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# What is mechatronics and why teach it?

David Bradley

*Epicentre, University of Abertay Dundee, Dundee, Scotland*

*E-mail: d.bradley@abertay.ac.uk*

**Abstract** Despite a world-wide interest in mechatronics education, there is no clear and consistent understanding of what mechatronics is, nor how, and at what level, it should be taught. The key challenge for mechatronics course designers is seen as that of ensuring an appropriate balance between depth and breadth while providing opportunities to enable students to practise integration. The paper discusses this in relation to a number of mechatronic themes. Factors influencing the design, structure and content of a mechatronics programme are discussed and suggestions made as to the possible core content of such a programme.

**Keywords** education; engineering design; robotics; systems

Mechatronics has developed in the UK from the mid-1980s to the point where there are currently some 42, three-year and four-year undergraduate courses at 27 UK institutions which involve mechatronics in some way in their title, the distribution being as in Table 1.<sup>1</sup> There are also many 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.<sup>2-6</sup> Additionally, there are 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 and the Mechatronics Forum.<sup>7-11</sup> These conferences are supplemented by technical journals having mechatronics as their subject area.<sup>12,13</sup>

However, and despite this 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. A review of the literature about mechatronics will rapidly result in a number of definitions, each of which perhaps seeks to emphasise a slightly different aspect of the mechatronics concept, ranging from design to precision engineering and from sensors to actuators.<sup>14,15</sup> Nevertheless, and despite their difference in emphasis, most of the definitions do manage to agree in some way 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 then providing the 'glue' which binds the whole together. This integration is also reflected in the various diagrammatic forms that have been used to represent the structure of a mechatronic system, as is seen from the two examples of Fig. 1.

In terms of the development of mechatronic education, the concern in course design has always been that of how to achieve a balance between providing the necessary depth of understanding of the core technologies and the ability to develop

TABLE 1 *Undergraduate degree programmes in the UK involving mechatronics*<sup>1</sup>

Course title	Number	Course title	Number
Mechatronics	20	Instrumentation and control (mechatronics)	1
Mechatronic engineering	11	Mechanical engineering and mechatronics	1
Engineering (mechatronics)	3	Mechatronics (extended)	1
Manufacturing engineering (mechatronics)	2	Plant and process engineering (mechatronics)	1
Automotive mechatronics	1	Robotics and mechatronics	1

solutions which integrate them. This may be compared with the perhaps more usual, subject-based approach to engineering education where the emphasis has tended to be on providing a depth of understanding, often at high levels of detail, within the subject area: something which may well result in a relatively narrow focus with a high degree of specialisation.

In contrast, the education of a mechatronics engineer has to place a greater emphasis on the ability to work across and between individual areas of technology. This is not, however, to suggest that a mechatronics engineer does not have to have a depth of knowledge in certain specialist areas; rather, that such depth is balanced by an understanding and appreciation of the contributions of other areas of technology, as is suggested by Figs. 2 and 3.

The achievement of a balanced programme of mechatronics education must therefore ensure that individuals are provided with sufficient depth in at least one area of technology in order to allow them to make an effective contribution to that area, whilst ensuring the breadth of understanding necessary to give them credibility in regard to other subject specialists. In particular, this means that the mechatronics engineer must be able to speak the 'language' of the individual specialists and hence to act as an 'interpreter' to ensure the correct communication of ideas and concepts between these specialists.<sup>19</sup> This basic problem of communication is compounded by the fact that, as will be seen in the following sections, not only do specialists use their own domain-specific terms to describe technologies in those domains but mechatronics, and particularly mechatronics education, can also be considered in relation to a number of 'themes', each of which emphasises a different aspect of the core concept.

The key challenge facing mechatronics course designers is therefore 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. This then raises questions as to whether mechatronics can, or indeed should, be taught at undergraduate level, particularly within a three-year degree programme, or whether it should be studied at Masters level as a bridging programme, taking students from a wide range of specialist backgrounds and providing them with the necessary breadth of knowledge and integration skills.

