UDC: 681.5-523.8:001.2
Professional paper

DEVELOPMENT OF MECHATRONIC TECHNOLOGY THROUGH A TRANSDISCIPLINARY KNOWLEDGE APPROACH

Rrahim Maksuti[1], Hysni Osmani[2], Nexhbedin Ismaili[1], Kushtrim Sulejmani[1], Ilir Mehmedi[1]

[1]Department of Mechatronics, Faculty of Applied Sciences, University of Tetova "Fadil Sulejmani", North Macedonia
[2] Department of Manufacturing and Automation, Faculty of Mechanical Engineering, University of Prishtina "Hasan Prishtina", Kosovo
Corresponding author e-mail: rrahim.maksuti@unite.edu.mk

Abstract

Today, mainly products of modern technology consist of both hardware and software components, integrated into monolithic entities that perform different macro functions useful for improving the quality of human life. The production of these products is enabled by the deep integration and interaction of various core technologies such as mechanic technology, electrical/electronic technology, and information technology, currently termed mechatronic technology. The trends of integration and interaction of various core technologies and processes, as a unique model of mechatronic technology, leads to further development, creating thus more possibilities for its contribution to improving the quality of human life. The proper integration and interaction of all these disciplines can be done only with a new approach to mechatronic technology, based on the principle of the synergistic effect.

Mechatronics technology is an open field in continuous development that transcends the limits of crossdisciplinary, multidisciplinary, and interdisciplinary knowledge and the continuous growth of interest for modern products and processes imposes the development of mechatronic technology through transdisciplinary knowledge approach, opening new development perspectives and the same time more benefits to fulfill of the human life needs.

In other words, the transdisciplinary knowledge approach is more successful than an interdisciplinary approach to creating new knowledge from constitutive disciplines of mechatronic technology and working jointly to solve problems of human life. The purpose of this paper is to describe the development of mechatronic technology in the context of a transdisciplinary knowledge approach, based on the review of literature data and experience from work as teachers of materials and production technology in mechatronics. From the research done in this paper, it is concluded that the development of mechatronic technology through passing from an interdisciplinary to a transdisciplinary knowledge approach helps to meet and improve more closely human life needs that will be emerged in the 21st century.

Keywords: mechatronics technology, interdisciplinary knowledge, multidisciplinary knowledge, transdisciplinary knowledge.

1 Introduction

Many engineering products and processes in industry are developed through combination and integration of knowledge from several technologies, such as the knowledge of mechanical technology are deeply integrated with the knowledge of electrical technology and thus improve the functionality of the respective engineering systems. This combination or interaction of knowledge among various technological disciplines may be: crossdisciplinary, interdisciplinary, multidisciplinary and transdisciplinary. It is worth noting that based on this combination and integration of knowledge between various technological disciplines is the emergence of mechatronic technology, which involves at least mechanical technology, electrical/electronic technology, and information technology. So, mechatronic technology is a field of technology that includes a combination or integration of mechanical technology, electrical/electronic technology, and information technology knowledge in different way to establish basic principles for the design, development, control and application of advanced products, processes, and systems. Crossdisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary transfer of knowledge among core disciplines are terms (notions) that are often interchangeably used in the literature and determine the degree of their applicability. The level development of mechatronic technology is determined by the way of integrating the knowledge of its constitutive core disciplines, therefore the aim of this paper is focusing on the transdisciplinary approach of knowledge on the continuous development of the mechatronic technology by reviewing a relatively broad literature sources that include: academic textbooks, published journals, engineering handbooks, engineering guidelines, databases for mechatronic technology as well as other sources.

2 Literature review

2.1 *Definition of mechatronics*

The term mechatronics is less recognized by the public, although the advent of mechatronics can be traced back to the early 1950s when a prototype numerical control machine tool was demonstrated at the Massachusetts Institute of Technology (MIT) in the United States (Paulo, 2012). It is worth noting in particular that the term mechatronics was first coined in 1969 by Tetsuro Mori, a senior engineer at the Japanese company Yaskawa Electric Corporation, who defined mechatronics as: the term which is a combination of "MECHA" from mechanisms or mechanics and the "TRONICS" from electronics (Bishop, 2002), figure 1.

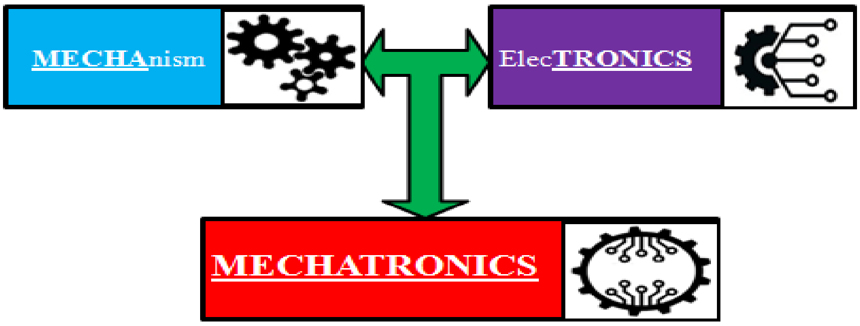


Figure 1. Illustration of terms describing the first definition of mechatronics

The term mechatronics emerged in Japan and reflected the merging of mechanical and electrical engineering disciplines (Ioan and Vistrin, 2009). At first, the definition that mechatronics is simply the combination of different technologies was not sufficient to explain mechatronics and the definition of mechatronics continued to evolve after Yaskawa suggested the common definition. Mechatronics is, however, more than just a merely combination of different technologies. Later, due to the market need for better quality products, were required new knowledge and more close integration between these disciplines and instead of the term combination, the term integration or synergistic integration began to be used. Over time the definition of mechatronics has fundamentally changed, including more technical and technological concepts, and is consolidated as a new engineering discipline, necessarily including information technology with all the latest achievements. Starting at the threshold of the twenty-first century, with advances in information technology and with other unforeseen technological developments, the future of mechatronics is full of potential and bright possibilities. Mechatronics gained legitimacy in academic circles with the publication of the first refereed journal: IEEE/ASME-Transactions on Mechatronics. In this publication, by (Harashima, et al., 1996), mechatronics was defined as: the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes. This journal, for the first time, is being recognized the interdisciplinarity of mechatronics and this is a very important indication for mechatronics in the technical and technological area. In a forthcoming publication (Harashima and Suzuki, 2008) the following definition is used: mechatronics is known as the discipline integrated by mechanical, electrical, and information technology and has been used to produce advanced artifacts used in modern society, which has been developed through the interdisciplinary studies of diverse engineering fields. According to (Onwubolu, 2005), mechatronics is: the synergistic integration of precision mechanical engineering, electronic control, and systems thinking in the design of products and manufacturing processes. According to (Grimheden, 2007), the subject of mechatronics is defined: to be crossdisciplinary, based on the concept of synergy and synergistic use of knowledge and skills in underlying subjects. In the literature (Paulo, 2012), there are many definitions of mechatronics, but these definitions are not exhaustive, and it is worth noting that they demonstrate noticeable diversity between them. Some definitions according to (Paulo, 2012) are as follows, table 1.

