of how he had made the discovery. The interpretation also makes it easy to understand why major discoveries often appeared without prior warning. Performing picture-based reasoning is like piecing together many elementary pieces in a jigsaw puzzle. It is less likely to build up anticipation because the search process for plausible answers tends to be non-sequential or non-systematic in nature. In other words, "random access" to plausible solutions is an inherent feature of parallel processing. An element of surprise is built into the process because of the inability to anticipate what comes next. The puzzle is solved when a crucial piece suddenly snaps into a strategic location, just like a lightning strike or an avalanche. Last but not least, it is also easy to understand why intuition is so difficult to articulate and to define explicitly in words, because a picture generates an overall, vague feeling. No words can define a picture completely. In addition, a difficult and elusive concept, known as serendipity, becomes easy to understand (see Sec. 4.9 of [16] or [17,18]). We shall see what Galileo had revealed explicitly in *Sidereus Nuncius* was only part of his discovery process.

III. Galileo's Report of His Discovery of Jupiter's Moons

A. Lawson's reconstruction of Galileo's thought process

The first question that I am obliged to answer is: If Lawson's theory is wrong, why was he so successful, at least superficially, in fitting Galileo's reasoning to the "*if … and … then … but … therefore …*" format? Perhaps the most eloquent answer came from Poincaré (p. 214 of [2]): "Pure logic could never lead us to anything but tautologies; it could create nothing new; not from it alone can any science issue." Had Lawson dug a little deeper into Galileo's publications, he would have found that Galileo was not on his side. In his *Dialogue Concerning Two New*

Sciences (p. 105 of [30]), Galileo stated through the word of his surrogate, the fictitious interlocutor Sagredo, "Logic, it appears to me, teaches us how to test the conclusiveness of any argument or demonstration already discovered and completed; but I do not believe that it teaches us to discover correct arguments and demonstrations."

It is important to realize that the expected format of scientific reports does not demand inclusion of the tortuous process of finding the desired solution. Most readers just wanted to know what had been found to be true. Any author who included the solution-generating phase in a report might cause unnecessary and unwanted confusion of the readers, thus undermining the acceptance of the author's main messages. Galileo seemed to have attempted to break away from this accepted format; his *Sidereus Nuncius* was written in a journal format of day-to-day observations, which most other investigators would lock up in their file cabinets. Galileo did include some false starts and detours of his reasoning. Still, he probably had more in mind to convince his contemporaries than to satisfy future science historians. No wonder Galileo invoked mostly deductive reasoning to describe his new discovery, and presented his arguments in accordance with the requirement of syllogisms. Lawson merely regurgitated what Galileo had written but translated them into a fancy computer-like language. It is tautologies!

Let us take a closer look at how Lawson had succeeded. On January 8th, Galileo's journal stated, "All three little stars [which subsequently turned out to be Jupiter's satellites] were to the west of Jupiter and closer to each other than the previous night." Thus, Lawson surmised correctly: [if they were fixed stars,] "their positions relative to each other should be the same." But the observation showed that "the stars are closer together than on the previous night," [therefore the observation contradicts the prediction of the fixed-star hypothesis]. Note that this reasoning involved only a single-step of logical deduction. What about multi-step logical deductions?

It turned out that the above-mentioned single-step deduction was Lawson's only success. But it was hardly convincing evidence to support the satellite hypothesis. Those little stars could be new planets, although it might appear quite unlikely to discover a cluster of new planets within a couple of nights. The rest of Lawson's reconstructions were either irrelevant or downright erroneous. Furthermore, he missed several important messages hidden in Galileo's narratives. We shall mention a few here.

In his two-month period of observations, Galileo made a casual remark some 14 times: the three little stars formed a straight line, which he found to be parallel to the ecliptic or, equivalently, the zodiac. Lawson merely interpreted the remark as an indication of a non-random distribution of Jupiter's three moons. Incidentally, Galileo's remark was derived by induction after repeated observations. Lawson accepted the remark without even raising some eyebrows. This was symptomatic of rule-based reasoning. Since Galileo did not explicitly mentioned induction while drawing his conclusion, Lawson simply did not recognize the implication of Galileo's act and he accepted Galileo's "illegally" obtained conclusion, without any reservation. People who had some rudimentary knowledge about astronomy would have recognized that this "non-random" distribution is a consequence of viewing the satellite orbits in an "edge-on" direction and a consequence of the satellite orbits being in the same plane as the orbit of the Earth. Of course, one needs to think in pictures in order to appreciate Galileo's remark.

Lawson also missed the significance of Galileo's description of non-twinkling of the little stars: This observation implies that the light was not from point sources but rather from tiny disks, thus suggesting the proximity of these little stars to the earth, as opposed fixed stars, which would always appear as point sources under the magnification of Galileo's telescope. Furthermore, Lawson failed to understand the "looping (or zigzag)" motion of outer planets, thus misinterpreting some of Galileo's reports. Unlike our own Moon, which moves from west to east relative to fixed stars on the celestial hemisphere, outer planets sometimes move forward from west to east (*direct motion*), sometimes standstill (at *station*), and sometimes move from east to west (*retrograde motion*). Usually, it takes months for an outer planet to complete one round of looping motion, i.e., two consecutive reversals are usually separated by months of time. A quick glimpse into Galileo's reports revealed that Jupiter had undergone too many reversals of motion during the two-month period, if the three or four little stars were regarded as fixed stars. Lawson missed this important clue entirely.

Thus, Lawson's reconstruction uncovered extremely weak evidence to support Galileo's satellite hypothesis. It would be insanely reckless for Galileo to have put his own life in jeopardy with such weak evidence. The fact that Galileo's discovery was eventually accepted means that his contemporaries seemed to have understood a lot more than Lawson did. Note that Lawson had the advantage of additional knowledge accumulated over the past 400 years, to which Galileo's contemporaries had no access! The master's own failure dealt a devastating blow to the credibility of his own theory.

B. Reconstruction via picture-based reasoning

My reconstruction of Galileo's discovery process turned out to be not as easy as I had anticipated, although I was benefited with hints from Galileo's reports. If I based my judgment on the interval between two consecutive reversals of Jupiter's relative motion, the earliest possible day to draw the satellite conclusion was January 12th or January 13th. Yet Galileo immediately abandoned the fixed-star hypothesis on January 10th, and he turned "from doubt to astonishment." By January 11th, Galileo quickly reached the conclusion that these little stars were Jupiter's satellites. Galileo's conclusion preceded mine by a two-day margin. Stillman Drake, one of the foremost Galileo scholars, even presented evidence to show that Galileo could not have reached the conclusion until January 12th (Note 19 on p. 225 of [31]; p. 150 of [32]; also p. 252 of [33]). However, I was willing to give Galileo the benefit of the doubt, because his astonishment caught my attention. I could not draw a conclusion on January 10th or 11th because I had to await another reversal of Jupiter's relative motion. Apparently, Galileo was able to detect the anomaly after seeing only a *single* reversal from direct to retrograde motion! What was his basis of jumping to conclusions so soon? What did I miss?

In order to find the subtle clue that drove Galileo to his conclusion, I must disown any knowledge, which had not been made available to me and to anyone prior to January 11th, 1610. Therefore, I must temporarily forget Galileo's records from January 12th through March 2nd, 1610. In particular, I had to erase my memory about Jupiter's frequent reversals of motion between January 12th and March 2nd. I was not supposed to invoke modern astronomy knowledge, which was not available to Galileo. Failure to do so could only aggravate my own confusion and deepen the mystery.

I re-enacted Galileo's observations in a strictly day-by-day and frame-by-frame fashion, without peeking ahead of his records in *Sidereus Nuncius*. Suddenly, I sensed *something missing* in the picture. By *deliberately* focusing on the picture part of my thought, I eventually succeeded in articulating the "gut" feeling: If it took months rather than days for Jupiter to switch from direct to retrograde motion, and vice versa, why did Jupiter turn from direct to retrograde motion *without* a temporary standstill relative to fixed stars, for at least a few days, if not for weeks? The absence of Jupiter's station was what had astonished Galileo. Yet he said nothing explicitly. Only his astonishment betrayed his "gut felling." This subtle point eluded most, if not all, Galileo scholars for the past four hundred years.

Ironically, Galileo's astonishment was my indirect clue, which both Drake and Lawson had missed. Presumably, Galileo sensed the anomaly by detecting *incongruity* of his mental pictures while compared what he had observed with what he had expected. Naturally, it was much more difficult for Galileo to say explicitly what was *unexpectedly absent* than what was *unexpectedly present*. Galileo's picture-based reasoning would explain why he had not said it explicitly, for the same reason that Gauss could not recall the clue of his inspiration. However, once the clue has been pinpointed, it is easy to explain it in conventional syllogisms, as I just did, and it became easy to understand why Galileo could draw the conclusion as early as January 11th, 1610.

Another simple piece of evidence in support of the satellite hypothesis could be made clear by sequentially viewing all the graphic diagrams, which Galileo furnished in *Sidereus Nuncius*. During Galileo's 2-month long observations, the four little stars never drifted away from Jupiter for more than 14 arc minutes. It conjures up a specter of four little stars following Jupiter wherever it went during the 2-month period. In fact, it was easy to visually demonstrate the effect by arranging Galileo's 65 graphic diagrams in an animation sequence. In the spirit of Occam's razor, the satellite interpretation is the simplest explanation. However, the most direct and perhaps also most quantitative evidence in support of the satellite hypothesis is the trajectories of Jupiter's moons as projected onto the celestial hemisphere. If the satellite hypothesis is correct, all four little stars are expected to undergo a *simple harmonic motion* along a straight line in parallel with the *ecliptic*! In spite of the limited accuracy of Galileo's visual estimates, the plotted graph revealed a sinusoid trajectory of Jupiter's outermost moon, *Callisto*. The measured period was 16 days, which was close to the modern accepted value of 16.7 days. Likewise, though less clear, the trajectory of the second largest moon, *Ganymede*, was also sinusoid, which yielded a measured period of 7 days, as compared to the modern accepted value of 7.15 days.

IV. Multi-Step Logical Deductions

Lawson's success in a single-step logical deduction cautioned me against premature dismissal of the role of deductive reasoning in making *some*, if not *all*, discoveries. Poincaré's wholesales denial of the role of logic in making discoveries might have occasional exceptions. A discovery made by means of a single step deduction may not be a tautology *unless* someone else has made the *same* discovery *previously*. Sherlock Holmes' frequent allusion of elementary deductive reasoning still rang in my ears. Perhaps I should be more cautious and give Lawson and Sherlock Holmes the benefit of the doubt. Still, I suspect that it is not very likely to make a major discovery, in modern time, by means of one-step deductive reasoning, because others could easily have made the same discovery a long time ago. Of course, deductive reasoning is always useful in solving minor and simple daily problems.

In his fictional adventure, Sherlock Holmes' reasoning often involved multiple steps of logical deductions. I suspected that multi-step deductive reasoning might just be an afterthought of Holmes following his prior picture-based reasoning. However, if multi-step syllogisms could be constructed subsequently later during the solution-verifying phase, they could, *in principle*, be "discovered" during the solution-generating phase. This lingering thought sent me into the path of finding out why multi-step deductive reasoning is so much more difficult than single-step deductive reasoning.

Poincaré explained over 100 years ago, "Evidently because it is guided by the general march of the reasoning. A mathematical demonstration is not a simple juxtaposition of syllogisms, it is syllogisms *placed in a certain order*, and the order in which these elements are placed is much more important than the elements themselves" (p. 385 of [2]). The key issue is proper arrangements of syllogisms: how to find the relevant syllogisms and how to find the proper way of arranging them so as to ensure a smooth logic flow? We shall demonstrate the salient point with first encounter between

Sherlock Holmes and, his sidekick, Johan Watson, M.D.

In Chapter 1 of *A Study in Scarlet* [34], Holmes greeted Watson with a now-famous remark: "You have been in Afghanistan, I perceive." Watson was astonished, and exclaimed, "How on earth did you know that?" Of course, Holmes was a fictional character, but a fictional description often reflected the author's real-life experience. In fact, the real-life counterparts of Watson and Holmes were Arthur Conan Doyle himself and Joseph Bell, M.D., of the Royal Infirmary of Edinburgh, respectively [35].

In Chapter 2, with a title of the Science of Deduction, Holmes explained his reasoning with four syllogisms, arranged in an easy-to-understand order. He further explained, "From long habit the train of thoughts ran so swiftly through my mind, that I arrived at the conclusion without being conscious of intermediate steps. There were such steps, however. … The whole train of thought did not occupy a second." Holmes' syllogisms certainly fit the "*if … and … then … but … therefore …*" algorithm. Willingham [24] claimed that Holmes explanation was "not [based] on incredible intelligence or creativity or wild guessing, but on having relevant knowledge." But the cited facts were not exotic knowledge. Besides, what Holmes had observed must be more than what he mentioned in his syllogisms. How on earth could he select, within a brief second, relevant knowledge from a plethora of observations, let alone arrange them in the *proper* order? In fact, merely reciting the above syllogisms in *silent speech* would take more than one second. I suspect that Holmes must have fit relevant pieces of knowledge together like a jigsaw puzzle; many irrelevant pieces were rejected without actually trying. However, like Gauss, Arthur Conan Doyle (or his alter ego, Sherlock Holmes) was not fully aware of his thought process, and still referred to his thought process as elementary deductive reasoning.

In discussing the thought process of Gregory House, M.D., a contemporary television character and a Holmes clone, Abrams pointed out that all great fictional detectives mistook their methods as deductive, and most, like Holmes, simply scoffed at guesswork [35]. Abrams thought that their thought process was, instead, *abduction*. Abduction was a term introduced by philosopher Charles Peirce. Essentially, it means reasoning backward, or reverse deduction. Abrams made a good point. However, Abrams also made a new mistake. Abduction is not the answer because it cannot fare any better than deduction (see below).