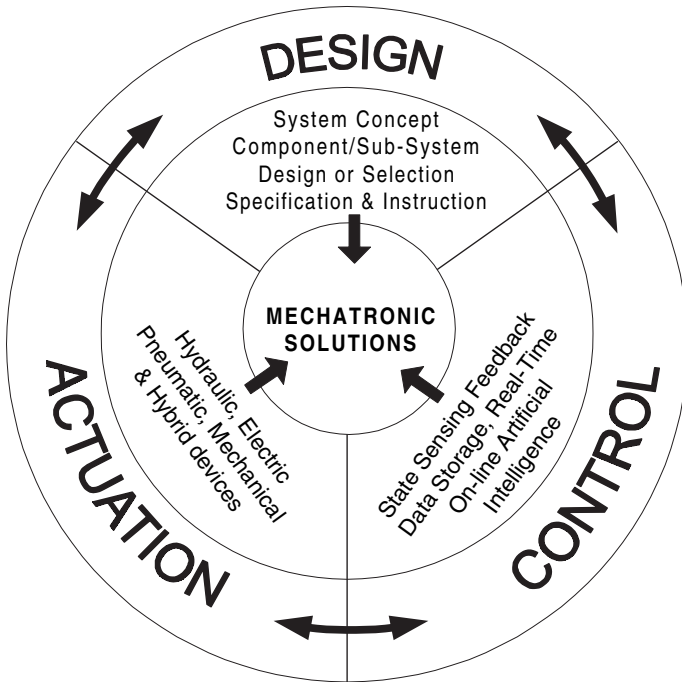
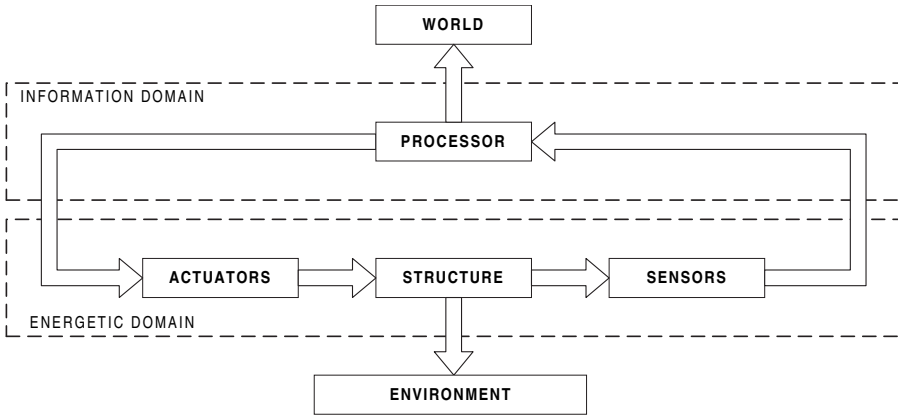