Table 1. Definitions of mechatronics according to (Paulo, 2012)

No.	Definitions of mechatronics
1.	Mechatronics is the ability to integrate electronics and computing technologies into a wide range of primarily mechanical products and processes.
2.	Mechatronics is the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design of products and processes.
3.	Mechatronics is the application of the methodology, techniques, and understanding of one or more disciplines to another discipline.
4.	Mechatronics is the synergistic combination of precision engineering, electronic control technology, and systems thinking in the design of products and processes.
5.	Mechatronics is the application of complex decision-making to the operation of physical systems.
6.	Mechatronics is the synergetic integration of physical systems with information technology and complex decision-making in the design, manufacture, and operation of industrial products and processes.
7.	Mechatronics is the synergetic integration of mechanical engineering, with electrical engineering and/or electronics, and possibly, with other disciplines, for the purposes of design, manufacture, operation, and maintenance of a product.

One of the most accurate definitions according to (Kyura and Oho, 1996) is as follows: mechatronics is the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes. According to (Craig, 2001): mechatronics is the synergistic combination of mechanical engineering, electronics, control systems and computers, all integrated through the design process. The Industrial Research and Development Advisory Committee of the European Union, (IRDAC, 1986) has formulated a general accepted definition of mechatronics as follows: the term mechatronics refers to a synergistic combination of precision engineering, electronic, control and systems thinking in the design of products and manufacturing processes. It is an interdisciplinary subject that both draws on the constituent disciplines and includes subjects not normally associated with one of the above. This Committee admits that mechatronics is of a major necessity for European research and for the educational programs. Mechatronics was thus recognized as a reality in permanent development in the integrated educational technologies suitable for a knowledge-based society (Liliana and Florina, 2015). The mechatronics teaching approach intends to give up the concept of passive theoretical learning and replace it with an active-educational attitude based on holistic approach and to explain the complex problems of reality. So, mechatronics comes to harmonize the dimensions and forms of education, allowing the connection of subjects to real life and the treatment of contents of inter and transdisciplinary options (Liliana and Florina, 2015). According to (Amerongen, 2000), mechatronics is: a technology which combines mechanics with electronics and information technology to form both functional interaction and spatial integration in components, modules, products, and systems. In the literature (John et al., 2007), the term mechatronics is defined as: the multidisciplinary application of mechanics, electronics, control systems and computer systems to optimize the performance of products or processes. According to (Azizi, 2019): mechatronics is: a multidisciplinary branch of engineering, combining mechanical, electrical and electronics, control and automation, and computer engineering fields. According to (Alciatore and Histand, 2012) the term mechatronics is defined as: the field of study involving the analysis, design, synthesis, and selection of systems that combine electronic and mechanical components with modern controls and microprocessors. Other definitions of mechatronics summarized in a separate article of David Alcicatore's creative activity are given in the table 2.

Table 2. Definitions of mechatronics according to (Alcicatore, 2012)

No.	Definition of mechatronics
1.	Interdisciplinary engineering field comprising the design and development of smart electromechanical systems.
2.	Field of study that combines the fundamentals of mechanical, electrical, and computer engineering.
3.	The blending of software (and) hardware for the design (and) analysis of advanced control techniques.

4.	Science that integrates mechanical devices with electronic controls.
5.	Synergistic combination of precision engineering, electronic control and systems thinking in the design of products and manufacturing processes.
6.	The interdisciplinary field of engineering dealing with the design of products whose function relies on the integration of mechanical and electronic components coordinated by a control architecture.
7.	The synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes.
8.	Mechatronics is a design philosophy that utilizes a synergistic integration of mechanics, electronics, and computer technology (or IT) to produce enhanced products, processes or systems.
9.	The synergistic use of precision engineering, control theory, computer science, and sensor and actuator technology to design improved products and processes or simply the application of the latest techniques in precision mechanical engineering, controls theory, computer science, and electronics to the design process to create more functional and adaptable products.
10.	The synergistic integration of mechanical engineering with electronics and electrical systems with intelligent computer control in the design and manufacture of industrial products, processes, and operations.
11.	The synergistic application of mechanics, electronics, and computer engineering in the development of electromechanical products and systems through an integrated design approach.
12.	Crossdisciplinary (field)… that simultaneously involves mechanics, electronics, and control of computer-integrated electromechanical systems”
13.	Integration of electronics, control engineering and mechanical engineering.
14.	An integrating theme within the design process combining) electronic engineering, computing and mechanical engineering.
15.	The application of complex decision making to the operation of physical systems.
16.	Pre-planned activity to consider electrical, mechanical, and software constraints over the product life cycle in a simultaneous manner early in the development process.
17.	Methodology used for the optimal design of electromechanical products.
18.	Filed (consisting) of the synergistic integration of three traditional engineering fields (mechanical engineering, electrical or electronics engineering, and computer science) for system level design processes.
19.	The synergistic integration of precision mechanical engineering, electronic control and systems thinking in the design of intelligent products and process.
20.	The synergistic combination of mechanical engineering, electronics, control systems and computers, all integrated through the design process.
21.	A flexible, multi-technological approach in the integration of Mechanical Engineering, Computer Engineering, Electronics, and Information Sciences.
22.	Technical systems operating mechanically with respect to at least some kernel functions but with electronics supporting the mechanical parts decisively.
23.	The integrated study of the design of systems and products in which computation, mechanization, actuation, sensing, and control are designed together to achieve improved product quality and performance.
24.	Mechatronics is concerned with the blending of mechanical, electronic, software, and control theory engineering topics into a unified framework that enhances the design process.

One of the definitions of mechatronics is presented by (Habib and Davim, 2013): mechatronics is a unifying interdisciplinary and intelligent paradigm that synergizes, permeates, and comprehends modern engineering technologies, systems, and practices. According to (Panga et al., 2013): mechatronics is the synergistic integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software to manage complexity, uncertainty, and communication in engineered systems. The Dictionary of Mechanical Engineering defines mechatronics as: the integration of mechanical, electrical, electronics and software engineering (Atkins & Escudier, 2019). Mechatronics is the synergistic combination of mechanical engineering, electronic engineering, controls engineering and computer engineering to create useful products (Gollamudi, et al., 2011). According to (Acar and Parkin, 1996), mechatronics is: a transdisciplinary approach, based on open communication systems and concurrent practices, to design better engineering products. This article states that the Japanese university educational system tends to foster engineers with a transdisciplinary approach while in recent years, mechatronic engineering courses at undergraduate and postgraduate levels as well as vocational training courses, have been rapidly increasing in both European and the US higher education institutions.

