Revolutionalising Engineering Programmes in Developing Countries by Incorporating a Mechatronics Curriculum

U. B. Akuru
Department of Electrical Engineering,
University of Nigeria, Nsukka,
Enugu State, Nigeria.
akurudo@yahoo.com

I. C. Ume
Woodruff School of Mechanical Engineering,
Georgia Institute of Technology,
Atlanta, USA.
charles.ume@me.gatech.edu

A. O. E. Animalu
Department of Physics and Astronomy,
University of Nigeria, Nsukka,
Enugu State, Nigeria.
nascience@aol.com

O. I. Okoro
Department of Electrical Engineering,
Michael Okpara University of Agriculture, Umudike,
Umuahia, Nigeria.
oiokoro@yahoo.co.uk

O. V. Ekechukwu
Department of Mechanical Engineering,
University of Nigeria, Nsukka,
Enugu State, Nigeria.
ovekechukwu@yahoo.com

E. Chikuni
Department of Electrical Engineering,
University of KwaZulu-Natal,
Durban, South Africa.
chikuni@yahoo.com

***Abstract*—The current engineering undergraduate curriculum in Nigeria, a developing country, is non-commensurate with the contemporary 21st century technological prospect and so the nation lags seriously in research and development (R&D), which in effect is a quantity for measuring infrastructural development. In the light of this development, a mechatronics curriculum becomes not only necessary but critical. This is so because it combines mechanics with electronics and information technology in components, modules, products and systems. This paper will share the experience in developing and implementing a novel mechatronics curriculum in an existing engineering programme at an undergraduate level – the need, the functions and the hopes. Also examined, were the strategies involved in initiating, developing and implementing this curriculum, which can easily pass off in any developing nation; Nigeria serving as a case to this particular study. In the quest for sustainable development in engineering education and research in universities, this is also offered as an appropriate action for at least, undergraduate engineering programmes.**

Keywords-developing country; engineering education; mechatronics; research and development (R&D); undergraduate curriculum

I. INTRODUCTION

Mechatronics is a concept which is debated extensively in academic environments. Many formal definitions are published and each of them points to one or several of explicit/implied features of the concept of mechatronics. Any physical artefact which functions to satisfy these *a-priori* features is considered to be a mechatronics product. However, the simplest and plain definition of mechatronics concept follows as; integration of electronics and software technology into a functional mechanical structure [1]. This definition states the necessary conditions, but it is not sufficient, hence any physical product which encloses electronics and software technology within a mechanical structure need not to be mechatronics. The keyword here is the "integration" of basic mechatronics components into a physical product, provided that the integration has been started at the very beginning of the design process.

Grimheden [2] said the vaguely awkward word was first coined in Japan over 30 years ago. During this lifetime, the subject 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 synergy.

The aim of this paper is to help bridge the research gap between the area of engineering education and the specific subject of mechatronics. This is accomplished by beginning with an analysis of the subject of mechatronics according to current research in the area of subject definition, and then implementing the results of that analysis – firstly in the context of curriculum formation and secondly using the empirical approach to learning – and examining the outcome of these implementations with regards to R&D.

A substantial amount of research has been performed in the field of engineering education, most of it during the last couple of decades. Areas such as engineering education, collaborative

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learning, international collaboration, and experimental approaches have been thoroughly researched, but rarely in the context of an applied engineering subject such as mechatronics. This is mainly because most academics choose to specialize in one field, either education or engineering, and attempts to bridge this gap are seldom found [2]. Educational research is often considered by the educational establishments to be difficult to understand and hard to implement, and so is commonly dismissed as irrelevant. However, the analysis of the subject of mechatronics presented in this paper provides a deeper understanding of the nature, history, and establishment of the subject, a state-of-the-art analysis of current curriculum in mechatronics in western countries, and a model for the development of the subject which can be used to facilitate the development of mechatronics education at university level in Nigeria. The research approach in this paper agrees to a great extent with the way it has been explained, that, despite the world-wide interest in mechatronics, it is still not certain that there is a clear and consistent understanding of what mechatronics is and how, and at what level, it should be taught and to what extent it can eventually benefit a country [3].