Fig. 1 Diagrammatic representations of mechatronics.<sup>16,17</sup>

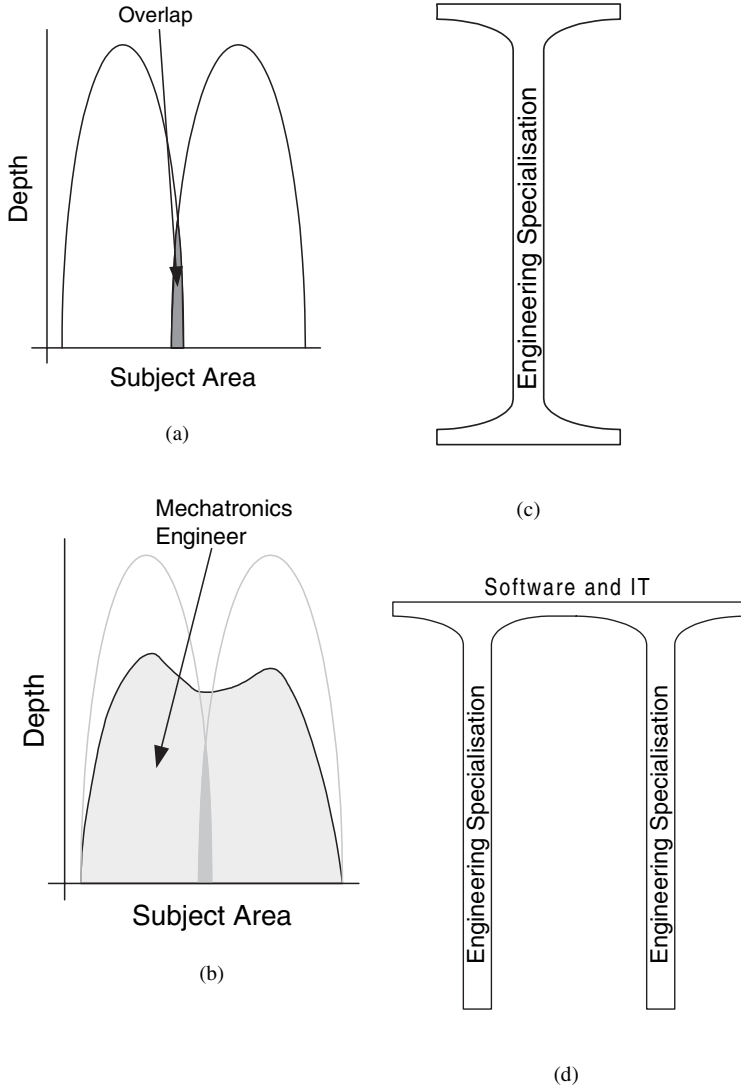


Fig. 2 Balance of technical expertise for specialist and mechatronics-educated engineers.<sup>18</sup> (a) Specialist education; (b) mechatronics education; (c) 'I' type (specialist) engineering education; (d) 'IT' type (mechatronic) engineering education.

### Mechatronics technologies and other factors

While there is a general agreement on the core mechatronics technologies of electronics, mechanical engineering together with information technology (IT) and software engineering, to focus exclusively on these technologies within the development of a mechatronics engineer would be misleading. As illustrated by Fig. 4, these tech-