During its almost 50-year lifetime, the definition of mechatronics has evolved through a series of redefinitions from the original concept of electrification of mechanisms to its current definition, which is based on the concept of integration and synergy. As a result of technological developments, the term mechatronics constantly enriched with new meanings, such as: mechatronics philosophy, science of intelligent machines, science of motion control, learning environment for the development of integrative thinking in the knowledge-based society. (Berian and Maties, 2011). According to (Mishra, et al., 2011): mechatronics is a design philosophy which encourages engineers to concurrently integrate conventional core industries and modern processing-developing industries. Vistrin Maties (Maties, 2016) quoted: mechatronics was born as a technology and very soon became philosophy, science of intelligent machines, science of motion control, and now, in the knowledge-based society it is environment for trans disciplinarity learning and integral education.

Mechatronics is a new field of engineering that combines mechanical engineering, electronic engineering, software engineering, computer engineering, control engineering as well as system design engineering. The combination of hardware effects from the layout of the mechatronic device is an average machine, bringing the sensors, actuators, and microcomputers together into the mechanical device. The integration of software is based mostly on an advanced era. (Sharma and Dhiman, 2021). In the book: Intelligent Mechatronics edited by Ganesh T. Naik, (Naik, 2011), Mechatronics is defined as: the field of study involving the analysis, design, synthesis, and selection of systems that combine electronic and mechanical components with modern controls and microprocessors.

A formal definition of Mechatronics is the synergistic integration of mechanical engineering, electronics, computer technology, and information technology to produce or enhance products and systems (Saha, 2005). According to (Saha, 2005) the term mechatronics should be used to represent a different meaning, namely, a design philosophy, where mechanical, electrical, electronics components, and information technology should be considered together in the design stage itself to obtain a compact, efficient, and economic product rather than designing the components separately. The central point of the concept design philosophy of mechatronics is the concurrent combination of mechanical, electronic, control and computer, in an integrated mode to obtain high quality products and processes with included intelligence.

There are many definitions of mechatronics as a scientific discipline, but from all of these definitions, one of the most used and most accurate definitions is that: mechatronics is synergistic integration of mechanical technology (mechanics), electro/electronic technology (electronics) and information technology (informatics), figure 2.

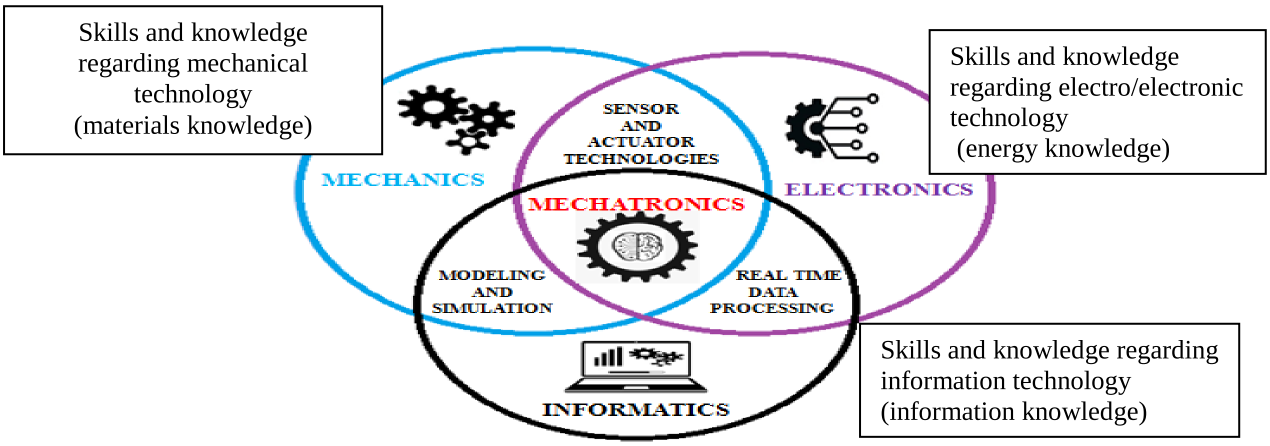


Figure 2. Synergistic integration of mechatronics core disciplines

It is worth noting that mechatronics is more than that. Except core disciplines (mechanics, electronics and informatics) mechatronics can also integrate with others technical or nontechnical disciplines, with the aim to produce simpler, economical, reliable and versatile products, processes and systems.

In the frame of the literature reviewed on mechatronics definition for this article lists over 50 definitions of mechatronics, each of which places a slightly different emphasis on the central theme of the integration of the core disciplines of mechanical technology, electro/electronics technology, and information technology. Many definitions of mechatronics exist, but all talks about the technological integration of these core disciplines, textually or graphically. These definitions are not exhaustive and demonstrate noticeable diversity between them. This lack of consensus means that this field is dynamic and in continuous development.

2.2 *Development of mechatronic technology*

Throughout the literature reviewed for the preparation of this paper it is clearly noted that mechatronic technology has developed continuously (evaluatively), starting from the mechanical (mechanics) technology. According to (Tecaru, 2014) and (Maties, 2019) in the first stage of integration, electronics components were integrated into mechanical structures, and this was called electromechanical integration. The next stage (second stage) in integration was due to the emergence of microprocessors, which were integrated into previous electromechanical structures. In the traditional technology the basics are the matter (material) and the energy, in mechatronics these two elements are added a third, information, the component that gives added value to mechatronic technology. This evolution in technological development has led to the emergence of mechatronics, figure 3.

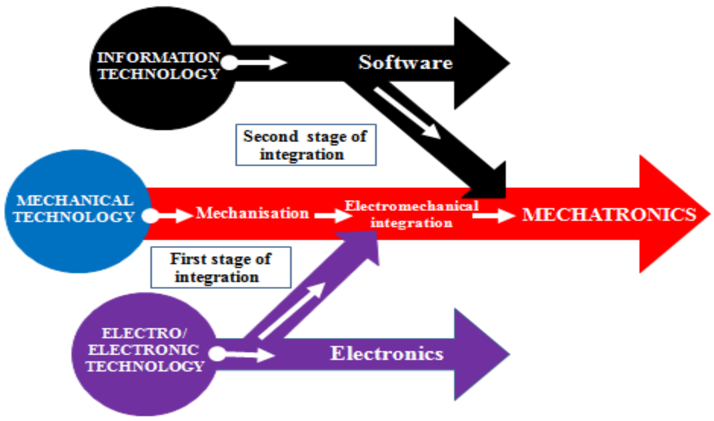


Figure 3. Evolutionary development of mechatronics starting from mechanical technology

A few years ago, but also currently in many universities throughout the world engineering studies were often organized separately by disciplines, i.e., mechanical engineering, electrical engineering, etc., however, due to the need to provide more quality and modern products to the market, integrative approach

to the organization of engineering studies began to be implemented and because of this disciplinary integration, mechatronics was born. Mechatronics inherently reflects this approach, considering the knowledge integration and interaction from multiple disciplines to produce new and more quality products, first in terms of functionality and reliability.