II. MECHATRONICS: PATHWAY TO AN APPROPRIATE DEFINITION

In considering the broad subject of mechatronics, it is proper to search out ways by which it cannot be defined. This implies that the best way to understand what mechatronics means, is to first know what it does not mean. This approach will help to understand the need for the final submission made in this paper.

Despite so many definitions, discussions, meanings and interpretations to the subject of mechatronics, it is still found to be at large for a simple comprehensible definition. This discovery is what gives the subject of mechatronics a critical outlook. Mechatronics is not electromechanical engineering neither is it anything near the teaching of robotics [4]. In simple terms, it should not be confused with electromechanics – the concept of converting mechanical forces and displacements to electromagnetic energy and vice versa. This is because mechatronics has a meaning that is somewhat broader than the traditional term "electromechanics". Electromechanical engineering is centred on coupling with servo action and motors. However, the concept of synergy that is reached when combining knowledge of different fields in mechatronics is to a large extent illustrated fairly well in robotics.

One definition of mechatronics, which may be seen as a milestone is presented in the first refereed mechatronics journal, IEEE/ASME Transactions on Mechatronics: The synergistic integration of mechanical engineering with electronics and intelligent computer control in the designed manufacturing of industrial products and processes [5]. Historically too, the subject of mechatronics has often been described as a combination of the subjects of Electrical Engineering, Mechanical Engineering, Computer Engineering and Applied Control Engineering; in the union between these subjects, the discipline of mechatronics emerges. Mechatronics, which can be treated not only as a technology, but also as a philosophy, came into being as an integration of mechanical and electrical engineering with control and computer science not only for the designing, but also for manufacturing and their operation. The marrying of the various engineering disciplines to produce mechatronics is colourfully depicted in Fig. 1. This comes against the backdrop of the definition that, Mechatronics, first introduced in Japan in 1980s, is a composite word with mechanics and electronics whose goal is to bring up the engineer who is not only familiar with mechanical engineering but also, can exploit the electronic technology and computer science smoothly [6]. This simply relates mechatronics to a multidisciplinary field of study.

Mechatronics has also been described as a methodology used to achieve the optimal design of an electromechanical product. The ideas and techniques developed during the interdisciplinary simulation process provide the ideal conditions to raise synergy and provide a catalytic effect for discovering new and simpler solutions to traditionally complex problems. This synergy can be generated by the right combination of parameters to make the final product better than just the sum of its parts [7]. If the primary definition for mechatronics should be advanced, it is simply in the fact that, as a hybrid engineering course, it integrates the basic curricula of the field of engineering, such as mechanics and electronics, so as to facilitate the production of more intelligent products that presents better economic performance and time efficiencies. Another keyword, like integration, is efficiency. Mechatronics as a word fails to exist in the independent state, a fact already corroborated above in the multidisciplinary presentation of its curriculum in Fig. 1. The sub-themes are; COGNITION – how to perceive, INFORMATICS – methods for the communication of data and knowledge, METAMETHODICS – the selection of the best analytic or algorithmic method, CYBERNETICS – the study of control, DESIGN – the principles governing optimized operation and aesthetics in artifacts, and finally METAMORPHICS – how to optimize making, transforming or fabricating.