Lawson's theory is not the answer, either. Galileo's cryptic report with embedded multi-step syllogisms completely eluded Lawson's hypothetico-predictive method. In making a sweeping generalization about tautologies, Poincaré obviously considered *only* multi-step deductive reasoning, as is commonly performed in mathematical reasoning with numerous equations. More than once, he mentioned the peril and futility of blind searches for solutions. Poincaré pointed out that most permutations and combinations of syllogisms (or equations) were meaningless, whereas the possibilities of such operations were virtually infinite so that even a lifetime would not be sufficient to complete the blind searches. Here, Poincaré touched upon an important issue, which, in computer science jargon, is called *combinatorial explosion*: the number of permutations and combinations of reasoning steps grows exponentially with increasing complexity of the problem.

He mentioned an incident occurring an evening when he drank black coffee and could not sleep (p. 387 of [2]). He decided to abandon his persistent efforts, which lasted 15 days, of trying a great number of combinations [of equations] and reaching no results. He wrote about his alternative approach, "Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making stable combination." His description in terms of the words "collide" and "interlocked" as well as the phrase "stable combination" betrayed his thought as a game of piecing together a jigsaw puzzle. That is, he performed picture-based reasoning. He thus cleverly evaded the wrath of combinatorial explosion, since he did not have to waste his time trying those combinations that had not interlocked into a stable configuration. This was indeed the case in view of what he wrote about what he had done in the following morning: it took him just a few hours to write out the results. This episode reminded me of what Mozart had done on a routine basis. Mozart often completed the entire piece of music in his head, and the subsequent commitment to paper was somewhat automatic, during which Mozart often engaged in other activities concurrently (see p. 238 of [36]). There is little doubt that Poincaré practiced picture-based reasoning, as we can further infer from the following remarks (p. 385 of [2]).

Poincaré wrote, "If I have the feeling, the intuition, so to speak, of this order, so as to perceive *at a glance* the reasoning *as a whole*, I need no longer fear lest I forget one of the elements, for each of them will take its allotted place in the array, and that without any effort of memory on my part." Interestingly, Poincaré linked intuition and parallel processing together — perceiving *at a glance* the reasoning *as a whole* — with regard to his "general march of the reasoning," which we now call visual thinking. Unfortunately, Poincaré's plain French failed to impress the experts; only the proper jargon could have done the trick. Explicitly, Poincaré pointed out that he did not rely on broad and deep knowledge of mathematics or his good memory to solve difficult problems. He said, his memory was not bad, but it would be insufficient to make him a good chess-player. Even Sherlock Holmes warned against indiscriminate acquisition of vast knowledge (Chapter 2 of *A Study in Scarlet*). Under Doyle's pen, Holmes was portrayed as a person with deficiencies in a number of major areas of science and humanities. Somehow, Holmes seemed to be able to manage to get sufficient in-depth knowledge to solve his cases. I suspected that he had acquired it "just in time"!

Now, let us turn our attention to the concept of abduction, or reverse deduction. Just like (forward) deductive reasoning, abductive reasoning is feasible only if it consists of a single step. Worse yet, for complex matters, there seldom exists a single cause. In other words, the causes and effects are not a one-to-one correspondence, and reasoning backwards does not always lead to the main cause, even if the main cause is within reach. Note that the wrath of combinatorial explosion put up roadblocks several times. First, one must make multiple attempts of single-step abductive reasoning, for reason just mentioned. That is, abductive reasoning must branch out backward. Second, multi-step abductive reasoning must be summoned, if one succeeded in exhausting all single-step abductions to no avail. Third, *multiple* attempts of *multi*-step abductions must be sought after if one intends to uncover or discover *all* relevant factors. Unless one attempts to *branch out backward several layers deep*, one runs the risk of locking onto the first success, thus becoming a victim of the so-called *confirmation bias*: the tendency to explain away in terms of the *first* available plausible cause, thus missing other more pertinent causes. All these formidable ramifications render the task of abductions no easier than finding a needle in a haystack. Therefore, abduction, in spite of its proponent's fame, is virtually useless for solving complex problems. Abduction or deduction, it was merely an illusion for the same reason that caused Gauss to forget his inspiration. My neurology professor and my mentor at medical school, Tsu-pei Hung, M.D., excelled at presenting lengthy syllogisms during clinico-pathological conferences. He confirmed that he had derived his multi-step syllogisms by reading off a preformed mental map (personal communication, 2007).

Regarding Abrams' allusion of guesswork, picture-based reasoning is indeed guesswork, since the validity of the conjecture is still subject to rigorous verification by means of deductive reasoning. However, it is not sheer guesswork but rather some kind of educated guesswork, which is known as heuristic search in computer science or operations research. Thus, both Poincaré and Holmes knew how to conduct heuristic searches by performing picture-based reasoning, so as to combat combinatorial explosion. It was amazing to witness how much computer science and artificial intelligence that Mozart and Poincaré had understood, in spite of the fact that they never had the benefit of taking a course of computer science or operations research. Intriguingly, a natural ability to conduct heuristic searches often disguises itself as luck. When Poincaré decided not to waste time on trying each and every possibility he could have thought of, he vastly increased his odds of hitting the correct solutions. Likewise, a card counter is usually not welcome in casinos, not because of his or her inexplicable propensity of luck but because of his or her ability to willfully increase the odds of winning a blackjack game. Without a doubt, card counting is a way of conducting heuristic searches in a casino setting. Sadly, Lawson's book did not even include a casual mention of the concept of heuristic search.

Finally, I must answer a question, which has not been raised by any debating parties but which may surface in the mind of readers. Elsewhere I have analyzed rule-based and picture-based reasoning in terms of digital pattern recognition and analog pattern recognition, respectively (see Sec. 4.6 of [16]). Picture-based reasoning thus demands matching of an observed pattern to pre-conceived templates, of which the distribution is *continuous* and which are, in principle, infinite in numbers. In contrast, templates used for digital pattern recognition are *discrete* in their distribution and tend to be finite in numbers. From this point of view, picture-based reasoning is expected to suffer more severely from combinatorial explosion than rule-based reasoning. Fortunately or unfortunately, *not all* possible templates can be pre-conceived; only *recognizable* templates can be pre-conceived. The number of recognizable templates is relatively miniscule but it can grow with *experience*. This interpretation is in agreement with the observation that intuition is experience-dependent but logic is not [10].

V. Why Did Exclusively Rule-Based Reasoning Become More Prevalent?

Although I did not have extensive field data to support my claim, the popularity of exclusively rule-based reasoning became so obvious at the turn of the century that I did not need statistics to ascertain the significance. If so, the question is why? Elsewhere, I have presented a detailed analysis of the sociological factors (Sec. 4.23 of [16]). A brief summary will be given here.

At least, two major factors could be identified: information explosion and fierce competition. Over the past few decades, admissions to medical schools became harder and harder in spite of my observed decline in students' intellectual performance. Not every medical-school teacher would agree to my assessment. Some even claimed that students became smarter and smarter in modern time. The difference was apparently due in part to different methods of evaluation. It is true that students nowadays know much more than their parents' generation did, but they understand considerably less. Standardized testing, commonly used in a large class, is rather insensitive to evaluating students' understanding. Worse yet, standardized testing evaluates primarily understanding at the rule level, whereas only more comprehensive testing such as essay or oral tests can penetrate the camouflage of superficial rule-level understanding. Needless to say, picture-based learning offers no advantages in taking standardized tests. But the effect was not immediately apparent because correct learning approaches also ensure good performance in standardized testing. With the advent of information explosion, some students believed that rule-based learning or sheer rote memorization would offer them a better edge of advantages in attaining high scores. Rule-based learning simply rose to the occasion. Rule-based learning is not exactly learning by rote memorization, because its practitioners know how to manipulate prescribed and pre-learned rules to get the correct answer even when the problem turns out to be not exactly the same as a previously encountered one. Merely recognizing the type of problems suffices to tip off its practitioners to initiate a previously learned procedure, with or without knowing why. However, its practitioners would encounter a formidable challenge when the problem demands a new recombination of existing rules or demands new rules to be discovered.

The deleterious effect of performance-driven learning seems to be an unexpected consequence of our cherished capitalist tenet: competition breeds excellence. But the side effect has been forecast about a hundred years ago. In 1908, Yerkes and Dodson reported a finding, which is now known as Yerkes-Dodson law [26]. In plain English, the capitalist tenet is true only to a certain extent. Beyond the optimum point, excessive competition leads to a decline of performance. There are profound psychological reasons. However, even at a superficial level, one should expect that excessive competition tends to encourage the performers to take shortcuts. In hindsight, rule-based learning was an ingenious shortcut for students to survive the assault of information explosion, but the shortcut approach happened to undermine students' creativity and to diminish their understanding. Since the inception of the No Child Left Behind Act around the turn of the century, many American K-12 schools began to teach for testing because school funding became tied to student performance. Learning just for testing must be a boring and, at the same time, a stressful experience. No wonder some American K-12 schools had unacceptably high dropout rate. Willingham explained why kids did not like school [37]. He claimed, "Contrary to popular belief, the brain is not designed for thinking. It's designed to save you from having to think." It was a euphemistic way of saying that the brain is designed to regurgitate previously learned solutions of known problems, thus glorifying rule-based learning. In view of the fact that such a fallacy ran unchallenged in the magazine of a teachers' union, it is obvious that the public sentiment gave experts a blanket license to mislead the teachers at large. The teachers' union is simply the wrong target to blame for our collective failure.

Deci and his colleagues explained the peril of grade-driven learning most eloquently [38]: extrinsic rewards undermine intrinsic motivation. It is not difficult to understand why motivation driven by fame, fortune and/or power is not conducive to creativity, since these factors discourage risk taking. Yet creative work often incurs high risks. By the same token, motivation driven by grade performance is not conducive to effective learning. Most educational psychologists did not differentiate between extrinsic and intrinsic motivation. Consequently, student failure was often attributed to lack of motivation. Paradoxically, I have seldom seen students more motivated than our dumb high-achievers. These high-achievers were mainly motivated to attain grade performance but they often could not care less about actual learning or understanding. Likewise, they were not inclined to take risks, which might jeopardize their grades. Consequently, they tended to play it safe. To them, nothing is safer than memorizing standard answers and regurgitating them back to the teachers. This mindset of modern students was best demonstrated by a recent experience. The test object was the horse puzzle depicted on p. 133 of [17] and on p. 105 of [18]. A student quickly learned how to take advantage of picture-based reasoning to solve the puzzle in less than one minute even though she had had no clue prior to my explanation. The real drama came when she tried to do it the second time and failed. The reason was simple. During first attempt, she relied on her intuition to figure out the strategy on the basis of picture-based reasoning, as she had been suggested to do. For the second attempt, she decided to play it safe and she reverted back to rule-based reasoning, but she could not recall the exact procedure for the same reason that one can hardly describe verbally how to tie a shoelace.

VI. Hidden Factors Underlying the Success of Small Group Teaching and Brain Storming

Over several decades, small group teaching has been high on the agenda of educational reforms. Consequently, the U.S. government poured a huge amount of money into its implementation. Common sense tells us the advantage of keeping the class size small if not for other reason than adequate individual attention, but the projected effect on learning was dubious. The effectiveness of small group teaching is probably similar to that of brainstorming, widely practiced in the corporate community. These approaches apparently worked well in the hand of experts, but why could not trained teachers bring about the *same* effect? Perhaps the experts knew something else that trained teachers did not know. Or, perhaps the experts did something else unconsciously, which was not included in the training of teachers.

Let us get back to the basic. The advantage of small group teaching was found empirically, i.e., by means of statistical correlation in repeated trials. Group setting was identified as the factor or, at least, the main factor. It is well known that correlation suggests causation but it does not affirm it. It is possible that there is yet another factor that is *loosely* coupled with group setting. That is, there is a hidden factor that hitchhikes with the main superficial factor. When the unidentified factor was present along with the superficial factor, the approach worked, but it did not work when the hidden factor was dissociated from the superficial factor.

My own preliminary observations, based on interactions with students, suggested that the heretofore-unidentified factor might be picture-based reasoning. This factor may be more important that the non-threatening environment provided by the group setting, as suggested by Yerkes-Dodson law. If our interpretation is/were correct, explicitly instructing students to perform picture-based reasoning will/would vastly increase the efficacy of small group teaching, cooperative teaching, and brainstorming. Our preliminary observation seemed to confirm this prediction. Likewise, constructivism tacitly created a learning environment that is conducive to picture-based reasoning but never identified picture-based reasoning as the essential factor. It is predicted that teaching methods based on constructivism can be enhanced by instruction of picture-based reasoning.

VII. Role of Liberal Arts Education

Traditionally, liberal arts education was the primary venue for fostering critical thinking, especially for non-science professionals [39]. This practice implied that science education had failed to uphold critical thinking in spite of the common perception that science and critical thinking are inseparable. Although good science demands critical thinking of its original thinkers, it was easy to bypass critical thinking in teaching or learning science because rule-based learning offered a convenient shortcut. However, the shortcut appeared to be less effective in a liberal arts curriculum, in part because of the inherent difficulty of reducing — thus diminishing — knowledge to just formulas or other kinds of recipe-like algorithm. Perhaps this was the reason why liberal arts education was more effective in cultivating critical thinking. The potential effect of science education on critical thinking was further undermined by the prevailing attitude of treating science as nothing more than a depository of canned solutions of technical problems. Therefore, it is possible to build a successful career in science and science-related endeavors by practicing exclusively rule-based reasoning, but it is virtually impossible to do so in most other specialties. (Does anyone wish to hire a defense attorney that could only perform single-step deductions or abductions?) This subtle difference ensured that critical thinking in liberal arts education could still survive the assault brought about by social changes that also brought us dumb high-achievers (in science).