Currently, worldwide, mechatronic technology is widespread and in continuous development together with its constitutive core disciplines, mechanical technology, electro/electronic technology, and information technology. The development of mechatronic technology is continuous (evolutive development) and is also related to other diverse scientific disciplines that generate the necessary knowledge, providing thus sufficient deep and wide background, enabling to solve complex engineering problems. It is worth noting that besides this supplementary knowledge from other scientific disciplines, the properties of smart materials also have a significant impact on the development of mechatronic technology (Rrahim et al., 2021). Here we must not neglect the development of artificial intelligence and its principles, the Internet of Things (IoT) and Cyber-Physical Systems (CPS), which are parts of the information technology, but indirectly affect the development of mechatronic technology.

The distinguishing feature analyzed in this paper is the concept of integration or in other words synergistic integration of knowledge from the core disciplines of mechatronic technology. From a technological point of view, the effect of synergy arises from the functional and spatial (physical) integration of the constitutive core technologies of mechatronics. In this case, integration refers to the close combination of disparate knowledge of core disciplines, while synergy (from the Greek word-synergia, meaning: working together) refers to the reinforced integration of this knowledge according to the crossdisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary approach. According to (Grimheden, 2006), mechatronics is a special subject, not easily understood or taught, to be mechatronics is to be synergistic, and to be synergistic generally demands expertise in all underlying subjects. It is worth noting that daily use and scientific publications are confused about the notions (concepts) of crossdisciplinary, multidisciplinary interdisciplinary, and transdisciplinary and sometimes this is harmful to an understanding of scientific discourse. While the basic definition of mechatronic technology across all these approaches is similar, there are often subtle, but significant differences between the terms which means they cannot (or should not) be used interchangeably. These notions (concepts) in most common usage namely crossdisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary are often considered to constitute a hierarchy in terms of the mechatronic technology development invoked by the notion (concept) however this is the source of greatest concern. Therefore, to make the definitions of mechatronics technology clearer, the meaning of these notions (concepts) is further clarified. Notions in these definitions are either used interchangeably or the term that implies the development level of mechatronics technology is simply taken as a definition with little consideration for what it means in terms of the level of mechatronics technology development. In the frame of the search, an adequate definition of mechatronics results in definitions that exist different attributes about disciplinary concepts. Therefore, this article, was further analyzed to finally provide the necessary terminological clarifications.

Mechatronic technology has undergone some developmental changes over time. Nowadays, scientific knowledge and technological achievements are different from those before, so mechatronic technology needs to be updated with this new knowledge and achievements to find sustainable solutions to social needs and problems in the industrial and non-industrial fields. Utilizing this scientific knowledge and technological achievements with a more perfect synergic integration, mechatronic technology creates the opportunity for greater direct or indirect contribution to social human life. The design philosophy of mechatronics as a particular way of thinking, coupled with other engineering and non-engineering disciplines would be great assets to be considered as it would empower it with more competencies. Practically, mechatronics is present in all the fields of human activity. In the future, the challenges of mechatronics advancement and development will be oriented on the involvement and collaboration of several different scientific disciplines, figure 4. These challenges to all involved scientific disciplines, will be successful in working jointly, particularly with computer sciences. As a result of the structuring integration of the constitutive core disciplines of mechatronics with other disciplines, will be reached new knowledge which will be used in new processes.

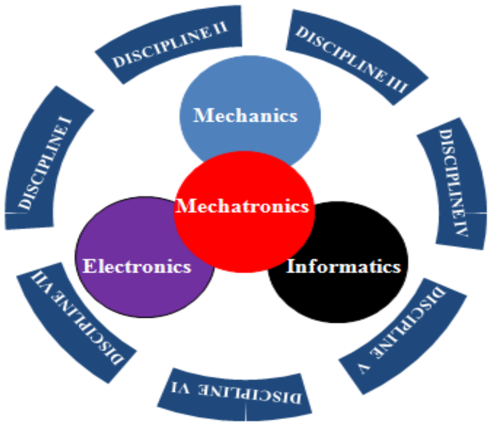


Figure 4. Multiple disciplines integrated with mechatronics

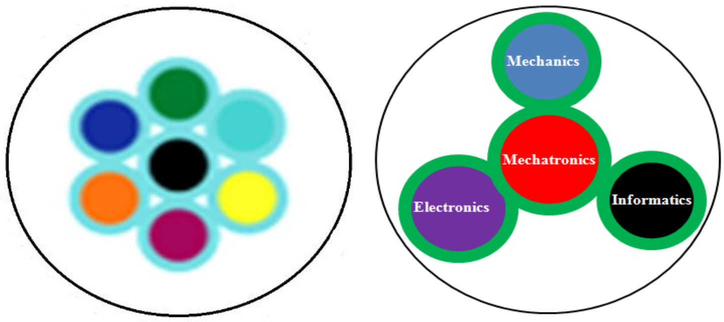
A decisive characteristic feature of mechatronic technology is the functional and spatial integration of constitutive core technologies and other various disciplines, that can participate. The main purpose of mechatronic technology is to use this integration to achieve a synergic effect, i.e. to obtain products with the highest possible technical and economical parameters. In this paper, the effect of integrative synergy on the continuous (evolutive) development of mechatronic technology is analyzed, through a crossdisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary knowledge approach. Mechatronic technology, through a synergistic integrated approach of constitutive components: matter (material)-energy-information makes possible the solution of all complex problems of society. It is understood that this synergistic integrated approach also requires synergistically integrated knowledge from different scientific disciplines that participate in human life and that also have multidisciplinary, interdisciplinary, and most recent trends for a transdisciplinary approach. All these approaches to knowledge from different scientific disciplines are in correlation with matter (material), energy, and information, which can be used in the best way to improve human life.

Efforts to promote the concept of integration and interaction in mechatronic systems are still in the early stages of development and the scientific community in this field continues to explore its beneficial potential in our daily lives. Mechatronics or smart systems, analogous to the body's biological system (Rrahim, et.al., 2021), are in continuous development (evolutive development) and tend to become hyper integrated systems, mainly based on the integration and integrability of: matter (material)-energy and particularly information as the key component of mechatronic systems, currently significantly important in the knowledge-based society. The need for such development removes the boundaries between various sciences and the development moves from the interdisciplinary approach towards a transdisciplinary one. It is worth noting that in this case where the level of synergistic integration is very high and versatile, used the concept of integronics is the advanced multi-integrative discipline. Integronics as the science of integration processes and hyper integrated systems deal with integration levels, integration degrees, hyper integrated systems, and the benefits of integration processes (Berkmeri, et al., 2014). In mechatronic technology, integration is a very important process because gives the possibility of an association to complementary elements, the possibility of connecting, of forming cycles and networks. Integration also gives the possibility of obtaining a surplus of elements, a structural redundancy. In the case of hyper integrated systems (e.g., human body) where everything is linked to everything and everything depends on everything, the structural redundancy results in a fantastic combinatory redundancy (Berkmeri, et al., 2014). According to (Gheorghe and Ilie 2015), integronic is defined as: the mechatronics perspective in a structure fully integrated of engineering mix in a design of integrated systems that aggregates intelligent constructive-functional-decisional solutions like the human body, behavior, and expression of intellectual, physical, and moral states of human beings.