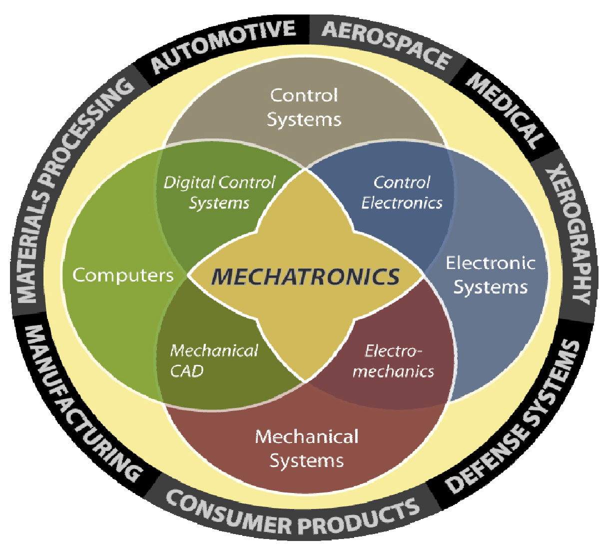

Figure 1. Multidisciplinary depiction of the mechatronics concept

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In so much as these sources (i.e. experts' definition) can speak for themselves with respect to the concept of mechatronics, on whether it is properly defined or not, it is the mechatronics evolution itself that definitely supports this fact. Moreover, in seeking to justify the import of a multi-common definition by experts, the mechatronics subject has systematically generated a platform for embedding the basic concepts – synergy, flexibility and hybrid efficiency. This evolutionary drive has led to continuous innovations in modern machines and systems triggered by more recent adaptations to computer technology which employs mechatronics as a functional tool for that purpose. In some way, most of the definitions do agree such that mechatronics is concerned with the integration of its core technologies to generate new and novel technological solutions in the form of products and systems in which functionality is integrated across those core technologies, with information technology and software engineering providing the 'glue' which binds the whole together [3].

Mechatronics, in saying the least, has surpassed the stage where a definition should continue to be debated. From the foregoing, it is evident to consider mechatronics as an interdisciplinary field of engineering with a multidisciplinary curriculum.

III. MECHATRONICS CURRICULUM IN ADVANCED COUNTRIES

A. *Some Challenges and Gians in Starting a Mechatronics Department*

A relevant question here is; What are the challenges presented to engineering educators by the field of mechatronics? This work is designed in order not to argue the adequacy of the mechatronics curriculum. However, few expert contributions believe mechatronics can attain the level of being a formally accepted engineering discipline. The impression is that traditional education system tends to resist the forming of new disciplines while other submissions are that the place of mechatronics in the academic hierarchy is actually an organizational cum bureaucratic issue. Occasionally, some professors want to learn what trends the operating universities are following in mechatronics so that they can set up their own programmes after a brief contact course, while some others prefer to remain practicing mechanical engineers with a keen interest to earn an academic degree in the fundamentals of mechatronics. It will be rather insufficient to try to highlight the community attracted by the mechatronics curriculum without emphasizing the aims of a mechatronics curriculum. The aims of a Mechatronics curriculum in the Johannes Kepler University of Linz, Austria have been underscored [8]. A key challenge facing mechatronics course designers is identified as that of ensuring that there is an appropriate balance between depth and breadth within the course, as well as providing opportunities to enable students to practise integration [3].

In Nigeria, potential mechatronics graduates are expected to be resourceful, creative, knowledgeable and able to perform certain functions like design and construction projects, developing production techniques, installation and maintenance of complex systems, invent technologies, have intelligent thought processes, improve management skills and provide local adaptations to problem solving capabilities [9]. Jean-Lou [10] pressed home a crucial point by stressing that it is not about globalization any longer, it is about "globality".

Mechatronics provides a natural focus for restructuring and creates an opportunity to better connect and utilize interesting exercises and design experiences throughout the curriculum. The goal is seen as not to create a novel "mechatronics programme" but rather, to give mechanical engineering programme a better focus. The reasons why a mechatronics theme is important in a mechanical engineering curriculum are that, mechatronics is an important discipline that provides many job opportunities and, the mechatronics theme allows a better coupling and integration of normally compartmentalized topics.

B. *Global Perpectives in Mechatronics Programmes*

The notion of choosing a representative selection of the subject of mechatronics and an interactive mode of communication is underlined by the years of experience in teaching mechatronics [11]. The results of some studies further show a relationship between collaborative projects and enhanced disciplinary learning and skills acquisition, increased awareness of cultural differences, and improved motivation.

In the academic world, the subject of mechatronics is widely debated, in particular terms of "How should the curricula be designed?", "Which traditional academic disciplines should organize the new programme?", and "How can these new courses be structured and taught?" Granted that mechatronics education is a necessity for any university that wishes to be technologically updated in its engineering programmes content, then it is good to ask, "How and who should teach mechatronics?"

At the Beihang University in Beijing, China, the mechatronics curriculum structure is proposed in a three dimension (3D) form; theory courses (curriculum based on topics), laboratory exercises (traditional experiments) and extracurricular innovation (research-oriented plan) [6]. But for an already existing mechatronics curriculum, it will be more constrained for the mechatronics curriculum to be thus integrated. The otherwise result will be a curriculum with contemporary emphasis, enhanced content, and improved sequencing and coupling of traditional topics including modeling and analysis, computing, electrical circuits and machines, measurements and instrumentation, control theory, and design [12].