It is obvious that liberal arts education "teaches" critical thinking in an implicit way, which is often described as a process of "osmosis." Walters thought that emphasis on the skills of critical thinking in a liberal arts curriculum should be supplemented by "training in alternative methodologies that focus on synthetic, dialectic, and creative modes of awareness and expressions" [40]. However, without a valid creativity theory, these proposed methodologies were all just shots in the dark.

Now, picture-based reasoning was found to be the key to critical thinking, explicit and effective methodologies could be designed. Does liberal art education become obsolete? The answer is a resounding no for the following reasons. Creativity and critical thinking cannot be taught out of thin air; a platform is needed to deliver the instructions. As far as non-science students are concerned, the platform remains to be liberal arts. A "logical" inference is: The platform for teaching critical thinking in a science environment is science itself. This logical inference is unfortunately incorrect or, at least, impractical. As explained in previous sections, scientific reports in the literature seldom contained information regarding how a novel discovery had been made. The alternative is to turn to science history. Regrettably, at the behest of the so-called "translational research" advocated by government funding agencies, science has become increasingly subservient to technology. Naturally, science history commands a low pecking order in government's funding priority. A vast depository of wisdom remained buried and hidden from plain view. Readily available autobiographies, such as Nikola Tesla's [4], and introspective reports, such as Poincaré's book [2], did not receive the attention it deserved. Lawson's contribution of bringing Galileo's *Sidereus Nuncius* to educators' attention was marred by erroneous interpretations. On the other hand, materials suitable for teaching are widely available and accessible in humanities. Authors (writers) and artists were expected to express their imagination without too much inhibition; conformity to logic is not a requirement. So far, I have been able to take advantage of detective stories, such as the Adventures of Sherlock Holmes, and popular television series, such as "Columbo" and "Monk." Music also provided a rich resource. German composer Richard Wagner often used operas as a vehicle to convey his philosophical ideas, including creativity. *Der Ring des Nibelungen* (in particular, *Siegfried*) showcased the inhibitory effect of fear on creativity whereas *Die Meistersinger von Nürnberg* presented one of the funniest parodies about combinatorial explosion.

Thus, liberal arts education as well as general education, which is a small-scale liberal arts education for science and engineering students, remains the ideal venue to cultivate critical thinking and creativity; almost no additional background in science is required. Now, liberal arts education can be lifted from the "osmosis" level to the explicit level, once we had a better understanding about human creativity and critical thinking. In this regard, some misconception needs to be rectified. Liberal arts appeared to be the proper antidote for the excess of trivial scientific knowledge. In the absence of a deeper understanding as to why liberal arts education works, some misguided educators misconstrued the so-called general education as humanities' (or social sciences') turn to force-feed college students with equally trivial knowledge (or just raw information), thus putting the cart in front of the horse. The outcome was dismal, as we could easily expect. Students regarded courses offered in general education as an easy way to get "soft" course credits and also as a "mental vacation" away from the suffocating load of "hard" science courses. Few students took general education seriously. With our newly acquired understanding, emphasis can now be shifted from knowledge to insights, from information to cognitive skills, and from memorization to understanding. Liberal arts education as well as general education could become more attractive to students.

Among liberal arts subjects, music and (graphic) art education deserves a special comment. Music and art education has seldom been regarded as essential or vital. Music and art activities often served the purpose of beefing up the resume of a college or professional school aspirant for the sole purpose of impressing admissions officers. The role of music and art education in children's cognitive development remains to be explored. Rauscher and co-workers [41] reported what is now known as the Mozart Effect: By exposing 36 college students to 10 minutes of listening to Mozart's Sonata for Two Pianos in D Major, their performance on IQ tests for spatial-temporal tasks was enhanced. Levitin [42] dismissed the validity of the Mozart effect because no plausible mechanism had been proposed to link music listening with performance on spatial-reasoning tasks. However, the dismissal was premature. It is true that a single-step logical deduction easily links music listening to temporal-reasoning tasks but not to spatial-reasoning tasks. Such a mechanism is, however, not inconceivable if we are willing to invoke multi-step logical deductions. Western classical music is synonymous with polyphonic music and/or monophonic music with polyphonic accompaniments (harmony and counterpoint). Obviously, simultaneously hearing different voices in a chorus demands a proficiency in *parallel processing*. So does a spatial-reasoning task. In my personal opinion, Western classical music offers one of the best training grounds for a multi-track mind, whereas science education, as being implemented presently, became one of the most potent training regimes to enforce a one-track mind. There is little doubt that music and art education is important in shaping cognitive skills (see discussion in Sec. 4.8 of [16]). The question is: To what extent? How to make it work better? The Mozart effect is therefore a respectable topic, which deserves further investigations. The next time a budget cut for music and art education is being contemplated, short-sighted politicians ought to have a second thought: Is it cheaper to fund music and art education or to fund drug rehabilitation programs and to build additional prison facilities? What if music and art education can decrease the dropout rate in high schools? These are not idle questions. The implication of music and art education is more than meet the eyes.

VIII. General Discussions and Conclusions

One of the original intents of public education was to enlighten the citizenry. The prosperity and affluence in developed countries were the fruit of public education. In the past, the dumbing down effect of public education was mentioned only in anecdotes. We could afford to ignore it because it was not generally true. Even when it happened it could be easily explained away, but it did not really go away. Eventually, it reached an alarming level, and it ushered in the appearance of the document, *A Nation At Risk*, about a quarter century ago.

Initially, the problem seemed to be limited to the so-called K-12 (kindergarten to 12th grade) education, thus leaving higher education intact. This observation offered a convenient correlation. Since unionism was primarily active at the K-12 level rather than at the college and university level, it was easy to blame teachers' unions for sustaining and perpetuating mediocrity of teachers' quality. Once this perception was ingrained and firmly lodged in the public consciousness, the stigma of unionism persisted. Besides, the rise of the right-wing politics in the late 20th century also made it politically correct to disapprove unionism. The experts were thus relieved of their obligation of searching for deeper reasons and more effective cures. When higher education began to deteriorate, we could continue to blame the unions for feeding college and universities with inferior products of high school education, since college and universities are on the receiving end. We thus missed the opportunity to explore and discover other hidden but perhaps more serious causes. Excessive emphasis on research at the expense of teaching at the college and university level also helped to sustain the status quo [43].

However, teachers' unions did respond positively to the warning of *A Nation at Risk*, by requesting a partnership of colleges and universities in a joint effort to upgrade the standard of teachers' education, thus resulting in significant improvement of teachers' training and induction, according to an article in *AFT [American Federation of Teachers] On Campus* [44], which appeared at the 20th anniversary of the publication of *A Nation at Risk*. Two seemingly unrelated articles, which also appeared in the same issue, painted a completely different picture, thus casting doubt on the alleged improvement. One of them reported an increasing incidence of psychological problems of incoming college freshmen, of which stress/anxiety problems topped the list since 1994 [45]. The other singled out "grade inflation" as an explanation of the superficial improvement [46].

The three articles cited above might not be totally unrelated; they might report three interlocking pieces from the same jigsaw puzzle. Merely raising the standard of test scores of either teachers in training or students in school would not alleviate the situation. The problem was, grades did not always reflect learning if rule-based learning had already made a significant inroad into the educational system. The boredom and burden of learning would drive up the incidence of students' psychological problems. An article in the same magazine two years later reported further deterioration of the situation [47]. For example, over a mere decade, the number of students with depression had doubled, the number of suicidal students had tripled, and sexual assaults had gone up fourfold. At the same time, there was a shortage of counseling personnel. The shortage resulted in a long waiting list, an overloaded counseling staff, and a tendency to dispose of the students by prescribing psychiatric drugs. Many cases escalated from anxiety to suicidal tendency when professional helps could not be made available in time. Anxiety-generated behavior problems were often misdiagnosed as the attention deficit disorder and were quickly swept under the carpet [48]. Countless pills of Ritalin (methylphenidate) were shoved down students' reluctant throat. This widespread practice transformed school health offices into the biggest legalized drug pushers ever. It is hard-pressed to expect the students to be able to "kick the habit," after they eventually outgrow their juvenile problems.

The problem of grade inflation was unmistakably real. About 5 or 6 years ago, I began to witness the arrival of a new breed of college graduates, who seemed to retain so little of what they had learned in college and in high school, as if, in the words of a candid student, "[they] had never taken the course before," in spite of high attained grades. With such a background, it is almost impossible for them to understand the course materials, unless the teachers made a special effort to re-teach high school topics, such as physics, in a highly abbreviated fashion. The increasingly common practice of tying student evaluations to teachers' merit raise also took its toll. Rumor had it that some teachers deliberately leaked the test questions to students in order to shore up students' grade performance so as to win good student evaluations. This behavior was exactly what Deci's theory had predicted.

In recent years, I observed a trend that was even scarier and more intractable than grade inflation. Our "B" students seemed to be better equipped to solve novel problems than "A" students, hence the term "dumb high-achievers." *Grade inversion* is certainly more difficult to neutralize than grade inflation (some college admission officers cleverly combated grade inflation by "renormalize" the test scores of individual high schools on the basis of their alumni's past performance). However, according to a graduate student, her father, a mid-level executive of a Detroit automobile company, had quickly learned to set the preference of new hires on "B" college graduates instead of "A" college graduates, because "[the latter] could not perform trouble-shooting but [the former] could."

Was the K-12 teachers' union the true culprit of "the rising tide of mediocrity"? The K-12 vs. higher education dichotomy offered a convenient correlation. But correlation does no always suggest causation, as pointed out earlier in Sec. VI. In view of the harmful effect of flawed educational psychology, perhaps there were other hidden factors. Another valid correlation suggests the following. The educational doctrine propounded in Lawson's book affected primarily K-12 teachers trained in a traditional teachers college. Few, if any, of college and university professors had the benefit of this type of formal training. Rather, most university teachers were trained "on the job." In other words, professors based their teaching approaches on their own intuitive feeling and they were allowed to explore and stumble. As expected, college and university teaching styles are rather heterogeneous and the quality of teaching varied widely. That is not to say, K-12 teachers were uniformly unsatisfactory. Strangely, some students managed to learn in spite of their teachers. So did some teachers managed to do it right in spite of the experts' recommendation and indoctrination. It was just that the relative lack of constraints allowed more non-conformist teachers to survive in colleges and universities. Ironically, the lack of formal teachers training miraculously spared college and university professors the assault of erroneous doctrines. This may explain why American universities were able to maintain a reasonably high standard in the previous century. However, the signs of erosion began to surface because of the continuing deterioration of the K-12 system. Now, the adverse effects of rule-based learning can no longer be swept under the carpet. Pretty soon, mediocrity may show up in research since graduate students often play a vital role in university-sponsored research. They do not just offer a pair of convenient hands in the laboratory.

Apparently, all the past educational reforms seemed to have missed the primary and more fundamental factors. It is about time to deal with these hidden factors. Or, maybe they were not so hidden if only we recognize the connection between creativity and learning. In fact, the key insights were laid down about 100 years ago. The publication of Poincaré's 1908 book provided an enormous amount of insights, about the cognitive aspect of creativity and learning, but, regrettably, his "opinions" were largely ignored. Yerkes and Dodson's 1908 article covered the psychosocial aspect of creativity and learning. The latter principle allows us to put "two and two together." The rise of students' test scores coincided with the increased incidence of psychological problems, and the Yerkes-Dodson law provided the causal link. Then came Lawson's flawed theory, which glorifies the value of vast knowledge, thus completing the links of a vicious cycle. Of course, we have reason to doubt whether Lawson's theory was the cause or the effect of "the rising tide of mediocrity." Nevertheless, the conclusion is the same: Lawson's theory is part of the problem rather than part of the solution.

A new danger lurking beyond the horizon is the recently popular buzzword of "knowledge-based economy." The excessive emphasis on knowledge at the expense of students' cognitive skills will, ironically, defeat the goal: knowledge without the accompanying skill to use it cannot drive a sound economy. Even Einstein said, "Imagination is more important than knowledge." However, schools continued to act like wholesales distributors of knowledge; the cognitive skills to utilize acquired knowledge seldom appeared in the list of priority. A significant fraction of biomedical students felt overwhelmed by the amount of detailed knowledge to be "learned," but the relief is nowhere in sight. Biomedical sciences happened to be at the epicenter of information explosion. In the public perception, a medical doctor is expected to command an ever-increasing amount of up-to-date knowledge. Ignorance conjures up a specter of quackery but inability to reason rationally was seldom regarded as a sign of professional incompetence and a threat to patients' well being.

Actually, back in 1966, West [49] already warned about it and pointed out that most knowledge transferred to medical students in school will either become obsolete or forgotten, by the time they practice medicine. It is even more so today in view of ever-accelerating information explosion. Few people can remember, for a long time, factual information acquired by means of purely rote memorization, if they use it only once at the time of testing. However, clinicians have no trouble remembering this type of knowledge without much effort if they use it routinely on a daily basis. What we can do now is reduce the amount of information to be "taught," concentrate on elucidating principles, and teach students primarily to enable them to learn on their own once they leave school.

In addition, the educational community, once misled by experts, must take a second look at the value of picture-based learning. Our own experience indicated that practicing picture-based learning would not significantly compromise acquisition of factual knowledge. What it lacks in enabling the acquisition of a large amount of factual knowledge, the approach makes up for by making it easier to remember integrated factual knowledge and by prolonging its retention, not to mention that the absence of stress also enhances learning and that picture-based reasoning enables one to utilize acquired knowledge efficiently and effectively. It seems to be an effective way to break the vicious cycle, generated by information explosion and fierce competition.