Almost all of the definitions of mechatronics from all consulted sources mention one of the notions (concepts): crossdisciplinary, multidisciplinary interdisciplinary, or rarely transdisciplinary combination or integration of the involved disciplines in the mechatronic technology. It is an undeniable fact that at least three scientific disciplines are involved, but the applied terminological approach causes minor confusion that deviates the meaning of the definition, depending on the disciplinary interaction approach. Seeing these various definitions of mechatronics presented above, and keeping in mind using crossdisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary approach included in the mechatronics definitions, these approaches were discussed separately.

2.2.1 Crossdisciplinary approach

Grimheden (Grimheden, 2007) in his report defined mechatronics as a crossdisciplinary subject, based on the concept of synergy and synergistic use of knowledge and skills in underlying subjects. He says that mechatronics engineering is characterized by crossdisciplinary work, utilizing competencies in various areas such as electrical engineering, and mechanical engineering as well as functional skills in programming, control, etc. His conclusions promote preparation of mechatronics engineers with crossdisciplinary knowledge. It is worth noting that crossdisciplinary approach involves the assessment of one discipline through the perspective of another, figure 5(a). Figure 5(b) shows the reflection of the crossdisciplinary approach of mechatronics through knowledge extracted from mechanics, electronics, and informatics.

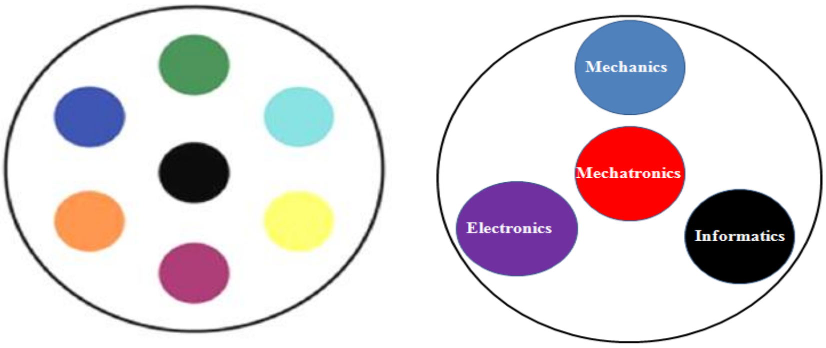


(a) (b)

Figure 5. Crossdisciplinary approach: a-in general, b-in mechatronics

2.2.2 Multidisciplinary approach

The multidisciplinarity approach implies the interaction of two or more disciplines in solving a particular problem, but with a minimum level of cooperation and with an independent methodological approach. A multidisciplinary approach extracts knowledge from two or more disciplines or two or more areas of knowledge, and this knowledge doesn’t necessarily need to be intersected or interacted on juxtaposition, figure 6(a). A multidisciplinary approach to mechatronics extracts knowledge from mechanics, electronics, and informatics, figure 6(b). Knowledge from these disciplines can be made available by integration to ensure the interpretation of the definition of mechatronics. According to (Neuman, 2012), multidisciplinarity is a disciplinary interaction model described as a juxtaposition of disciplines in a strictly additive manner without any explicit cooperation between the different disciplines. The relationships between the disciplines remain limited and temporary, and no exchange of scientific methods and procedures takes place. A multidisciplinary approach in mechatronic technology means that different disciplines are represented in this area, but they are included relatively independently from one another and not with a lot of integration between them, figure 6(b).



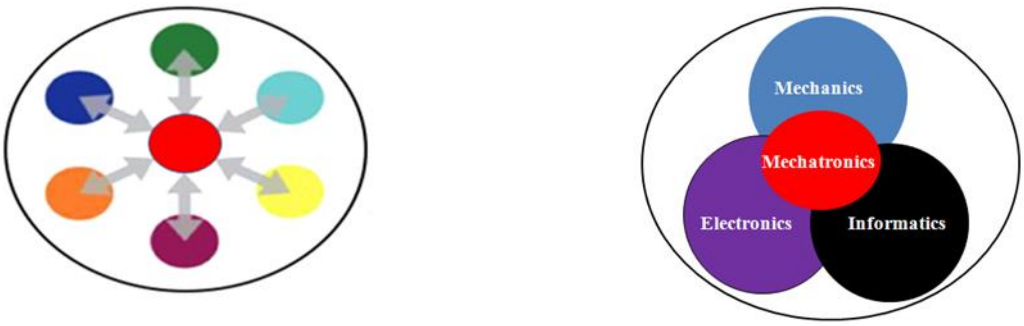
(a) (b)

Figure 6. Multidisciplinary approach: a-in general, b-in mechatronics

As seen, some definitions of mechatronics emphasize that mechatronics has a substantial multidisciplinary character. It means that mechatronic technology requires multidisciplinary collaboration between constitutive core disciplines. A multidisciplinary approach offers a solution to problems from different technical perspectives, but in this case, always taking in mind the principles of mechatronics.

2.2.3 Interdisciplinary approach

The interdisciplinary approach implies the interaction of two or more disciplines with a higher level of cooperation, with bridges between disciplines, and with independent methodological approaches. The interdisciplinary approach involves the transfer of knowledge from one discipline to another, figure 7(a) and 7(b). According to the interdisciplinary approach, mechatronics tends to broaden the engineering perspective and eliminate the technical barriers between constitutive core disciplines. The interdisciplinary approach is a coordinated interaction between disciplines to generate a new application of knowledge. In this article, knowledge from mechanics, electronics, and informatics successfully integrates around the mechatronics 7(b), to promote this discipline as an interdisciplinary field, but is not limited only to these disciplines because it also interacts with other disciplines derived from the development of matter (materials), energy and informatics.



(a) (b)

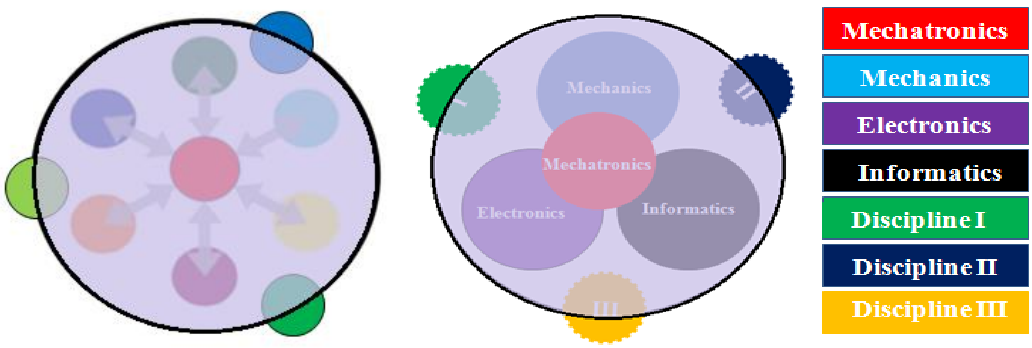
Figure 7. Interdisciplinary approach: a-in general, b-in mechatronics

According to the analysis of the literature and empirical findings presented in this paper, it is seen that most of the authors, mechatronics defined as an interdisciplinary subject and currently worldwide to a greater extent than other traditional engineering disciplines. According to (Neuman, 2012), Interdisciplinarity is a disciplinary interaction model characterized by the proactive interaction and integration of multiple disciplines working on a common topic. Usually, interdisciplinary, and multidisciplinary approaches are used interchangeably although it can be said that the interdisciplinary approach is more advanced and more significant for the definition of mechatronics. In the substantive sense and terms of the terminological clarification of the disciplinary interaction, the interdisciplinary approach is the best approach to confirm the nature of the interactions in case functional and spatial integration targeted disciplines of mechatronics. Due to the described interdisciplinary nature, mechatronics is considered a thematic discipline with its theoretic knowledge level and it may be therefore considered as an independently discipline from the other constitutive involved disciplines.