The idea of mechatronics is both a new engineering field of interest and, simultaneously, a new philosophy in engineering, which reflects a novel approach to integrated complex technical devices. In other words, it means that mechatronics can be characterised as either a new interdisciplinary engineering specialisation or as a new high quality in engineering research and education. Introducing mechatronics into research and education activities requires the breaking up of many traditional barriers and as a consequence, a great deal of engagement and enthusiasm in connecting experiences and engineering knowledge in quite a new, flexible and easy way

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by rearranging the whole status quo. It seems that the educational, organisational and research activity of the Centre for Education in Mechatronics (CEM), a satellite of the UNESCO International Centre for Engineering Education (UICEE), will be helpful in the successful realisation of this important educational process [13]. Besides, a number of critical factors that influences curriculum development and the teaching of mechatronics suffices in the research conducted by Grimheden [4]. Already, countries where Mechatronics education has been in place are no doubt progressing in research and development [3]. These come as; mechatronics-based programmes and courses around the world, including relatively recent developments in countries such as those in Southern Africa, New Zealand, Lithuania, Hungary, Colombia and Switzerland; growing numbers of international conferences supported, among others, by the International Federation of Automatic Control (IFAC), the American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronic Engineers (IEEE) and the Mechatronics Forum and; supplementary technical journals having mechatronics as their subject area.

In summary, this part of this work has underscored the need to appreciate that the mechatronics curriculum is receiving a gradual but steady recognition in advanced economies with a proportional impact on R&D. Even in remote situations as earlier mentioned, developing countries are growing to appreciate the importance of a mechatronics undergraduate curriculum, for a start, and aim more importantly at integrating the programme into an already existing, closely-related, engineering field. The basic challenge for a developing country like Nigeria is to borrow the good traits of these other advanced countries so as to incorporate [the] same (i.e. mechatronics curriculum) in pioneer engineering faculties of its first generation universities, where engineering disciplines have a history of international competitiveness and economic viability. Somehow, it should not be considered too early in this paper to propose a critical look in the direction of introducing a mechatronics curriculum in the suggested universities so that Nigeria can start experiencing the delight of invention cum innovation in contemporary technologies rather than feeding defenselessly on foreign outdated ones. Another benefit is that engineering graduates could become technically productive through intrinsic R&D proficiencies, academically enterprising and economically marketable at the very word "go".

IV. Functional Implications of a Mechatronics Curriculum in a Developing Country Like Nigeria

The functional implications of mechatronics in a developing country like Nigeria can easily be expressed through the question; *Is there a need for mechatronics in Nigeria?* In response, the field of Mechatronics is very demanding and this could create a myriad of new academic and professional opportunities, with applications in very many industries. The application of mechatronics in Nigeria can help increase productivity; maintain consistency in the production process and produce new products of higher quality with greater efficiencies and flexibility as well as lower operating cost to enable the products to compete successfully with international standards. Also, there is the need for Nigeria to harness scientific and technological knowledge and skills necessary to induce innovation in the industrial sectors so as to keep pace with the requirement of strategy for sustainable development. With mechatronics systems new opportunities for innovative technical solutions arise and the importance of mechatronics products have risen in an above-average way and is still rising today [14], [15].

It is therefore technically reasonable to induce that irrespective of the components of infrastructure, whether economic or social, mechatronics as a discipline which supports R&D is a vital tool for establishing sustainable infrastructural development in Nigeria. Looking generally at the history of mechatronics, we can see that mechatronics is related to a kind of effort at solving technology problems using interdisciplinary knowledge among mechanical engineering, electronics and computer technology. To solve problems, classical engineers used some knowledge provided only in a classical area, like mechanical, electrical and so on. Because of increase of difficult technology problems to be solved and the arising need of designing and constructing more advanced products, researchers and engineers are required to find novel solutions for them by using R&D. This motivates them to look at different areas of knowledge and technology to develop new products. This is what mechatronics strategies have shown to support. In effect, it enables the development of new products and markets, enhances existing products, while responding to the introduction of new product lines by a competitor.