Speaking about picture-based learning, the popular teaching approach by means of custom-tailoring instructions to students' "learning styles" deserves a comment. Students are classified as visual (or global) learners, auditory (or analytic) learners, which roughly correspond to practitioners of picture-based learning and rule-based learning, respectively, plus "tactile" and "kinesthetic" learners. Superficially, it seems to make sense, and it is even politically correct to leave students' learning styles alone and to cater to their individual needs. What was not generally recognized is that an auditory learner could be trained to become a visual learner. As discussed in this article, leaving auditory learners alone without intervention forever condemns these students to a perpetual handicap in reasoning. In reality, there was no evidence that the learning style approach actually worked, according to an article by Stahl [50].

In recent years, instead of doing what should have been done, policy makers decided to make public schools accountable in an effort to reverse the trend of deterioration of public education. Students' grade performance is now tied to funding in the so-called No Child Left Behind Act. Yerkes-Dodson law and the research of Deci's group predicted that the situation would get worse, as some schools began to teach just for testing. Fortunately, objections to teaching just for testing and concrete suggestions to combat this problem began to surface [51,52].

There is a lingering question: If the theory advocated by educational psychologists is so wrong, do we need to thoroughly revamp teachers' education? Could the cure be worse than the disease? Fortunately, a radical restructuring of teachers' education may neither be necessary nor desirable. All one needs to do in implementing these teaching methods is add the instruction of visual thinking, which may significantly increase the success rate of traditional teaching approaches, such as small group teaching and cooperative learning. It is likely that these empirically derived methods may well continue to flourish in the absence of constraints imposed by a dysfunctional theory.

It is much harder, however, to alter the student culture of grade-driven learning. It is also politically difficult to undo the performance-driven accountability, which the public seemed to expect. A less disruptive strategy is to turn the trend to our advantage. This means: criteria of student performance have to change. In the past, standardized testing worked well and the grades so obtained also reflected students' learning with reasonable accuracy. However, as Hans Sachs in *Die Meistersinger von Nürnberg* suggested, it is wise to "test the rules [i.e., criteria] themselves once [in a while] to see whether in the dull course of habit their strength and life doesn't get lost and whether [we] are still on the right track with nature." It was the marriage between standardized testing and rule-based learning that doomed the time-honored testing method. However, we do not have to go as far as outlawing standardized testing. If we simply added a small fraction (e.g., 5 to 10 %) of thought-provoking and insight-demanding essay questions, few, if any, of the highly motivated students would be willing to forfeit the essay points. That alone might change their learning behavior. Likewise, that alone might discourage teachers' behavior of teaching just for testing. This less-than-radical reform has a better chance of enlisting support of college and university professors than a total elimination of standardized testing.

Last but not least, we must realize that exposing the fallacies of Lawson's theory is not merely of academic interest. It is an imperative to halt the continuing path towards the demise of public education and perhaps also the destruction of civilization. By identifying background knowledge as the only source of inspiration and by advocating the acquisition of a vast amount of knowledge, Lawson's theory would serve as the scientific justification of shoving an increasing amount of knowledge down students' reluctant throat. With the ever-accelerating information explosion and the emphasis on knowledge-based economy, students would never have time to think or learn to think. Implementing Lawson's theory would cripple students' critical thinking, thus further exacerbating the casualty of information explosion. Lawson's theory has the potential of driving us back to the Dark Age. It is one thing merely to craft a defective theory, because it usually does not cause an enduring harm as long as critical thinking still prevails in the citizenry. It is yet another thing to champion a dysfunctional educational approach that is so potent as to produce future generations that are by and large devoid of ability of critical thinking, thus dashing human's ultimate hope of self-correction. It is, therefore, not an exaggeration to regard Lawson's theory as one of the greatest threats to civilization. We have witnessed, at the beginning part of the 21st century, the triumphant return of irrationality, resulting in many harmful environmental policies, exacerbating politicization of science and science policies, and financial crisis and worldwide recession. It is a consolation that the enigma of human creativity was elucidated just in time of need. After all, self-preservation is a difficult problem to solve. Human's collective wisdom must then rise to the occasion. Speaking about collective wisdom, we are thus brought back to square one: education. However, education is a double-edged sword. Education, intended for enlightenment, accomplishes its task primarily by enlightening the mind. However, it can also shape the mind in the opposite way: dumbing down. Regrettably, in spite of good intention, research in educational psychology went terribly awry at the turn of the century. In hindsight, the investigators should have figured out how humans achieve high creativity before settling on a half-baked but erroneous theory. However, it is better late than never. Although it has already been a hundred years over due, it is not too late to incorporate the insights gained through the work of Poincaré and that of Yerkes and Dodson in future educational reforms. After all, collective wisdom can only be accumulated and sustained by means of sound education of the general public.

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Sensor Based Control of Autonomous Wheeled Mobile Robots

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Abstract — The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a mobile robot motion in an unknown environment with slopes and obstacles. The model of the vehicle has two driving wheels and the angular velocities of the two wheels are independently controlled. When the vehicle is moving towards the target and the sensors detect an obstacle or slopes, an avoiding strategy and velocity control are necessary. We proposed the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and a fuzzy reactive navigation strategy of collision-free motion and velocity control in an unknown environment with slopes and obstacles. Outputs of the fuzzy controller are the angular speed difference between the left and right wheels of the vehicle and the vehicle velocity. The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment and velocity control of the proposed fuzzy control strategy. The proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot.

Keywords – sensor-based, remote control, Sun SPOT technology, fuzzy reactive navigation strategy, collision-free motion, obstacle avoidance, mobile robot Khepera®

I. INTRODUCTION

The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a wheeled mobile robot motion in an unknown environment with slopes and obstacles. The autonomous mobile robots are very interesting subjects both in scientific research and practical applications. The wheeled mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and a stereo-vision system. The model of the vehicle has two driving wheels and the angular velocities of the two wheels are independently controlled. This model is the simplest and the most suitable for the small-sized and light, battery-driven autonomous vehicle. First, the modeling of the autonomous wheeled mobile robots is considered. Then the fuzzy control of a wheeled mobile robot motion in an unknown environment with obstacles and slopes is proposed.

Outputs of the fuzzy controller are the angular speed difference between the left and right wheels of the vehicle and the vehicle velocity.

The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment and velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy.

Finally, the proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot from the Sun Spot technology.

The paper is organized as follows:

- Section 1: Introduction.
- In Section 2 modeling of the autonomous wheeled mobile robots is illustrated.
- In Section 3 strategy of autonomous wheeled mobile robot motion in an unknown environment with obstacles and slopes is proposed.
- In Section 4 the simulation results are illustrated.
- In Section 5 Sun SPOT based remote control of mobile robots is proposed
- Conclusions are given in Section 6.

II. MODELING OF THE AUTONOMOUS WHEELED MOBILE ROBOTS

We consider a mechanical system with n generalized coordinate's q subject to m kinematics constraints. A large class of mechanical systems, such a wheeled vehicle and mobile robots involve kinematics constraints. In the literature these kinematics constraints can generally be classified as: nonholonomic or holonomic. A mobile robot involving two actuator wheels is considered as a system subject to nonholonomic constraints. Let's consider the kinematics model for an autonomous vehicle. The position of the mobile robot in the plane with obstacle and target position is shown in Fig. 1.

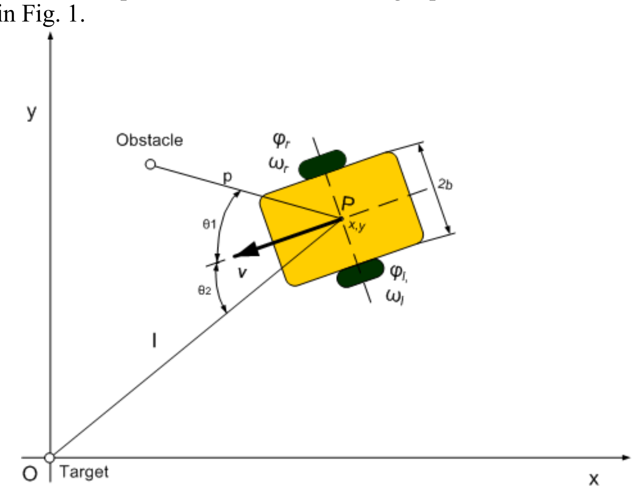

Figure 1. Position of mobile robot in plane

Where: p - the obstacle distances, θ_1 - the obstacle orientation, l - the target distances, θ_2 - the target orientation.

The inertial-based frame (Oxy) is fixed in the plane of motion and the moving frame is attached to the mobile robot. In this paper we will assume that the mobile robots are rigid cart equipped, with non-deformable conventional wheels, and they are moving on a non-deformable horizontal plane. The center of the driving wheels is regarded as the gravity center.

During the motion: the contact between the wheel and the horizontal plane is reduced to a single point, the wheels are fixed, the plane of each wheel remains vertical, the wheel rotates about its horizontal axle and the orientation of the horizontal axle with respect to the cart can be fixed. The center of the fixed wheel is a fixed point of the cart and b is the distance of the center of the wheel from P.

The contact between the wheel of the mobile robots and the non-deformable horizontal plane supposes both the conditions of pure rolling and non-slipping during the motion. This means that the velocity of the contact point between each wheel and the horizontal plane is equal to zero. For low rolling velocities this is a reasonable wheel moving model.

The rotation angle of the wheel about its horizontal axle is denoted by $\varphi(t)$ and the radius of the wheel by R. Hence, the position of the wheel is characterized by two constants:

b and R

and its motion by a time-varying angle:

$\varphi_r(t)$ – the rotation angle of the right wheel and

$\varphi_l(t)$ – the rotation angle of the left wheel.

The configuration of the mobile robot can be described by five generalized coordinates such as:

$$q = [x,\ y,\ \theta,\ \varphi_r,\ \varphi_l]^T \qquad (1)$$

Where: x and y are the two coordinates of the origin P of the moving frame (the geometric center of the mobile robot), θ is the orientation angle of the mobile robot (of the moving frame). The vehicle velocity v can be found in (2):

$$v = R(\omega_r + \omega_l)/2 \qquad (2)$$

where:

$\omega_r = \frac{d\varphi_r}{dt}$ – angular velocity of the right wheel,

$\omega_l = \frac{d\varphi_l}{dt}$ – angular velocity of the left wheel,

The position and the orientation of the mobile vehicle are determined by a set of differential equations (3-5) in the following form:

$$\dot{x} = (R\cos\theta\,(\omega_r + \omega_l))/2 \qquad (3)$$

$$\dot{y} = (R\sin\theta\,(\omega_r + \omega_l))/2 \qquad (4)$$

$$\dot{\theta} = R\,(\omega_r - \omega_l)/2b \qquad (5)$$

Finally, the kinematics model of the vehicle velocity v and the angular velocity $\dot{\theta}$ of the mobile robot can be represented by the matrix as follows:

$$\begin{bmatrix} v \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} R/2 & R/2 \\ R/2b & -R/2b \end{bmatrix} \begin{bmatrix} \omega_r \\ \omega_l \end{bmatrix} \qquad (6)$$

III. Strategy of Autonomous Wheeled Mobile Robot Motion in an Unknown Environment with Obstacles and Slopes

Currently many researches in robotics are dealing with different problems of motion of wheeled mobile robots. Let us consider the autonomous motion of wheeled mobile robots in an unknown environment. The mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and a stereo-vision system. The role of cameras is to identify the relative position and direction of motion of biped robot in unknown environment. The accurate distance of the obstacle can be obtained from the ultrasonic sensors. In moving towards the target and avoiding obstacles, the mobile robot changes its orientation and velocity. We proposed a fuzzy reactive navigation strategy of collision-free motion and velocity control of mobile robots in an unknown environment with obstacles and slopes. In this section fuzzy control is applied to the navigation of the autonomous mobile robot in an unknown environment with obstacles and slopes [1], [2], [3]. We supposed that: the autonomous mobile robot has two wheels driven independently and groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle. When the vehicle is moving towards the target and the sensors detect an obstacle, an avoiding strategy is necessary. While the mobile robot is moving it is important to compromise between: avoiding the obstacles and moving towards the target position.

With obstacles present in the unknown environment, the mobile robot reacts based on both the sensed information of the obstacles and the relative position of the target [4]. In moving towards the target and avoiding obstacles, the mobile robot changes its orientation and velocity. When the obstacle in an unknown environment is very close, the mobile robot slows down and rapidly changes its orientation. The navigation strategy is to come as near to the target position as possible while avoiding collision with the obstacles in an unknown environment.

The intelligent mobile robot reactive behavior is formulated in fuzzy rules. Fuzzy-logic-based control is applied to realize a mobile robot motion in an unknown environment with obstacles. Inputs to the fuzzy controller are: the obstacle distances p, the obstacle orientation θ_1 (which is the angle between the robot moving direction and the line connecting the robot center with the obstacle), the target distances l, the target orientation θ_2 (which is the angle between the robot moving direction and the line connecting the robot center with the target).

Outputs of the fuzzy controller are:

- the angular speed difference between the left and right wheels (wheel angular speed correction) of the vehicle: $\Delta\omega = \omega_r - \omega_l$ and
- the vehicle velocity.

The obstacle orientation θ_1 and the target orientation θ_2 are determined by the obstacle/target position and the robot position in a world coordinate system, respectively. The obstacle orientation θ_1 and the target orientation θ_2 are defined as positive when the obstacle/target is located to the right of the robot moving direction; otherwise, the obstacle orientation θ_1 and the target orientation θ_2 are negative [1].

The block diagram of the fuzzy inference system is presented in Fig. 2.