2.2.4 Transdisciplinary approach

The transdisciplinary approach emerged in the latter part of the twentieth century and has gained recognition as a mode of research applied to real-world problems that need not only to be understood in new ways but also demand practical solutions (Bernstein, 2015). The transdisciplinary approach is largely used today in many fields, and it is different from the more established multidisciplinary and interdisciplinary approach in the way that it transcends disciplinary boundaries and creates a major reconfiguration of disciplinary divisions within a systemic, global and integrated perspective (Ren, 2021). According to (Berian and Maties, 2011), mechatronics, through its integrative, synergic character, is an open field that transcends the limits of a single discipline. The transdisciplinary approach

in its highest form implies the interaction of two or more disciplines without discipline boundaries between them and the use of a single methodological platform to solve a common problem, figure 8(a). In addition to the core disciplines, the transdisciplinary approach involves
different various forms of knowledge and factors of society that are interested in shedding light on and solving complex human life problems. The identity of mechatronics is a trans-thematic one, founded on the thematic concept of complexity, figure 8(b).



(a) (b)

Figure 8. Transdisciplinary approach: a-in general, b-in mechatronics

The knowledge produced through a transdisciplinary approach, however, is what is needed to be able to solve complex societal problems, enhance the quality of life, crossing borders between and beyond academia. Solving complex problems requires a contribution from many disciplines, including engineering, social sciences, and environmental sciences. etc. Hence, universities tend to deliver their programs in disciplines to transfer knowledge within a certain domain, and to allow students to apply this knowledge to real problems through a transdisciplinary approach (Wognum et al., 2019). Key in transdisciplinary education is the creation of opportunities in the curriculum for students to experience and practice design on a realistic problem through project-based learning. While the concept of transdisciplinary research and processes has existed already for several decades, much research is necessary to increase understanding of the nature of transdisciplinary work, support and manage complex teams, measure their output, and progress, and manage and support collaboration between people with many different backgrounds. Transdisciplinary science and engineering are a way of study where researchers go beyond the boundaries of academic fields to solve the complex problems shared by global society. Although the transdisciplinary approach cannot widely be found in the literature yet, a transdisciplinary approach is deemed relevant for many engineering problems. The emergence of this new type of knowledge approach is complementary to the traditional disciplinary one and is a very important issue for mechatronics. The transdisciplinary approach or transdisciplinarity was introduced to the world in 1972 at a Paris seminar held by the Organization for Economic Cooperation and Development and is a relatively new, emerging approach to knowledge creation, competing with longstanding multi and interdisciplinary focus (Appel and Appel, 2018). In the book Manifesto of Transdisciplinarity (Nicolescu, 2002), the author claims that only the transdisciplinary approach can efficiently and effectively recognize the challenges of the twenty-first century. According to (Nicolescu, 2010), transdisciplinarity, from the prefix “trans” indicates knowledge integration: what is at once, between the disciplines, across the different disciplines, and beyond all disciplines, as well as embracing nondisciplinary knowing and perspectives i.e., life-world perspectives from civil society, government, and industry, so the finality of all of this is the understanding of the world through the unity of knowledge. Therefore, Basarab Nicolescu introduced a complementary knowledge concept that helps understand the world through the unity of knowledge (Nicolescu and Ertas, 2013). In this context, mechatronics enables a transdisciplinary knowledge approach, stimulating thus creativity in various problem solutions. It is important to note that, disciplinarity, interdisciplinarity, and transdisciplinarity are complementary approaches (Maties et al., 2012). Mechatronic knowledge is a technological one, or knowledge about how to manufacture intelligent products, systems, and services. Taking into account the trans-thematic identity of mechatronics, mechatronics knowledge is transdisciplinary knowledge (Maties et al., 2012). Through the transdisciplinary approach of knowledge, mechatronics provides ideal conditions to raise the effect of synergy, thereby providing possibilities for further technological development for new solutions to technically more complex situations in the future. Such an approach to knowledge is a natural process and due to the synergic effect promotes the development of mechatronic technology, integrating thus matter (materials)-energy and processed information. A transdisciplinary approach is applied in modern research areas, in which natural sciences are integrated with social sciences, requiring mixed methodologies for achieving collaborative work. This would supplement (not supplant) the traditional interdisciplinary approach of mechatronics technology. Such a transdisciplinary approach would represent a development of mechatronic technology and that all this should be included in the higher education system and that it is not an easy task to accomplish. Mechatronic technology, which integrates mechanics, electro/electronics, and information technology exemplifies the innovative approach needed in transdisciplinary research and education and may even extend knowledge from other disciplinary fields, thus advancing to a higher level of development. From a transdisciplinary aspect, mechatronics is an open field, so its identity transcends the limits of simple thematical identity. The stating and the argumentation of the idea that the identity of mechatronics founded on the thematic concept of complexity is trans-thematic, serves as a starting point in the substantiation of a future complex and rigorous transdisciplinary approach to mechatronics (Berian and Maties, 2011).

A distinctive characteristic of transdisciplinarity is the thinking approach that must be multi-laterally, imaginatively, and creatively to combine all possible factors that need to be considered for concrete problem solving. So, in this case, mechatronic technology extends cooperation with other scientific disciplines and areas, related to the improvement of human life, thus the benefit will be multidimensional and very useful. In the transdisciplinary approach, interdisciplinarity and multidisciplinarity are parts of transdisciplinarity, which goes beyond them, hence even at the hierarchical level is it a more advanced approach.

Following the integration of the disciplines involved in mechatronic technology, evolutionary development is ascertained, which goes up to the final or thematic stage with its own identity, different from its constitutive core disciplines (mechanics, electro/electronics, and information technology). The transition from disciplinary identities to a thematic identity is made up of certain steps where the most important are presented in (Maties and Pop, 2008), figure 9.