A country like Nigeria has many prospects in mechatronics application today. Many of the indigenous industries that use mechatronics systems installed by other foreign countries hardly understand their operational techniques when using them or in some cases, do not use them at all. Some of them are non-functional due to the absence of proper technology or sometimes immediately go bad after installation due to poor operational understanding. The power sector, transportation, education, agriculture, and other product design institutions as well as industries are some prospective field for applying mechatronics. Adopting a mechatronics curriculum in Nigerian universities is one good step in the right direction by which the applications of mechatronics can benefit the larger society.

V. Content Structure of a Typical Mechatronics Curriculum

A. *Structural Proposition for a Mechatronics Curriculum*

The actual structure of any course will be determined by the academic structure of which it forms a part [3]. It (mechatronics curriculum) is designed in such a way that the academic year can be portioned into terms or semesters and the degree of modularity achievable, including flexible structures based around prerequisites which will influence the way in which a course is configured, as well as the length of the course. Bradley [3] opined that with an increasing move to modularity, and hence transferability, the danger within a mechatronics programme is that the need to modularise will result in a loss of the flexibility which is required to provide students with the opportunity to put into practice the integration that is part of mechatronics. Therefore, within a modular

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structure there is, for reasons of resource management and scale, the requirement to use modules developed for specialist courses to provide the required input in that area into other courses, again perhaps prejudicing the opportunity to practise integration.

In proposing a mechatronics programme for incorporation into an existing engineering programme in a Nigerian university, the example of institutions with established programmes in some developed countries have come up. This includes a variety of means by which the proposed curriculum can be structured. However complex the nature of the mechatronics curriculum is, because of the many approaches to its curriculum design, a common point to note is the universality of its contents. It is stressed that this commonality in curriculum must above all seek to address active learning, constant assessment, emphasis on meaning and not facts, freedom and responsibility, access to resources [3], [16].

B. Traditional Departments Responsible for the Development of a Mechatronics Curriculum

At some universities and institutes, mechatronics has been taught and researched for more than 30 years, and the subject has gained enough momentum to create its own identity, but at the majority of the mechatronic-nodes in the emerging global mechatronics-network, the subject is fairly new [17]. In perspective of this, at least three quite different standpoints can be viewed in the background of the respective departments that have taken the responsibility of teaching this subject. The three standpoints reflect the traditional educational view held by respectively the departments of mechanical engineering, electrical engineering and computer science. Since the mechatronics products designed by mechatronics engineers by definition consist of mechanical and electrical components in symbiosis, these two traditional departments have since mechatronics emerged, fought over the optimal curricula [3]. A recent development is the entrance of department of computer science in the debate, which is usually motivated by the connection between mechatronics and embedded systems – which expands the subject of mechatronics to also encompass aspects such as real-time operating systems, safety critical software, etc.

Based on a simple search on the internet it seems that university organizations with some connection with mechanical engineering are the most common to include mechatronics in their organizations, followed by electrical engineering and computer science [18]. An explanation to this can be the view that an electrical component, such as a microcontroller, can be seen as a machine element, a component that exists in many modern machines, but the machine itself cannot realistically be seen as an electrical component.

C. Underscoring an Appropriate Approach to Mechatronics Curriculum Development

Mechatronics, with its characteristic identity and legitimacy is preferably taught in a problem based setting. Again, Bradley [3] supposes that the use of a theme, which can be divided into a large number of learning objects, or problems, can be seen as a bridge between disciplines, and therefore facilitate the establishment of mechatronics as an academic discipline. Moreover, in defining the course goals of an established mechatronics curriculum, a mechatronics designer must have certain qualities which have been comprehensively described [19].

The core sequence of a mechatronics undergraduate curriculum, being proposed here and for onward implementation in Nigeria, is usually to integrate courses with their laboratory into the existing electrical and mechanical engineering curriculum which culminates in an end-of-course design project centred on the facilities available in the laboratory. Thereafter, undergraduate students are led to creatively identify leading design projects in mechatronics systems. This design project is realized through the use of open laboratories with the participation of industrial sponsors, who assist in defining projects and provide – in kind and cash – support for individual projects. The outline of a mechatronics course is summarised in Fig. 2.