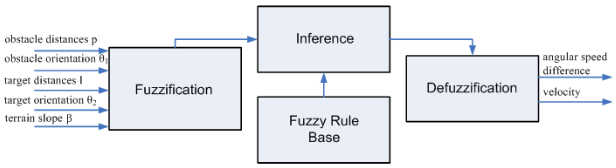

Figure 2. The block diagram of the fuzzy inference system

For the proposed fuzzy controller the input variables for the obstacle distances p are simply expressed using two linguistic labels *near* and *far* (p ϵ [0, 3 m]). Fig. 3 shows the suitable Gaussian membership functions.

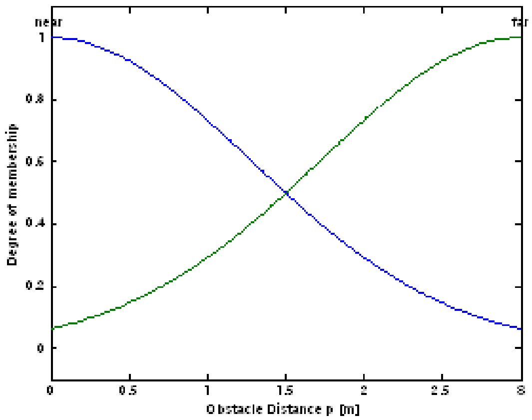

Figure 3. Membership functions of obstacle distances p

The input variables for the obstacle orientation θ_1 are expressed using two linguistic labels *left* and *right* (θ_1ϵ[-π,π rad]). Fig. 4 shows the suitable Gaussian membership functions.

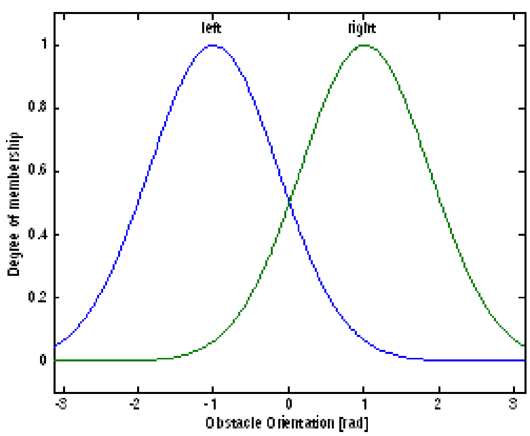

Figure 4. Membership functions of obstacle orientation θ_1

For the proposed fuzzy controller the input variables for the terrain slope β is simply expressed using three linguistic labels: *slopedleft, flat* and *slopedright* (β Є [-3.14, 3.14 rad]). Fig. 5 shows the suitable Gaussian membership functions (β is the average slope value).

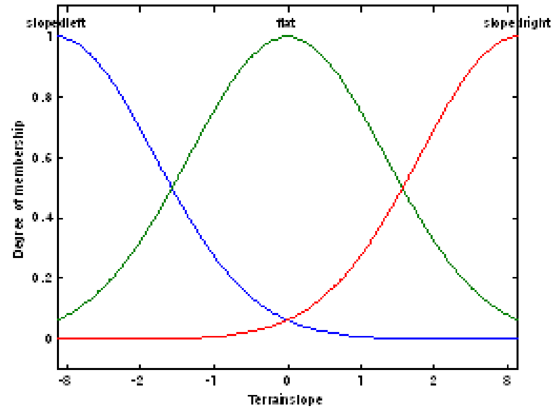

Figure 5. Membership functions of terrain slope β

The input variables for the target distances l are expressed using two linguistic labels near and far (l Є [0, 3 m]). Fig. 6 shows the suitable Gaussian membership functions.

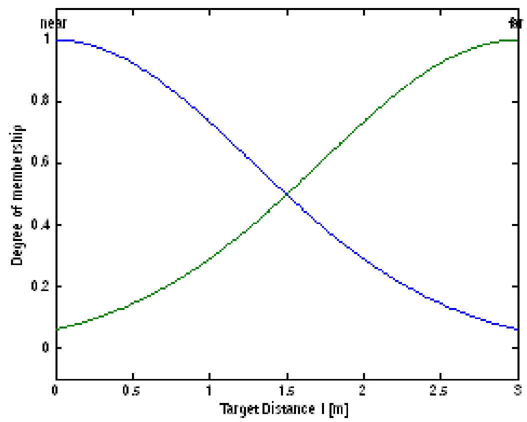

Figure 6. Membership functions of target distances l

The input variables for the target orientation θ2 are simply expressed using three linguistic labels left, targetdirection and right (θ2 Є [-3.14, 3.14 rad]), (Fig. 7).

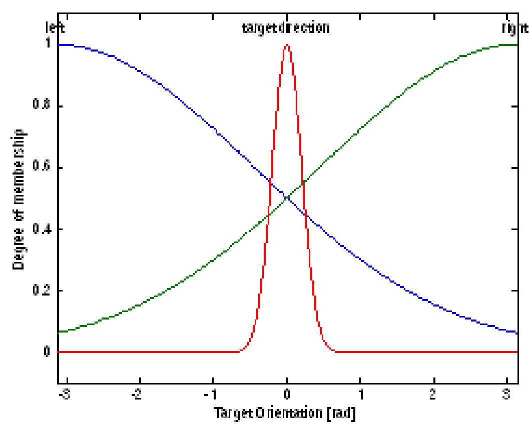

Figure 7. Membership functions of target orientation θ_2

The fuzzy sets for the output variables the wheel angular speed correction $\Delta\omega = \omega r - \omega l$ (turn-right, zero and turn-left) of the mobile robot are shown in Fig. 8.

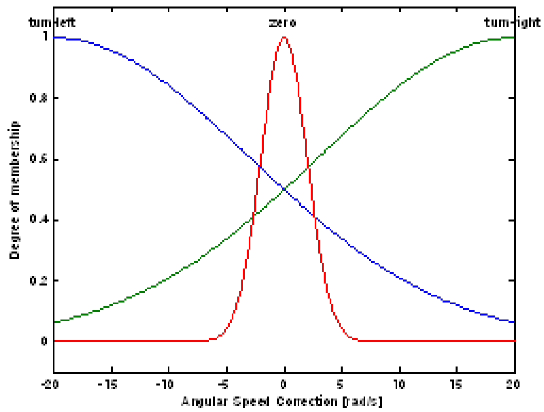

Figure 8. Membership functions of the angular speed difference $\Delta\omega$

The output variables are normalized between: $\Delta\omega \in [-20, 20$ rad/s]. The other output variable of the fuzzy controller is the vehicle velocity. The output variables are normalized between: Velocity $\in [-10, 20$ m/s]. The fuzzy sets for the output variables - Velocity (low and high) are shown in Fig. 9.

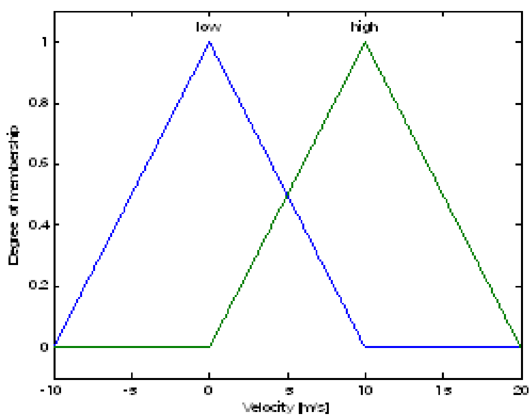

Figure 9. Membership functions of the velocity of the mobile robot

The rule-base for mobile robot fuzzy control are:

R1: If θ_2 is right and β is slopedleft then $\Delta\omega$ is turn-right

R2: If θ_2 is left and β is slopedright then $\Delta\omega$ is turn-left

R3: If p is near and l is far and θ_1 is left and β is slopedleft then $\Delta\omega$ is turn-right

R4: If p is near and l is far and θ_1 is right and β is slopedright then $\Delta\omega$ is turn-left

R5: If θ_2 is targetdirection and β is flat then $\Delta\omega$ is zero

R6: If p is far and θ_2 is targetdirection and β is flat then $\Delta\omega$ is zero

R7: If p is near and l is far then velocity is low

R8: If p is far and l is far then velocity is high

R9: If p is far and l is near then velocity is low.

In the present implementation of the fuzzy controller the Center of Area method of defuzzification is used. Control surface of the proposed fuzzy controller as a function of the inputs is shown in Fig. 10.

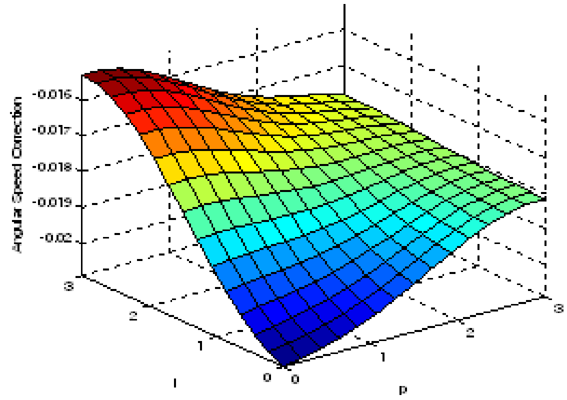

Figure 10. Control surface of fuzzy controller

IV. SIMULATION RESULT

Now, we applied the proposed fuzzy controller to the mobile robot moving in an unknown environment with obstacle. The results of the simulation are shown in Fig. 11-15. Fig. 11, Fig. 12 shows the x and y coordinates. Fig. 13 shows the vehicle velocity. Fig. 14 shows the wheel angular speed correction.

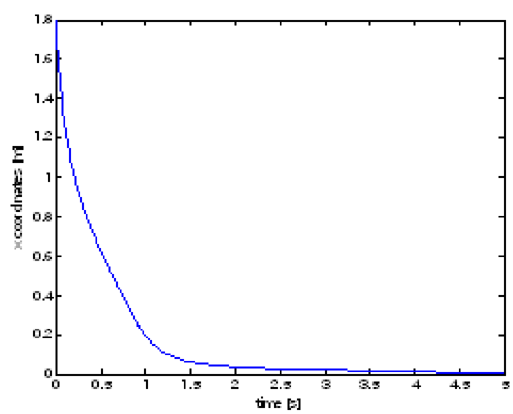

Figure 11. x coordinates

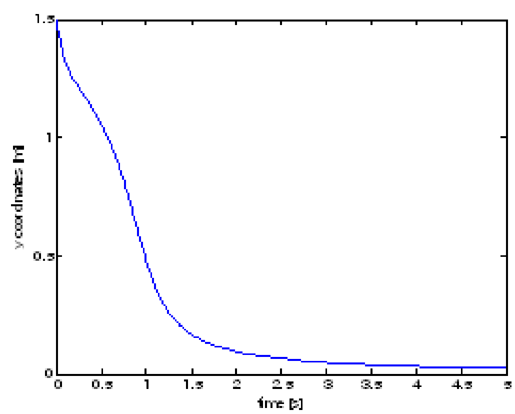

Figure 12. y coordinates

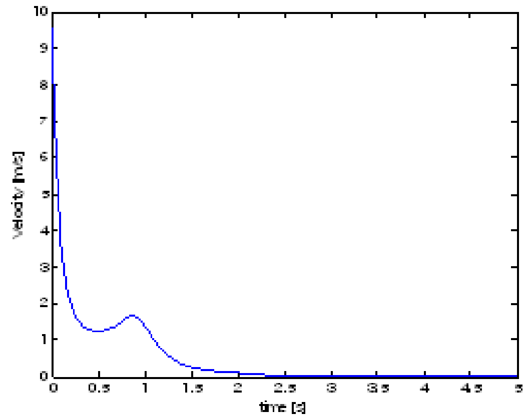

Figure 13. Vehicle velocity

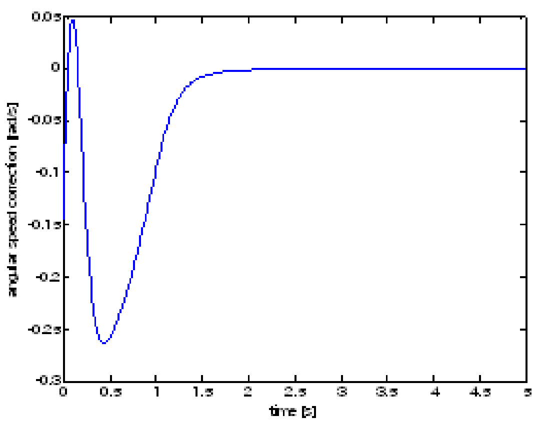

Figure 14. Wheel angular speed correction

Fig. 15 shows the goal seeking and the obstacle avoidance mobile robot paths of the right

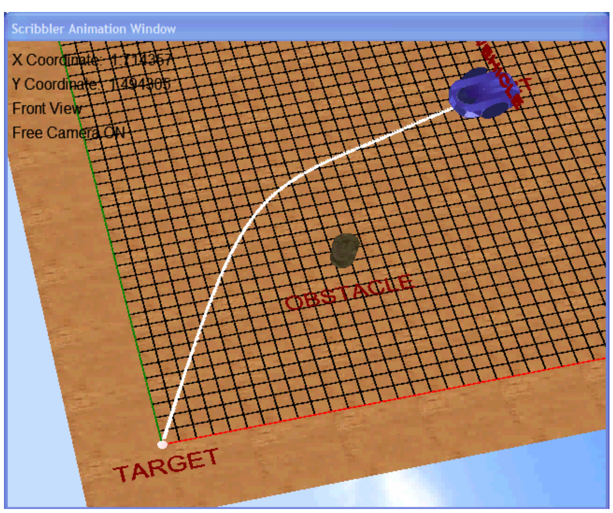

Figure 15. Obstacle avoidance trajectory of mobile robot

V. SUN SPOT BASED REMOTE CONTROL OF MOBILE ROBOTS

In this paper we have used:

SunSPOT-s

(Small Programmable Object Technology) to achieve remote control over a Kephera mobile robot. For this task we have used 2 SunSPOT-s from the development kit.