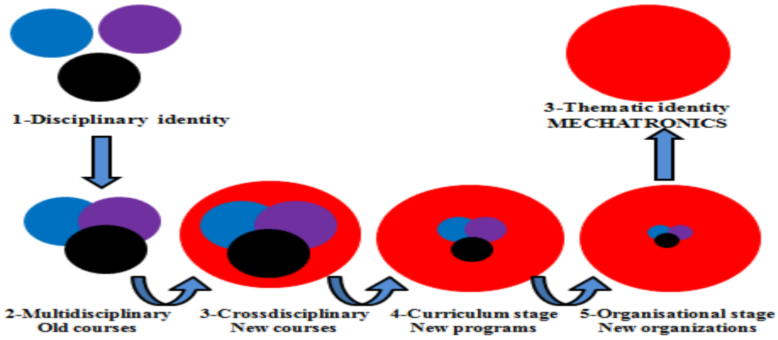


Figure 9. Evolution of mechatronics as an academic discipline

Due to the fact that the understanding of the present world cannot be accomplished within the framework of single-disciplinary research, transdisciplinarity is the only way of explaining complementarity both to multidisciplinary and crossdisciplinary research, being entirely (radically) distinct from them, even though multidisciplinarity and crossdisciplinarity temporary cross disciplinary boundaries, they always remain within the framework of a disciplinary context (Maties and Pop, 2008). The transdisciplinary approach to knowledge in a knowledge-based society opens a new creative way of mechatronics. Trandisiplinarity approach implies an indispensable need for bridges between the different disciplines, where these bridges are built by codisciplinary connection, multidisciplinary combination, crossdisciplinary overlap, and transdisciplinary synergistic synthesis (Maties and Pop, 2008), figure 10. According to the proposal of (Maties and Pop, 2008), the transition from the crossdisciplinarity stage to that of the transdisciplinary synergistic synthesis stage is made by a combination of circular and radial flows through the synergistic transdisciplinary inner nodal points which generate the thematic, experimental, interactive and functional mechatronic hard central core, the crossdisciplinary medium nodal points generating fluid belt that is crossed by innovative ideas, new courses, new programs and organizational learning patterns integrated into mechatronics. Due to these radial centripetal flow new mechatronic disciplines (optomechatronics, robotics, biomechatronics, etc.) emerge as satellites in the outer diffuse space, where the codisciplinary outer nodal points are working as a resource spring generating epistemological, ontological, and creative mechatronic knowledge.

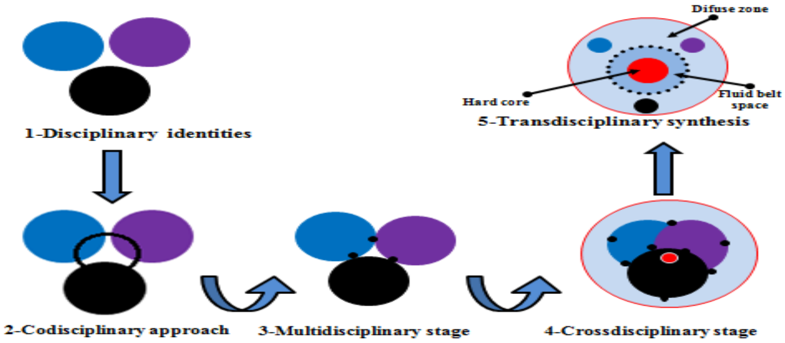


Figure 10. Transdiciplinary approach for mechatronics

Considering the trans-thematic identity of mechatronics should be emphasized that mechatronics knowledge is transdisciplinary knowledge and currently learning transdisciplinarity is a major need in a knowledge-based society. (Maties, et al., 2012).

Although the term mechatronics is almost 50 years old, its philosophical foundations have not yet been sufficiently developed, so mechatronic technology is in continuous (evolutive) development. The transdisciplinary approach of knowledge can explain the development path of mechatronic technology, with a synergistic integration as action through the creation of ideas, design, modeling, prototyping, and simulation of processes, to realize smart products, sustainable technologies, and specific methods to give solution to the emerging problems (Pop, 2009). In research conducted by (Rupnik and Avsec, 2020) it was found that the transdisciplinary approach creates a deeper interaction and synergy between technology, the natural environment, and society.

Conclusions

By reviewing the available literature data, the following conclusions can be drawn:

-Mechatronic technology explains the great interest in the world and become the technology of the twenty-first century through the synergistic integration of matter/material, energy, and information. The synergy effect of mechatronics has opened unforeseen horizons in all scientific fields and will be a challenge for future improvement of social human life.

-The transition from interdisciplinary to a transdisciplinary knowledge approach is a specific multiple processes in the functional and structural level of mechatronic technology, but this approach will open new perspective in the sense of systemic thinking of the knowledge-based society to achieve abilities and skills for teamwork So, the transdisciplinary approach of knowledge can give solutions to the theoretical and practical problems that will be emerged in the century that just started.

-Development of mechatronic technology through passing from interdisciplinary to transdisciplinary knowledge approach, undoubtedly will find new application areas and brings a bright future in the twenty-first century and will improve society human life.

References

[1]. Acar, M., Parkin, R. M. (1996). Engineering Education for Mechatronics. *IEEE Transactions on Industrial Electronics*, 43(1), 106-112.

[2]. Alciatore, D. G., Histand, M. B. (2012). *Introduction to Mechatronics and Measurement Systems*. McGraw-Hill Companies, Inc. New York.

[3]. Amerongen, J. (2000). The Role of Control in Mechatronics. *Engineering Science and Education Journal,* July, pp.1-14.

[4]. Appel, J., Appel, D. K.. (2018). Towards A Transdisciplinary View: Innovations in Higher Education. *International Journal of Teaching and Education*, 6(2), 61-74.

[5]. Atkins, T., Escudier, M. (2019). *A Dictionary of Mechanical Engineering*. Oxford. University Press.

[6]. Azizi, A. (2019). *Emerging Trends in Mechatronics*. IntechOpen Limied. London.

[7]. Berian, S., Maties, V. (2011). A Transdiciplinary Approach to mechatronics. *Transdisciplinary Journal of Engineering & Science,* 2(12), 20-32.

[8]. Berkmeri, C. V., Bleba, I., Rad, C. R. (2014). Considerations Regarding the Integration-Inttrication Process in the Nature and Technology. *Acta Universitatis Cibiniesis-Technical Series,* 64(1).

[9]. Bernstein, J. H. (2015). Transdisciplinarity: A Review of its Origins, Development, and Current Issues. Journal of Research Practice, 11(1), 1-17.

[10]. Bishop, R. H. (2002), The mechatronics Handbook, *What is Mechatronics* (pp.17-27). Boca Raton-London-New York-Wachington D.C. CRC Press LLC.

[11]. Craig, K. (2001). Is anything really new in mechatronics education. *IEEE Robotics Automation Magazine,* Vol. 8, no. 2, 12-19.

[12]. De Silva, C.V. (2008). *Mechatronic Systems-Devices, Design, Control, Operation and Monitoring*.CRC Press, Taylor and Francis Group. Boca Raton-London-New York.