D. Confronting Anticipated Challenges to the Current Proposal, Sustainable Development Content, and a Case for Urgent Action

The proposition so far given in this work for the design of an undergraduate Mechatronics curriculum is plagued by a "cooperation drawback", which is often complicated for a multidisciplinary engineering discipline like mechatronics due to the significant differences in basic terminology and occupational culture of its pre-existing base engineering disciplines. However by collaborative and communicative approaches, this setback can be defeated for engineers working in mechatronics development projects.

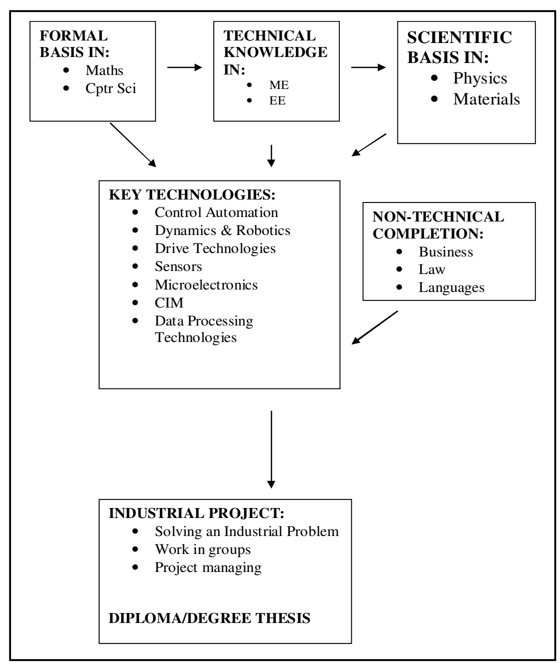

Figure 2. Multidisciplinary depiction of the mechatronics concept

Sustainable development which is seeking to meet the need of the present without compromising those of future generations, is today gaining grounds in almost all works of life. In engineering education, it aims to help people to develop their attitudes, skills, and knowledge to make informed decisions for the benefit of themselves and others, now and in the future, and to act upon these decisions as well. This work hopes that the incorporation of mechatronics in pre-existing engineering programmes will seek to achieve this when offered in developing countries.

Consequently, reckoning the role mechatronics stands to achieve in modern R&D, it becomes necessary for projections to be made for the urgent establishment of an undergraduate curriculum in Nigeria's core universities. At the start, it should not come as a surprise that the unprecedented offering of mechatronics at the undergraduate level in Nigeria may create preliminary difficulties in selection of adequate text and reference books; proper equipment for the supporting laboratory projects; the relevant experiments for the courses that involve laboratory projects; and the proper format in documenting course notes and lab manuals as well as the required formats for grading and assessment. Therefore, this introduction of mechatronics curriculum will require certain foreign collaboration with established Nigerian institutions where a memorandum of understanding (MOU) could be established in terms of curricula structuring, staff training/sharing, and laboratory construction and equipping so as to ensure seamless condensation into pre-existing engineering disciplines.

VI. CONCLUSION AND RECOMMENDATIONS

Despite the focus on seeking to place mechatronics in the engineering field by providing a convincing definition, this work shows examples of inadequate reception of the technology with respect to its associated traditional engineering disciplines. In this paper, it has been stressed that the relationship between mechatronics and R&D is critical for a nation's infrastructural development, and for that, Nigeria and other developing countries should borrow a leaf.

The body and objective of this research embarked since mid-2007 in a multidisciplinary trainee research collaboration by most of the authors, seem to have recently gathered independent momentum and action by the National Universities Commission (NUC), a statutory regulatory agency charged with responsibility of ensuring the quality of university education in Nigeria, when it received the draft curriculum for mechatronics engineering degree programme in the Nigerian university system (NUS) from a panel of experts comprising deans of engineering of 14 pilot institutions [20]. If this novel development should be critically considered, then the need might arise, apart from thrusting for the development of an undergraduate curriculum in mechatronics, to pursue and passionately so, the immediate commencement of academic programmes in those steering institutions selected.

Future studies need to investigate the relation between the need for a mechatronics curriculum and the organizational challenges that may suffice.

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