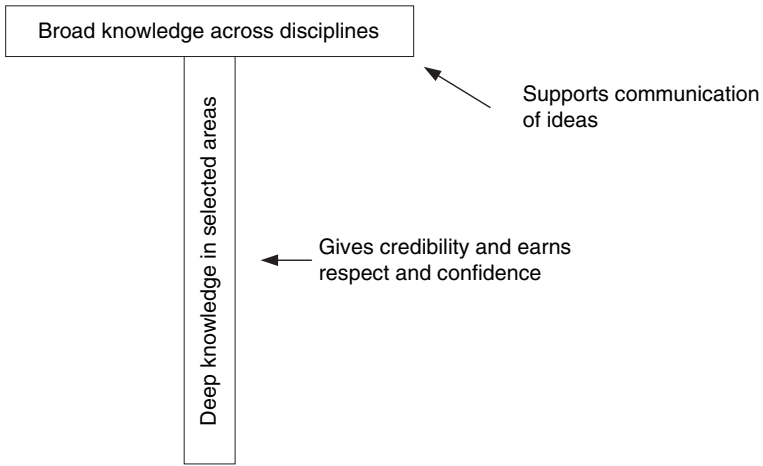


Fig. 3 *The mechatronics 'T'.*

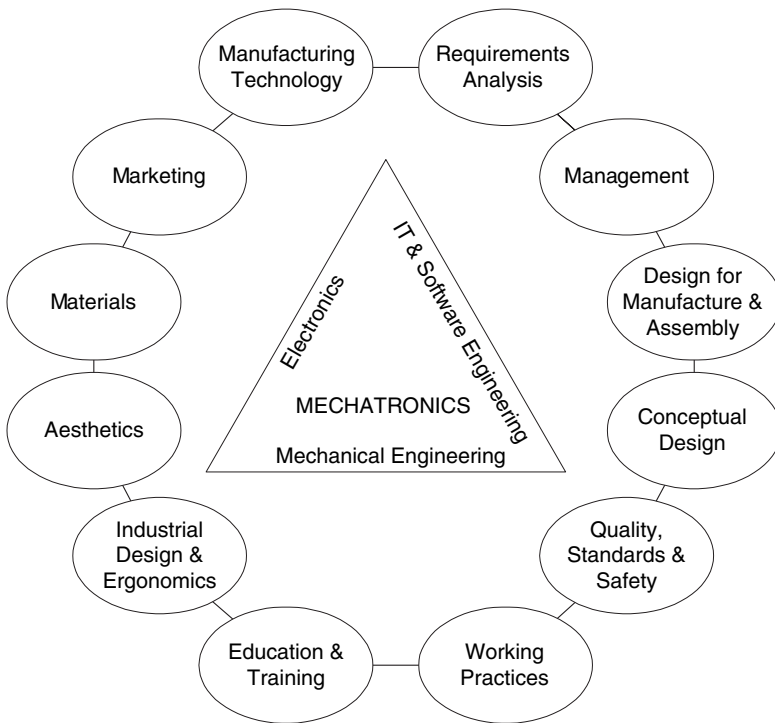


Fig. 4 *Mechatronics technologies and related domains.*

nological domains do not exist in isolation, either from each other or from a much wider group of domains, all of which will influence the way in which a mechatronic product or system will evolve. Viewed in this way mechatronics can be seen as a holistic approach to the design, development and manufacture of complex engineering systems, products and processes in which there is an emphasis on the communication and integration of knowledge in a collaborative manner.

Consider the education and training domain. In problem solving, all individuals will draw upon their knowledge and experience in reaching a decision and can be reluctant to incorporate ideas and concepts from elsewhere, particularly where these are seen as conflicting with or challenging their own position. The education and training of mechatronics engineers must therefore be such as to encourage them actively to seek solutions from outside their own direct experience while giving them the confidence, and the ability, to integrate knowledge from other sources. An openness of approach, and a willingness to accept and use ideas from a wide range of sources, is therefore key to the formation of a mechatronics engineer.

Another domain of Fig. 4, that of aesthetics, presents a somewhat different challenge to the education of the mechatronics engineer by forcing them to consider what may often be perceived as a non-engineering aspect of the design process. However, in the case of many products it is the visual aspects that provide the initial impact and, along with the marketing, attracts consumers to that product. The requirement here is therefore to enable mechatronic engineers to gain an understanding of the balance between the aesthetic, and other related, drivers in product development and the underlying engineering, perhaps through the use of CAD and other computer-based tools as illustrated by Fig. 5.

If the mechatronics engineer is going to function as the link between domain specialists, it is important that it is recognised that this role may well extend beyond the core technologies into these other, often less well-defined and unconsidered, areas of mechatronics. This will again require that course structures provide the opportunity for students to practise these and related skills within an appropriate context.

### The language of mechatronics

While individual subject domains have developed their own 'language' to describe their activities, the same cannot be said of mechatronics which must take the domain-specific terms and integrate them across domains as part of its communication role. The problem is further compounded by the fact that there are what may be considered as a number of mechatronic 'dialects' depending on the context or theme being considered or referred to. This means that even within the mechatronics community there is the potential for misunderstanding depending upon which dialects are being spoken by the individuals concerned. This situation may be illustrated by considering the session titles at three major mechatronics conferences (Table 2) from which it can be seen that out of a total of 42 sessions, only four are common to all three conferences, while a further 10 are shared across two conferences, leaving 28 to be exclusive to a single conference. While such an analysis is somewhat simplistic as it does not take into account any special themes that the conference is seeking to