[13]. Gheorghe, I. G., Ilie, I. (2015). Mechatronics, Integronics & Adaptronics, Excellence in the field of Intelligent Specialization. *Precision Mechanics, Optics & Mechatronics,* 1(47), 17-21.

[14]. Gollamudi, E. B., Mamilla, V. R., Rao, T. B. (2011). Introduction to the Development and Design of a Mechatronic System. *International Journal of Engineering Researsh and Applications (IJERA,* 1(3), 542-545.

[15]. Grimheden, M. (2006). *Mechatronics Engineering Education*. Doctoral Thesis, KTH School of Industrial Engineering and Menagement. Stockholm, Sweden.

[16]. Grimheden, M. (2007). Preparing Swedish Mechatronics Engineering Students for a Global Industry-KTH, Royal Institute of Technology. *American Society for Engineering and Education*. 1-10.

[17]. Habib, K. M., Davim, J. P. (2013). *Interdisciplinary Mechatronics-Engineering Science and Research Development.* John Wiley and Sons, Inc. London.

[18]. Harashima, F., Suzuki, S. (2008(. Future of Mechatronics and Human-Machine Operation Skill and Visual Perceptioon. *SICE Journal of Control, Measurement, and System Integration*, 1(1), 018–025.

[19]. Harashima, F., Tomizuka, M., Fukuda, T. (1996), Mechatronics -What Is It, Why, and How. An Editorial", IEEE/ASME *Transactions on Mechatronics*, 1(1), 1-4.

[20]. Ioan, G. P., Vistrian, M. (2009). Considerations About the Mechatronical Transdisciplinary Knowledge Paradigm, *The 5th IEEE International Conference on Mechatronics*, April, 14-17.

[21]. IRDAC, (1986). The Industrial Research and Development Advisory Committee of the European Union.

[22]. James, A. M., Nima, L., Nikhil, B., Vishesh, V., Michael, A. G. (2020). Mechatronics and Robotics Engineering Definitions among Students, Educators, and Industry Professionals. *American Society for Engineering Education Virtual Conference*, June, 22-26.

[23]. John, V., Henry, E., Eliza, E. James, A. I., Michael, A. B. (2007). *Mechatronics-A Technology Forecast.* Waco, Texas. TSTC Publishing.

[24]. Kyura, N., Oho, H. (1996). Mechatronics – an industrial perspective. *IEEE/ASME Transactions on Mechatronics*, 1(1), 10-15.

[25]. Liliana, D., Florina, P. S. (2015). Education, Knowledge and Inovation from a Mechatronics Perspective. *Procedia-Social and Behavioral Science,* 203, 205-209.

[26]. Maksuti, Rr., Osmani, H., Ismaili, N. (2021). Properties of Smart Materials for Mechatronic Applications. *Journal of Applied Sciences*, 7(13-14), 118-125.

[27]. Maties, V. (2016). The National Mechatronic Platform. The Basis of the Educational Programs in the Knowledge Society. *Materials Science and Engineering,* 147(1).

[28]. Maties, V., Hancu, O., Rad, C. R. (2012). Mechatronic Platforms for Transdisciplinarity Learning. *Transdisciplinary Journal of Engineering & Science,* 3 (12), 69-79.

[29]. Maties, V., Pop, I. G. (2008). A tramsdisciplinary Approach to Knowledge in Mechatronical Education. M*echatronics, 5,* 21-23.

[30]. Maties, V., Vlas, I., Tamas, V. (2019) Transdisciplinarity, Mechatronics and Organizational Learning. *Transdisciplinary Journal of Engineering & Science*, 10 (6), 158-168.

[31]. Mishra, P., Ahuja, A., Shivpuri T. (2011). Mechatronics, Concept of Past Core Competence of Future. *International Journal of Power Control Signal and Computation (IJPCSC),* 2(2), 88-93.

[32]. Naik, G. R. (2011). *Intelligent Mechatronics*. Rijeka, Croatia. Intech Pub.

[33]. Neuman, F. (2012). Mechatronic Product Development: Potentials, Challenges, Terminology. *9th International Workshop on integrated Product Development,* (pp.5-7). Magdeburg.

[34]. Nicolescu, B. (2002). *Manifesto of Trandisciplinarity*. SUNY Press. New York.

[35]. Nicolescu, B. (2010). Metodology of transdisciplinary-levels of reality, logic of the included middle and complexity. *Transdisciplinary Journal of Engineering & Science,* 1(1), 19-38.

[36]. Nicolescu, B., Ertas, A. (2013). *Transdisciplinary Teory & Practice*. The ATLAS Publishing. Unitat States of America.

[37]. Onwubolu, G. C. (2005). *Mechatronics-Principles and Applications*. Amsterdam-Boston-Heidelberg-London-New York-Oxford-Paris-san Diego-San Francisko-Singapore-Sydnes-Tokyo. Elsevier Butterworth-Heinemann.

[38]. Panga, N., Ganesh, N., Gupta, R. (2013). Mechatronics-An Introduction to Mechatronics. *International Journal of Engineering Research & Technology (IJERT),* 2(8), 128-134.

[39]. Paolo, D. J. (2012). Mechanical Engineering Education, *Mechatronics Education* (pp. 62-105). London-Hoboken. ISTE Ltd and John Wiley & Sons, Inc.

[40]. Pop, I. G. (2009). Considerations About the Transdisciplinary Knowledge Search Window in Mechatronical Education. 5th Balkan Region Conference on Engineering Education & 2nd International Conference on Engineering and Busssines Education LBUS Sibiu, Romania, 15-17 Ocober.

[41]. Ren, O. (2021). Transdisciplinarity: Synthesis towards a modular approach. *Futures*, 130, 1-18.

[42]. Rupnik, D., Avsec, S. (2020). Effects of a Transdisciplinary Educational Approach on Students Technological Literacy. *Journal of Baltic Science Educatioon,* 19(1), 121-141.

[43]. Saha, S. K. (2005).. Mechatronics-An Experience at IIT Delhi. Invited Lecture Note on “Mechatronics”. Workshop on Mechatronics National Institute of Technology, Nagpur, Maharastra, (1), 1-4.

[44]. Tecaru, C. V., Blebea, I., Rad, C.R (2014). Considerations Regarding the Integration-Intrication Processing the nature and Technology. *Acta Universitatis Cibiniensis-Technical Serie,* 14(1), 82-87.

[45]. Vanston, J. H., Elliott, H., Bratell, J., Evans, E., Irwin, J.A., Bettersworth, M.A. (2007*). Mechatronics, A Technology Forecast.* TSTC Publishing. Texas.

[46]. Wognum, N., Bil, C., Elgh, F., Peruzzimi, M., Stjepandic, J., Verhagen, W. (2019). Trandisiplinary Systems Engineering: Implications, Challenges and Research Agenda. *Int. J. Agile Systems and Management, 12(1),* 58-89.

[47]. Sharma, R., Dhiman, B. (2021). Mechatronics Around the World - at a Glance. *Journal of Mechatronics and Robotics,* 5(1), 1-7.