Sun SPOT's wireless protocol is ZigBee, standard: IEEE 802.15.4.

Sun SPOTS are small, battery operated wireles sensors. It contains:

32-bit ARM920T CPU,

512KB RAM, with

4 Mb Flash memory.

Wireless networking is based on ChipCon CC2420 following the 802.15.4 standard with integrated antenna and operates in the 2.4GHz to 2.4835GHz ISM unlicensed bands.

The SPOT has flexible power management and can draw from rechargeable battery, USB host or be externally powered. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules.

We used the SunSPOT base station to read a file from the controlling computer and send its contents to the second free range SPOT.

The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received. These outputs control the speed of the wheels individually.

The Hardware basically centers around Sun SPOTs

The Sun SPOT base station will send data to Sun SPOT on mobile robot which will drive the controller to DC. The microcontroller will drive the Motors which will run the Khepera mobile robot. The Sun SPOT connection strategy is presented in Fig. 16.

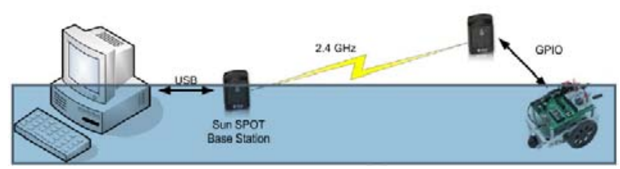

Figure 16. The Sun SPOT connection strategy

The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules.

We used the SunSPOT base station to read a file from the controlling computer and send its contents to the second free range SPOT.

The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received.

These outputs control the speed of the wheels individually. The Hardware basically centers around Sun SPOTs and DC Motors. The Sun SPOT base station will send data to Sun SPOT on mobile robot which will drive the Basic Stamp controller to DC IO pins. The microcontroller will drive the Motors which will run the Khepera mobile robot.

Figure 17. Control of Khepera mobile robot motion in Sun Spot environment

The user can start control experiment of mobile robots in Sun SPOT environment (Fig. 17). Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself [12]. Because of its Java implementation, programming the Sun SPOT is easy. The Software consists of two parts: first from the program used on the base station and from the program implemented on the free range SPOT [13].

The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules. We used the SunSPOT base station to read a file from the controlling computer and send its contents to the second free range SPOT. The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received. These outputs control the speed of the wheels individually. The Hardware basically centers around Sun SPOTs.
The Sun SPOT base station will send data to Sun SPOT on mobile robot which will drive the Basic Stamp controller to DC IO pins. The microcontroller will drive the Motors which will run the Khepera mobile robot.

Acknowledgments

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VI. Conclusions

The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a mobile robot motion in an unknown environment with slopes and obstacles. The model of the vehicle has two driving wheels and the angular velocities of the two wheels are independently controlled. When the vehicle is moving towards the target and the sensors detect an obstacle or slopes, an avoiding strategy and velocity control are necessary. We proposed the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and a fuzzy reactive navigation strategy of collision-free motion and velocity control in an unknown environment with slopes and obstacles. Outputs of the fuzzy controller are the angular speed difference between the left and right wheels of the vehicle and the vehicle velocity. The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment and velocity control of the proposed fuzzy control strategy. The proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot.

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Control of the Greenhouse's Microclimatic Condition using Wireless Sensor Network

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Abstract — As it is well known, greenhouses have a very extensive surface where the climate conditions can vary at the different points. In the last years, WSNs are becoming an important solution to this problem. This paper describes the implementation and configuration of the wireless sensor network using the Sun SPOT platform. Sun SPOT is a small electronic device made by Sun Microsystems. They have a wide variety of sensors attached to it. Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself. It has a quite powerful main processor running the Java VM "Squawk" and which serves as an IEEE 802.15.4 wireless network node. The SPOT has flexible power management and can draw from rechargeable battery, USB host or be externally powered. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules.

Keywords – WSN, Sun SPOT, embedded system, Java, PIC, ZigBee

I. Introduction

Wireless sensor networks consist of tiny devices that usually have several resource constraints in terms of energy, processing power and memory. In order to work efficiently within the constrained memory, many operating systems for such devices are based on an event-driven model rather than on multi-threading. Continuous advancements in wireless technology and miniaturization have made the deployment of sensor networks to monitor various aspects of the environment increasingly possibilities. Wireless Sensor Networks have recently received a lot of attention within the research community since they demand for new solutions in distributed networking. A common scenario associated with these networks is that tiny nodes, equipped with several sensors and hardware for wireless communication, are deployed randomly and in large numbers within a certain area. In order to report the data they gather in their proximity to an interested application or user, nodes connect to their neighbors and send valuable information on a multi-hop path to its destination.

The concept of wireless sensor networks is based on a simple equation:

Sensing + CPU + Radio = Thousands of potential applications

As soon as people understand the capabilities of a wireless sensor network, hundreds of applications spring to mind. It seems like a straightforward combination of modern technology. However, actually combining sensors, radios, and CPU's into an effective wireless sensor network requires a detailed understanding of the both capabilities and limitations of each of the underlying hardware components, as well as a detailed understanding of modern networking technologies and distributed systems theory.

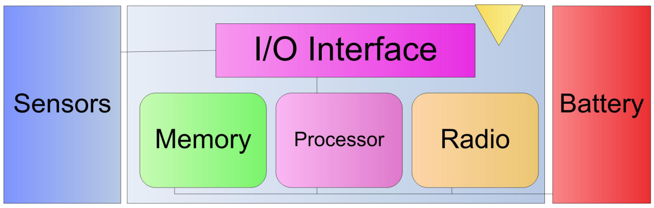

Figure 1. Sensor Node Architecture

Wireless sensor networking is one of the most exciting technologies to emerge in recent years. Advances in miniaturization and MEMS-based sensing technologies offer increases by orders of magnitude in the integration of electronic networks into everyday applications. Traditional microcontroller design strategies have not reached the best possible power consumption, especially for the specialized application set of sensing networks. Power efficiency is a prime concern in wireless sensors, whether powered by a battery or an energy-scavenging module. Trends in miniaturization suggest that the size of wireless sensors will continue to drop, however there has not been a corresponding drop in battery sizes.

II. Routing Management of the WSN

Increasing computing and wireless communication capabilities will expand the role of the sensors from mere information dissemination to more demanding tasks as sensor fusion, classification, collaborative target tracking. This paper current provides comprehensive investigation of different routing schemes used in wireless sensor networks. routing protocols may be classified in to one of the ensuing three models :

- single hop model
- multi-hop model
- cluster-based hierarchical model.

Single hop is the simplest model to reach a base station or the sink node. however, This kind of single hop transmission is highly unrealistic in the real world. The multi-model supports the collaborative effort of several nodes within the sensor cloud. each sensor node has a radio range, which is referred to as the distance which the signal strength remains above the minimum usable level for that particular node to transmit and receive.

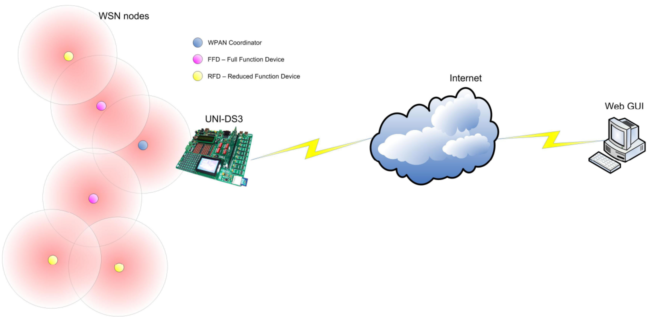

Figure 2. Schematic of the operational sensor network

In the cluster based model, the network is divided into clusters comprising of number amount of nodes. Cluster head, which is master node, within each respective cluster is responsible for routing the information to other cluster head.

III. Greenhouse Climate Problems

The dynamic behavior of the greenhouse microclimate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapour fluxes and CO_2 concentration). These processes depend on the outlet environmental conditions, structure of the greenhouse, type and state of the crop, and on the effect of the control actuators.

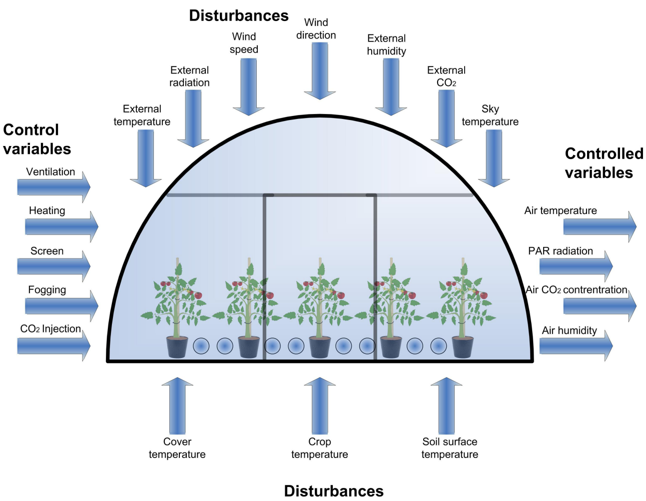

Figure 3. Climatic control variables

The main ways of controlling the greenhouse climate are by using ventilation and heating to modify inside temperature and humidity conditions, shading and artificial light to change internal radiation, CO_2 injection to influence photosynthesis, and fogging/misting for humidity enrichment. Crop growth is mainly influenced by the surrounding environmental climatic variables and by the amount of water and fertilizers supplied by irrigation. This is the main reason why a greenhouse is ideal for cultivation, since it constitutes a closed environment in which climatic and fertirrigation variables can be controlled to allow an optimal growth and development of the crop. The climate and the fertirrigation are two independent systems with different control problems. Empirically, the requirements of water and nutrients of different crop species are known and, in fact, the first automated systems were those that controlled these variables.

As the problem of greenhouse crop production is a complex issue, an extended simplification consists of supposing that plants receive the amount of water and fertilizers that they require at every moment. In this way, the problem is reduced to the control of crop growth as a function of climate environmental conditions.

IV. Temperature Control

Plants grow under the influence of the PAR radiation (diurnal conditions), performing the photosynthesis process. Furthermore, temperature influences the speed of sugar production by photosynthesis, and thus radiation and temperature have to be in balance in the way that a higher radiation level corresponds to a higher temperature. Hence, under diurnal conditions, it is necessary to maintain the temperature in a high level, being optimal for the photosynthesis process. In nocturnal conditions, plants are not active (the crop does not grow); therefore it is not necessary to maintain such a high temperature.

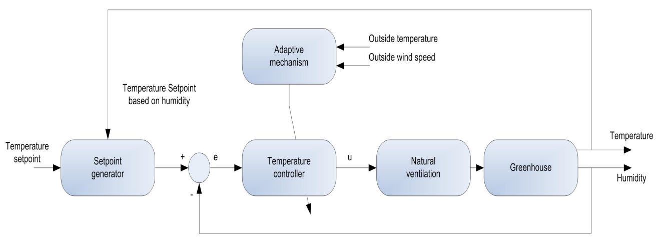

Figure 4. Temperature controller

On the other side, the nocturnal temperature control problem is the heating of the greenhouse (with temperatures lower than the nocturnal set-point) using heating systems to reach the nocturnal optimal temperature.

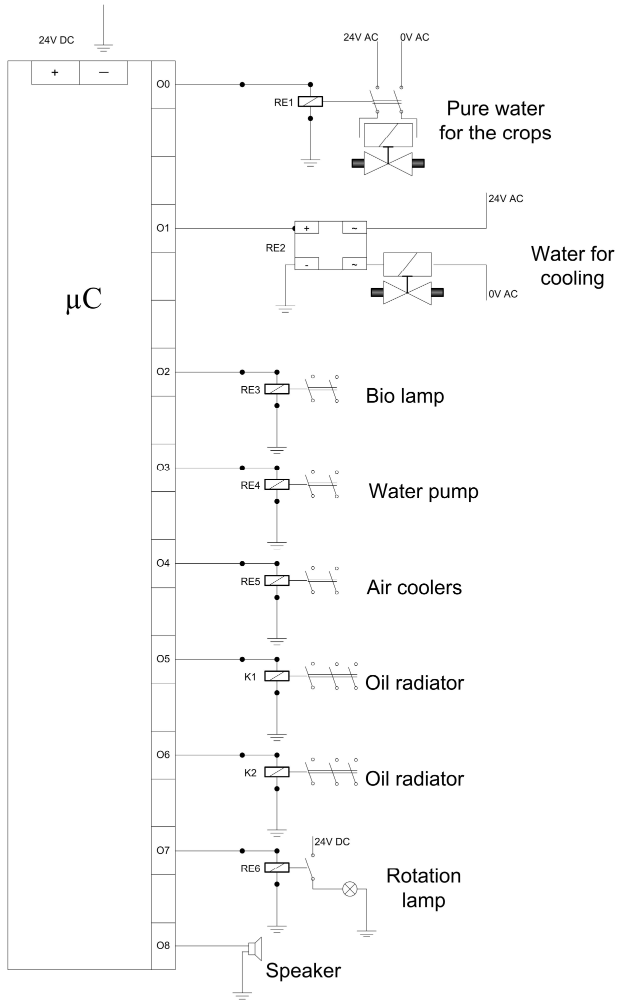

Figure 5. Actuator elements

The modification of the temperature set-point value depends on actual humidity level, selecting a maximum allowable modification for a specific kind of crop. A lower temperature set-point allows evacuating the humid air as a consequence of the exchange with the outside air because it is drier than the internal air.