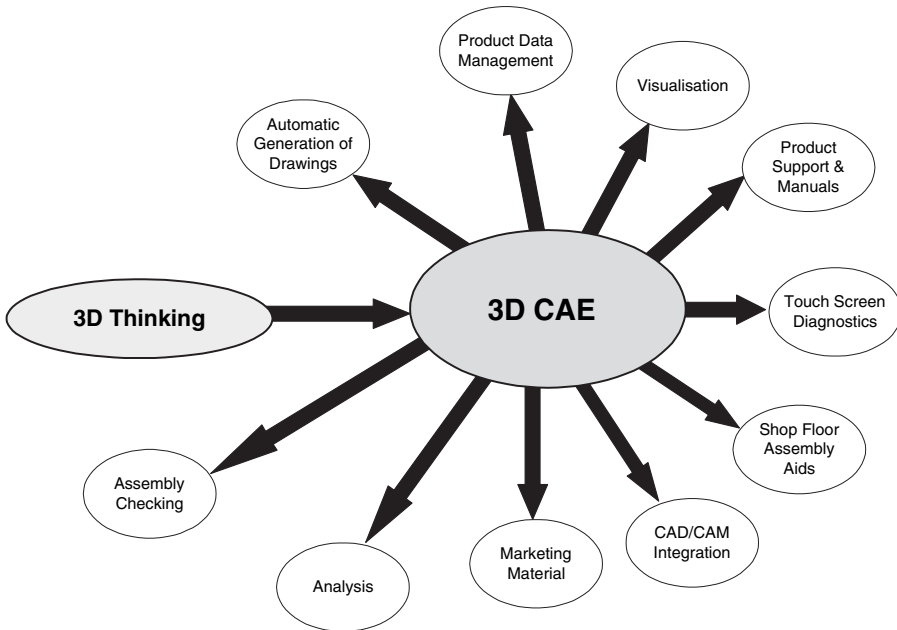


Fig. 5 Computer-aided integration.<sup>20</sup>

address, it nevertheless provides some indication of the diversity that exists within the mechatronics community when it comes to describing itself.<sup>21,14</sup>

While there are arguments that what is required is an ontology of mechatronics, perhaps a better approach would be through the medium of mechatronics education to identify how concepts are developed and the ways in which they are linked.<sup>21</sup> At the moment there is perhaps a tendency for those outside the mechatronics community to view it as a ‘non-subject’ as it often appears to outsiders to seek to present itself as an all-encompassing area of technology and engineering instead of as an approach, or perhaps indeed a methodology, to achieving integrated solutions to engineering problems, and to breaking down the traditional barriers between disciplines (Fig. 6).

**Mechatronic themes**

As has already been suggested, mechatronics and mechatronics education is increasingly being seen and considered in relation to a number of themes which emphasise different aspects of the mechatronic concepts of integration. Given the breadth of subject material, as suggested by Fig. 4 and Table 2, the fact that mechatronics may be perceived by many as encompassing this division into themes is perhaps only to be expected, despite the fact that it can increase the problems of understanding the true nature of the subject. In relation to mechatronics education, the choice of theme is dictated by a number of factors including:

TABLE 2 *Mechatronic conference sessions*

Session title	Mechatronics 2002	IFAC 2002	ASME 2001	Session title	Mechatronics 2002	IFAC 2002	ASME 2001
Actuators	✓	✓	✓	Control architecture	✓		
Mechatronics education	✓	✓	✓	Control design	✓		
Mobile robots	✓	✓	✓	Devices		✓	
Fluid power (hydraulics & pneumatics)	✓	✓	✓	Display robotics/robot games		✓	
<b>Biomechatronics</b>	✓		✓	Embedded control systems	✓		
<b>Data storage systems (hard drive disk systems)</b>		✓	✓	Fault detection	✓		
<b>Manufacturing</b>	✓		✓	Flexible manipulators			✓
<b>Mechatronic system design</b>		✓	✓	Human machine interface			✓
<b>Micromechatronics</b>	✓		✓	Identification		✓	
<b>Motion control</b>	✓	✓		Marine systems	✓		
<b>Sensing</b>		✓	✓	Measurement systems	✓		
<b>Teleoperation and haptics</b>	✓		✓	Modelling and simulation	✓		
<b>Vision</b>	✓	✓		Neural and fuzzy control			✓
<b>Walking machines</b>	✓		✓	Noise control	✓		
Adaptive control		✓		Piezoelectric transducers		✓	
Adaptive vibration control	✓			Planning			✓
Aerospace	✓			Railway vehicles		✓	
Automatic guided vehicles	✓			Robot force control			✓
Automotive power train		✓		Space systems		✓	
Automotive systems			✓	Vehicle control		✓	
Biomedical systems		✓		Virtual reality	✓		

- The backgrounds and interests of the staff involved in teaching;
- Industrial requirements, both locally and nationally;
- Student perceptions and interests;
- Availability of resources, particularly human and financial;
- Research activity.

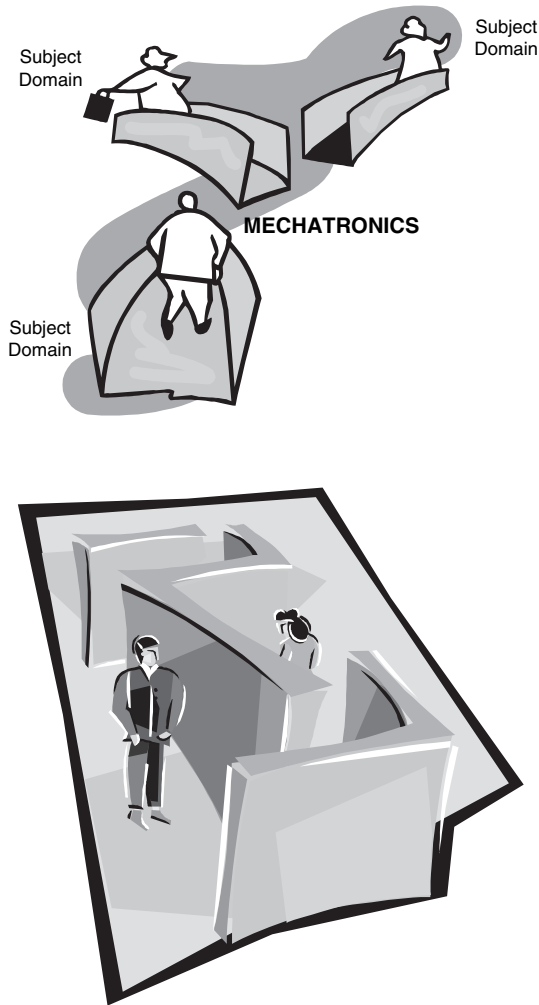


Fig. 6 *Mechatronics – building bridges, not walls.*

While it is unlikely that any one of these considerations will dominate course development, they will all play a role in determining the structure of any course. For instance, resource implications will often mean that teaching of specialist material will require that mechatronic engineers are incorporated as part of a larger group of subject specialists for this purpose, with the courses then being structured to meet the needs of the subject specialists rather than the mechatronics students. Also, the increasing modularisation of programmes can tend to mitigate against the ability to introduce the necessary integrating material, particularly where modules are seen as having to be complete and entire within themselves.