V. HUMIDITY AND IRRIGATION CONTROL

Water vapor inside the greenhouse is not one of the most important variables affecting the crop growth. However, the humidity control has a special interest, because high humidity may produce the appearance of diseases and decrease transpiration, and low humidity may cause hydric stress, closing the stomata, and thus reducing the photosynthesis due to a decrease in the CO_2 assimilation.

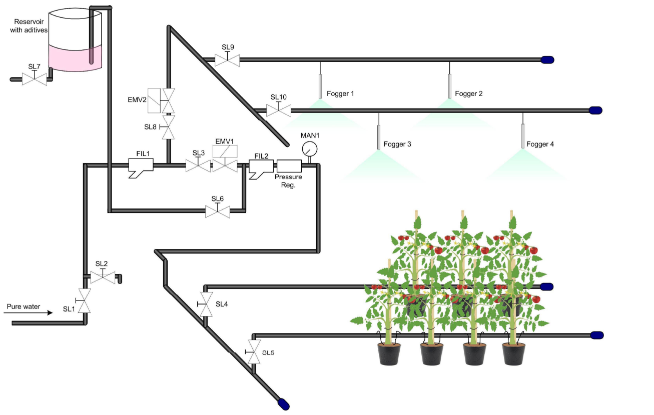

Figure 6. Humidity and irrigation control

There are two problems involved in the humidity control: (1) the greenhouse inside temperature and the relative humidity are inversely related when the greenhouse air not mixed with the external air, generally colder and drier (when one of them increases the other one decreases and vice versa); (2) the same actuators are used for controlling temperature and humidity. The temperature control has the main priority because it affects to the crop growth directly. In order to keep the humidity within a determined range, the temperature set-point can be changed based on the inside relative humidity value. Hence, the humidity controller acts as a set-point generator being able to change the temperature set-point in small ranges. The modification of the temperature set-point value depends on actual humidity level, selecting a maximum allowable modification for a specific kind of crop. A lower temperature set-point allows evacuating the humid air as a consequence of the exchange with the outside air because it is drier than the internal air. However, a higher set-point provokes that the ventilation remains closed for longer periods of time keeping the water vapour of air inside the greenhouse, and so increasing the humidity.

VI. WSN AND EVENT-BASED SYSTEM FOR GREENHOUSE CLIMATE CONTROL

As commented above, this paper is devoted to analyzing diurnal and nocturnal temperature control with natural ventilation and heating systems, and humidity control as a secondary control objective. Under diurnal conditions, the controlled variable is the inside temperature and the control signal is the vent opening. The use of natural ventilation produces an exchange between the inside and outside air, usually provoking a decrease in the inside temperature of the greenhouse. The controller must calculate the necessary vent opening to reach the desired set-point. The commonest controller used is a gain scheduling PI scheme where the controller parameters are changed based on some disturbances: outside temperature and wind speed. In the case of nocturnal temperature control, forced-air heaters are used to increase the inside temperature and an on/off control with dead/zone was selected as heating controller.

Climate monitoring is vitally important to the operation in greenhouses and the quality of the collected information has a great influence on the precision and accuracy of control results. Currently, the agro-alimentary market field incorporates diverse data acquisition techniques. Normally, the type of acquisition system is chosen to be optimal for the control algorithm to be used. For traditional climate monitoring and control systems, all sensors are distributed through the greenhouse and connected to the device performing the control tasks. These equipments use time-based data sampling techniques as a consequence of using time-based controllers. Nowadays, commercial systems present more flexibility in the implementation of control algorithms and sampling techniques, especially WSN, where each node of the network can be programmed with a different sampling algorithm or local control algorithm with the main goal of optimizing the overall performance.

VII. Conclusion

The applications for WSNs are many and varied. They are used in commercial and industrial applications to monitor data that would be difficult or expensive to monitor using wired sensors. They could be deployed in wilderness areas, where they would remain for many years (monitoring some environmental variable) without the need to recharge/replace their power supplies. They could form a perimeter about a property and monitor the progression of intruders (passing information from one node to the next). There are a many uses for WSNs.

Figure 7. Crops in greenhouse

Typical applications of WSNs include monitoring, tracking, and controlling. Some of the specific applications are habitat monitoring, object tracking, nuclear reactor controlling, fire detection, traffic monitoring, etc. In a typical application, a WSN is scattered in a region where it is meant to collect data through its sensor node. The WSN-based controller has allowed a considerable decrease in the number of changes in the control action and made possible a study of the compromise between quantity of transmission and control performance. The limit of the level crossing sampling has presented a great influence on the event based control performance where, for the greenhouse climate control problem, the system has provided promising results.

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E-Collaboration Technologies in Teaching/Learning Activity

Zaščerinska, J. and Ahrens, A.

Abstract—A proper use of e-collaboration technologies in the teaching/learning process is provided by varied cooperative networks, which penetrate teacher's and student's activity more thoroughly with the availability of broadband services. However, the successful use of e-collaboration technologies in teaching/learning activity within a multicultural environment requires that the key factors have to be considered. Aim of the following paper is to identify and to analyze these key factors in the use of e-collaboration technologies in teaching/learning activity. The meaning of the key concepts of e-collaboration technologies, collaboration and factors is studied within the search for factors affecting the use of e-collaboration technologies. The results of the paper reveal the factors forming a successful use of e-collaboration technologies in teaching/learning activity to become more mobile, to learn from the experiences of others and to work in a qualitative way.

Index Terms—*E-collaboration Technologies, Factors, Knowledge Triangle of Education, Research and Innovation*

1. *Introduction*

E-collaboration technologies offer potential solutions for the quality, maintenance and sustainable development of public services, social-security and health-care systems where educational system is one of them. Synergies between e-collaboration technologies are created through active collaboration, where the increased data exchange within the network is no longer a limiting parameter with the current developments in the infrastructure. With current developments such as Web 2.0 and beyond, information can be exchanged in both directions. Applications such as Facebook and MySpace are classical examples and have found widespread acceptance in the community, where with the current developments in the web infrastructure, users of e-collaboration technologies not only draw information from the Web, but also add information to it (Vossen, 2009). Aim of the paper is to identify and to analyze factors affecting the use of e-collaboration technologies within a multicultural environment on the pedagogical discourse. The search for factors influencing the use of e-collaboration technologies within a multicultural environment involves a process of analyzing the meaning of key concepts, namely, e-collaboration technologies, collaboration and factors affecting the use of e-collaboration technologies. The study would show a potential model for development, indicating how the steps of the process are related following a logical chain: defining e-collaboration technologies → collaboration within the use of e-collaboration technologies → factor definition → factors influencing the use of e-collaboration technologies within a multicultural environment → empirical study of key factors affecting the use of e-collaboration technologies within a multicultural environment.

The remaining part of this paper is organized as follows: Teaching/learning activity is defined in section 2. Section 3 introduces e-collaboration technologies. Collaboration within the use of e-collaboration technologies is studied in section 4. Section 5 focuses on theoretical analysis whereas section 6 offers an empirical study of factors influencing the use of e-collaboration technologies within a multicultural environment. The associated results are presented and interpreted in section 7 and 8. Section 9 provides some concluding remarks. Finally, a short outlook on interesting topics for further work is given in section 10.

2. *Defining Teaching/Learning Activity*

Teaching/Learning activity as a joint activity creates a context for a student and expert (teacher in the frame of the present research) interaction (Benson, 1995, p. 8).

Collaboration with the use of e-collaboration technologies, namely, Web-based chat tools, e-mail, listservs, Web-based asynchronous conferencing technologies, collaborative writing tools, group decision support system and etc., is determined as a form of life activity and, consequently, as a form of teaching/learning activity. Moreover, certain teaching/learning forms and methods are the activity's unity that allows considering collaboration with the use of e-collaboration technologies as the organization method and form of teaching/learning activity.

3. *Defining E-collaboration Technologies*

E-collaboration technologies assume user participation as well as socialization.

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Contemporary users of e-collaboration technologies not only draw information from the Web, but also add information to it (Vossen, 2009). Moreover, the dimension of socialization (or social dimension) exhibits various overlaps with other dimensions of Web 2.0, namely, the infrastructure dimension, the functionality dimension, the data dimension: technology enables functionality, which as a "byproduct" leads to data collections, and users have a new tendency to socialize over the Web by exploiting that functionality and the technology (Vossen, 2009). According to Vossen (Vossen, 2009), e-collaboration technologies involve two forms of user participation as well as socialization. Firstly, software or even use-generated content is shared or jointly used with others. Examples can be found in a huge variety, e.g., Skype, the eBay seller evaluation, the Amazon recommendation service, or Wikipedia. Secondly, online social networks connect people with common interests and may be as simple as a blog, or as complex as Facebook or MySpace for mostly private applications.

Implementation of e-collaboration technologies is based on collaboration (Tapscott, Williams, 2006).

4. *Defining Collaboration within the use of E-Collaboration Technologies*

Huber and Huber (Huber and Huber, 2007) point out that "collaboration" and "cooperation" are used synonymously in many publications. However, the distinctive use of these terms is emphasized by Huber and Huber (Huber and Huber, 2007). Product orientation is linked to an understanding of collaboration and process orientation is seen as cooperation. Product on the pedagogical discourse is defined as experience. Experience is seen as the unity of knowledge, skills and attitudes gained during life, evaluated positively by the individual, strengthened in his/her habits and used in a variety of activity's situations. Moreover, the findings of neuro-psychology about brain activity as intrapersonal, interpersonal and introspective processes (Roth, 2007) widen the understanding of knowledge and allow further defining product as knowledge triangle of education, research and innovation.

Thus, collaboration is seen as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle and Teasley, 1995) where collaboration with the use of e-collaboration technologies is an integral part. However, collaboration is formed by factors.

5. *Defining Factors*

Factor is defined as a reason of the research subject change (Lasmanis, 2008). They are considered to be as external and internal (Lasmanis, 1997). External factors are determined as surroundings and resources whereas internal factors are seen as the aims of the student's activity, motivation, interest, skills, and experience. Thus, factors form collaboration to enable synergy between e-collaboration technologies.

6. *Factors affecting Use of E Collaboration Technologies*

The analysis of external and internal factors as well as the definition of collaboration within the use of e-collaboration technologies allows considering the following factors on the pedagogical discourse: factors forming communication, teacher's purposeful activity as an external factor (Žogla, 2008) and learning factors.

6.1 Factors Forming Communication

Factors forming communication are determined by Shumin (Shumin, 1997) as follows: aural medium, socio-cultural factors and non-verbal communication system. All these factors will be supported by the availability of broadband services as a key component for an efficient use of e-collaboration technologies.

6.1.1 Aural Medium

During interaction, every speaker plays a double role – both as a listener and a speaker. Speaking feeds on listening which precedes it (Shumin, 1997): one person speaks, and the other responds through attending by means of the listening process. The main potential problems of listening comprehension are determined as follows (Ur, 1984): hearing the sounds, understanding intonation and stress, coping with redundancy and "noise", predicting, fatigue, understanding different accents and using visual and aural environmental clues. With the availability of broadband services, online-services can be used to optimize this process, where a new dimension can be achieved with new applications such as Web 2.0 where contemporary users of e-collaboration technologies not only draw information from the Web, but also add information to it (Vossen, 2009)

6.1.2 Socio-cultural Factors

Socio-cultural characteristics, namely, social-economical status, religion, language, address (urban, country, more or less prestigious area), interests, abilities and talents, also form communication where the shift has changed from focusing on macro-cultures to micro-cultures (family culture, school culture, class culture, professional culture, gender culture, culture of interest groups, political groups/parties, generation) (Dirba, 2007, p. 102-103). Also, each language has its own rules of usage as to when, how, and to what degree a communicator may impose a given verbal behaviour on his/her conversational partner where due to influence or interference of their own cultural norms, it is hard for non-native speakers to choose the forms appropriate to certain situations (Shumin, 1997, p. 9). Thus, all groups/classes are understood to be multicultural. It has led to a new perspective:

people behave being influenced by identification with different groups, not only one group (Dirba, 2007, p. 102-103).

6.1.3 Non-verbal Communication System

Moreover, communication involves a very powerful non-verbal communication system (gestures such as the language of gazes, the language of poses and bodily movements; interaction through the use of their bodies, faces, hands, legs, eyes, mimicry, intonation, space management, dress code, gift giving, emoticons or smileys) adding meaning to verbal judgments, which sometimes contradicts the messages provided through the verbal listening channel. A lack of familiarity with the non-verbal communication system of the target language often leads to misunderstanding (Shumin, 1997, p. 9). Out of all types of non-verbal components of communication it is significant to concentrate on the description of several aspects of mimics and gazes that constitutes a separate language, the so called "kinesic gaze". Mimicry is often considered to be the most universal way of communication. The representatives of different cultures express six main human feelings: fear, disgust, fury, astonishment and happiness – in a similar way. Facial expression is a "mask", a mask that at the same time reflects the emotional state and certain cultural predispositions or customs of an individual. It is common knowledge that in order to function in society successfully one has "to put up a proper face" to show proper attitude towards particular situations, to observe etiquette.

6.2 Teacher Activity

In order to organize teaching activity, teacher needs to take into consideration several areas (Kramiņa, 2000, p. 75): careful preparation of material including specifically chosen lexical areas and seeking repetition of information, careful clarification of the task before undertaking it, planning whether the activity should fit into the general progression of the syllabus or whether it should be an independent activity aimed at satisfying the study purpose of certain individual learners, finding out whether it fits in with other and parallel teaching situations, negotiating a balance between task needs and individual or group needs, planning how varied the types of activities should be, competition as a stimulus and not as a hostile activity, scoring the activity results to help the learners to be aware of their progress and ensuring sensitivity to any emotional or cultural blockages which might interfere with the learners' confidence to use the knowledge in relation to the particular topic, situation or functional purpose. Thus, the teacher is identified in a number of roles that relate to the process of organizing teaching activity (Hedge, 2000, p. 26): assessor, corrector, organizer in giving instructions for the pair work, e.g., initiating it, monitoring it, and organizing feedback, prompter while students are working together and resource if students need help. Correction can be made up of two distinct stages (Harmer, 2001, p. 106): teachers show students that a mistake has been made and teachers help the students to do something about it. There are a number of different ways how to show incorrectness (Harmer, 2001, p. 106-107), e.g., repeating, i.e., by asking the students to repeat what they have said, echoing, i.e., by repeating what the student has said and emphasizing the part of the utterance that was wrong and questioning, i.e., by indicating that something has not quite worked. An alternative way is to use simple facial expression or a gesture (for example, a wobbling hand) by indicate that something does not quite work. However, this needs to be done with care as the wrong expression or gesture can, in some circumstances, appear to be mocking or cruel. Hinting can also be considered to be a quick way of helping students to activate rules they already know (but which they are temporarily "disobeyed"). For example, we might just say the word "tense" to make them think that perhaps they should have used the past simple rather than the present perfect or "countable" to make them think about a concord mistake they have made. This kind of hinting depends upon the students and the teacher sharing metalanguage (linguistic terms) which, when whispered to students, will help them correct themselves. Reformulation is another correction technique for the teacher to repeat what the student has said correctly, by reformulating the sentence without making a big issue of it. Furthermore, teachers can write down points they want to refer to later; teachers can also record students' performance on audio or videotape. Another alternative is to divide students into groups and have each group watch for something different – for example, one group focuses on pronunciation, one group listens for the use of appropriate or inappropriate phrases, etc. Another possibility is for the teacher to transcribe parts of the recording for future study. However, after the event teachers might want to give an assessment of an activity, saying how well the teacher thought the students did in it and getting the students to tell us what they found easiest or most difficult. Teachers can put some of the mistakes they have recorded on the board and ask students firstly if they can recognize the problem, and then whether they can put it right. Another possibility is for teachers to write individual notes to students, recording mistakes they heard from those particular students with suggestions about where they might look for information about the language – in dictionaries, grammar books, or on the Internet, which is becoming more and more popular among the young generation.

In case students do not know or understand what the problem is because it is dealt with an error or an attempt that is beyond the students' knowledge or capability the teacher will want to help the students get it right (Harmer, 2001, p. 106-107). Alternatively, if the student is not able to correct him/herself, or respond to reformulation, we need to focus on the correct version in more detail. The correct version emphasizes the part where the problem is (e.g. Flight 309 GOES to Paris) before saying the sentence normally (e.g. Flight 309 goes to Paris), or we can say the incorrect part correctly (e.g. Not "go". Listen, "goes"). If necessary we can explain the grammar or a lexical issue. We will then ask the student to repeat the utterance correctly. We sometimes ask students to correct each other. We might hope that other students know the correct version of the utterance – after which the student who made the mistake should be able to say the sentence, question, or phrase accurately.

Student-to-student correction works well in classes where there is a genuinely cooperative atmosphere; the idea of the group helping all of its members is a powerful concept (Harmer, 2001, p. 107). Nevertheless it can go wrong where the error-making individual feels belittled by the process, thinking that she/he is the only one who does not know grammar or vocabulary: there is a need to be exceptionally sensitive here, only encouraging the technique where it does not undermine such students.

Thornbory (1999, p. 92) concludes that a practice activity which is good for knowledge improving will have these characteristics: attention to form, i.e., the practice activity should motivate learners to be accurate, and they should not be so confused on what they are saying so that they have no left-over attention to allocate to how they are saying it. Learners need to be familiar with the subject that they are trying to get right, thinking time, i.e., monitoring for accuracy is easier and therefore more successful if there is sufficient time available to think and reflect and feedback, i.e, learners need unambiguous messages as to how accurate they are – this traditionally takes the form of correction. Teachers need to respond to the content not just the language form; teachers need to be able to untangle problems which students have encountered or are encountering (Harmer, 2001, p. 107). Discussing the role of teacher as resource it is important to remember that students are also resources (Hay, 1996, p. 5). In order to have sufficient subject-specific knowledge, Popova (1996, p. 14-15) suggests to keep in touch with other students' subject teachers. She claims that it is a time-consuming task but it pays. It gives you information about: what they have already studied, what they are studying now, what sources they need to consult for subject-specific information and what the subject teacher can help you with in terms of diagram reading, equivalents of terms, specific skills that students need to develop in relation to their job prospects. If the teacher has all this information, she/he can (Popova, 1996, p. 14-15) draw on students' former knowledge and experience, teach those aspects that will help them acquire subject-specific information, make use of what each student is good at for classroom activities and tasks and boost his/her self-confidence by relying on expert information and consultancy.

Another way that can be suggested is to contact other teachers doing the same work. That reveals the necessity to emphasize on more general social and political theories such as democracy, social justice, equality and legitimacy in order to be able to (Feerick, 2007, p. 4-5) work with information, technology and knowledge, work with their fellow human beings – pupils, students, trainees, adult learners, colleagues, and other partners in education and work with and in society – at local, regional, national, European and broader global levels. There is also a discussion on the issue of a European Teacher (Auziņa, 2009, p. 10) where common European teacher's principles are as follows (Feerick, 2007, p. 5): a graduate profession with three cycles, a profession placed within the context of lifelong learning, a mobile profession and a profession based on partnerships.

6.3 Learning Factors

There is a range of learning factors. Learning achievements depend on (Shumin, 1997, p. 8; Maslo, 2007, p. 42) the age of students, affective factors, namely, such as emotions, self-esteem, empathy, anxiety, attitude, motivation and learning experience.

6.3.1 Age

The age is considered as one of the most commonly cited determinant factors of success or failure in learning (Shumin, 1997, p. 8). For example, beginning to learn a foreign language in early childhood through natural exposure gives higher proficiency than those beginning as adults.

6.3.2 Affective Factors

The affective factors related to learning are emotions, self-esteem, empathy, anxiety, attitude and motivation (Shumin, 1997, p. 9). Also, the tendency to be sensitive to perceived views of themselves by others is a worry about personal images of great personal importance for everyone thereby developing extreme anxiety as a variable of emotional responses where seven categories of anxiety are emphasized (Shumin, 1997): comparison of myself with other students, emotive responses to the comparisons described above, the desire to outdo the other students, emphasis on tests and grades, the desire to gain the teacher's approval, anxiety experiences during the class and withdrawal from the learning experience when the competition was overpowering. In order to overcome ethno-centricity as an attitudinal variable there is a need to build positive attitudes to the subject study through motivating content and tasks (Hedge, 2000, p. 20).

6.3.3 Motivation

Then, a significant aspect in the learning/teaching process is seen as motivation defined as that we have to want to do something to succeed at it (Harmer, 2001, p. 51). Motivation can be extrinsic, i.e, caused by a number of outside factors and intrinsic, i.e., motivation that comes from within the individual and is especially important for encouraging (Harmer, 2001, p. 52). Intrinsic motivation consists of six components (Kalkiene and Virbickaite, 2008, p. 50): enthusiasm, feeling when you can control situation yourself, rejoice when you have some achievements, own experience in interesting learning process, an ability to estimate your achievements and any support from environment. Motivation is ensured by earning a living, intellectual stimulation, a feeling of satisfaction and fulfillment and receiving recognition.

There are three areas where teacher can attract students' continuing participation (Harmer, 2001, p. 53): goals and goal settings, learning environment and interesting classes. A way to motivate students is to focus on creating successful employment prospects for students (Hedge, 2000, p. 23-24). A new outlook emphasizes focusing not on today's problems or contradictions but on student's desires where desire is a subjective component of motivation. Moreover, individuals are especially motivated if they can control their own learning process, set their own goals, take responsibility for their learning, are able to work independently, are able to evaluate their own learning process and continue to improve their skills (Maslo, 2007, p. 39).

6.3.4 Learning Experiences

Also, drawing upon the experiences of individuals is important; both life-experiences as well as abilities that may be dormant (Maslo, 2007, p. 39). The following description of language acquisition/learning illustrates the role of experience in learning: acquisition, i.e, native or second language, and learning, i.e, the first, second or third foreign Language. The model of first language acquiring outlines two dimensions: the universal (born condition in order to learn a language) and the learning environment that is an investment a child takes life-long (everything that is around the child during his/her life can influence it (people, circumstances, possibilities, etc.)). The process of second as a foreign language learning already involves three more factors: native language experience, private life experience and learning experience, including motivation. In accordance with the ideal model of foreign language learning, the next foreign language learning becomes easier (Maslo, 2007, p. 43). But real life reveals problems that appeared in the process of previous language learning and make next foreign language learning difficult: even creating ideal circumstances for foreign language learning, teacher cannot be sure about learning ideal results because there is a student who acquire a new language therefore it is more important to pay attention to what the student get from different types of activities in the classroom (Maslo, 2007, p. 43).

7. Empirical study

The target population of the present empirical study involves 22 participants of Fifth Baltic Summer School *Technical Informatics and Information Technology* at the Institute of Computer Science of the Tartu University from the 7th to the 22nd of August 2009 in Tartu, Estonia.

All 22 students have got Bachelor or Master Degree in different fields of Computer Sciences and working experience in the different fields.

The International Summer School offers special courses to support the internationalization of education and the cooperation among the universities of the Baltic Sea Region.

The aims of the Baltic Summer Schools *Technical Informatics and Information Technology* are determined as preparation for international Master and Ph.D. programs in Germany, further specialization in computer science and information technology and learning in a simulated environment.

The Summer School *Technical Informatics and Information Technology* contains a special module on Web 2.0 where e-collaboration technologies are an integral part.

Analysis of key factors in the use of e-collaboration technologies in teaching/learning activity is based on the following questionnaire: Question 1: Do you know the basic idea of Web 2.0? Question 2: Do you think Web 2.0 is useful for your individual needs? Question 3: Do you think Web 2.0 is useful for your organizational use? Question 4: Do you think Web 2.0 is useful for your professional use?

Key factors in the student use of e-collaboration technologies were evaluated by the students themselves on the first day, namely, the 7[th] August 2009, and on the fifth day, namely, the 11[th] August 2009, of Baltic Summer School 2009.

The analysis of the first measurement (see Figure 1) revealed that the student use of e-collaboration technologies is heterogeneous and the students consider Web 2.0 where e-collaboration technologies are an integral part to be most useful for their individual needs (see Question 2).

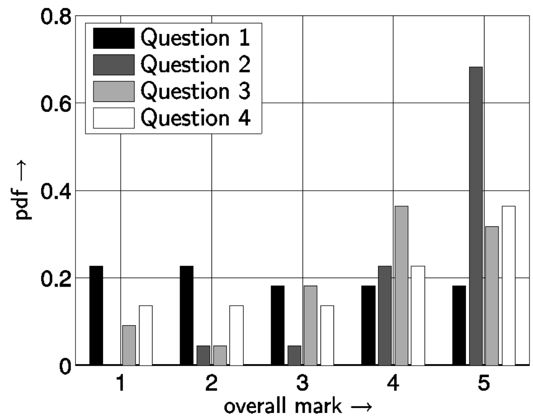

Figure 1: PDF (probability density function) of the first student's evaluation on August 6[th], 2009

Between the first and second student's evaluation of key factors in the student use of e-collaboration technologies teaching/learning activity involved courses in Technical Informatics and Information Technology (German and English), preconference tutorials for introduction into advanced research topics, attendance of conference *Advanced Topics in Telecommu-nication*, tutorials and practical tasks, language

training for talk and presentation (optional in English or German), leisure activities and social contacts and practical work at IT Company.
Then, the analysis of the second measurement (see Figure 2) revealed that the student use of e-collaboration technologies has become homogeneous and the students have put the emphasis on the use of Web 2.0 where e-collaboration technologies are an integral part for professional needs (see Question 4).

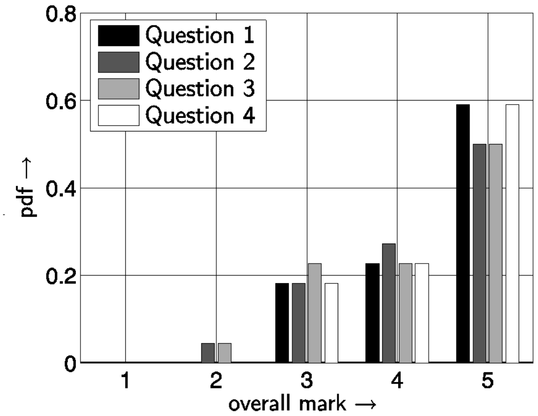

Figure 2: PDF (probability density function) of the second student's evaluation on August 11th, 2009

8. Results

The search for factors forming the use of e-collaboration technologies within a multicultural environment involves a process of analyzing the meaning of key concepts, namely, e-collaboration technologies, collaboration and factors affecting the use of e-collaboration technologies. The study shows a potential model for development, indicating how the steps of the process are related following a logical chain: defining e-collaboration technologies → collaboration within the use of e-collaboration technologies → factor definition → factors affecting the use of e-collaboration technologies within a multicultural environment → empirical study of key factors affecting the use of e-collaboration technologies within a multicultural environment.

9. Conclusions

The identified and analyzed factors allow forming productive collaboration within a multicultural environment that enables synergy between e-collaboration technologies to increase their use.

10. Outlook

Further research on factors affecting productive e-collaboration within a multicultural environment that enables synergy between e-collaboration technologies to increase their use is considered to include criteria, indicators and levels of collaboration, a relevant set of methods to evaluate each criterion, the questionnaire development, other samples for further empirical studies and their statistical analysis.

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