## Design

This may be considered to be the primary theme for mechatronics as by implication it is this aspect which attempts to bring together concepts and ideas in relation to a product or system. However, as suggested by Fig. 7, the design theme is also probably the most abstract and least technically based of those considered here, placing the emphasis on conceptual areas such as requirements analysis and capture, concept generation, information and knowledge management supported by areas such as modelling and analysis rather than the more direct application of technical skills.<sup>16</sup> Elements of the design theme are also likely to found embedded within all other themes, though this may be in an implicit form rather than as explicit course content. Nevertheless, it is essential that all mechatronics courses contain an element of design to support the concepts of integration and to bring in factors such as those shown in Fig. 4.

## Automation and robotics

This is seen by some as the key technological area of mechatronic development and brings together a wide range of mechatronic technologies, including the 'hard' technologies of drives, actuators and sensors and the structural aspects of robotics together with artificial intelligence and software. However, by focussing on the specific area of application it is possible that consideration of the wider implications of mechatronics are, if not ignored, given only a limited consideration within the course structure. Nevertheless, courses in this area often provide a unique perspective on mechatronics, as for instance the programme dealing with high-powered systems developed by the Technical University of Denmark and Aalborg University.<sup>19,22</sup>

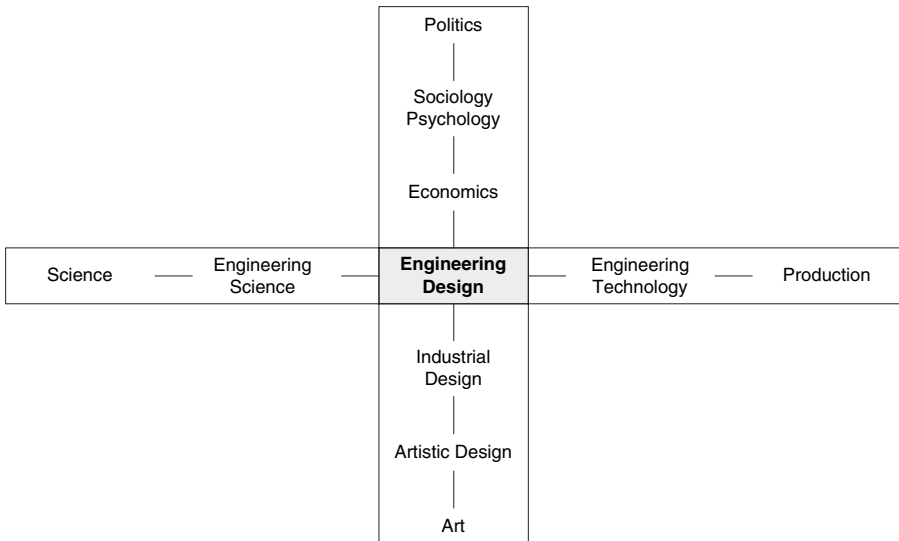


Fig. 7 Positioning engineering design.

### Manufacturing

Manufacturing systems are inherently mechatronic in their configuration and can be considered to be so at a number of different levels, as suggested by Fig. 8. In considering the approach to mechatronics adopted by courses taking manufacturing as their theme, the emphasis is often not on the components of the system; CNC machines, robots, handling systems and so forth, but on the way in which these may be integrated to create the required environment. Given the increasing trend towards Computer Integrated Manufacturing (CIM) and the move away from the traditional hierarchical organisation in which function dominates to a more knowledge-based structure centred on knowledge sharing and clusters and which is dominated by process, as suggested by Fig. 9, this means that courses based around this theme will perhaps increasingly need to emphasise areas such as knowledge management rather than technology.

### Systems

There is no doubt that mechatronics is concerned with systems of all types, whether they be products in their own right or the integration of components to generate a larger system, as for instance in a manufacturing system. However, perhaps the best illustration of this systems-level approach to mechatronics is seen in the automotive industry where a mechatronic theme has been present for many years dealing with a wide range of on-board systems from active suspensions to engine management. In a wider context, the systems theme for mechatronics tends to place emphasis on the functionality of the system and of the choice of components to meet that functionality. In this sense it is perhaps closest to the design theme, but with what might be considered to be a narrower focus.

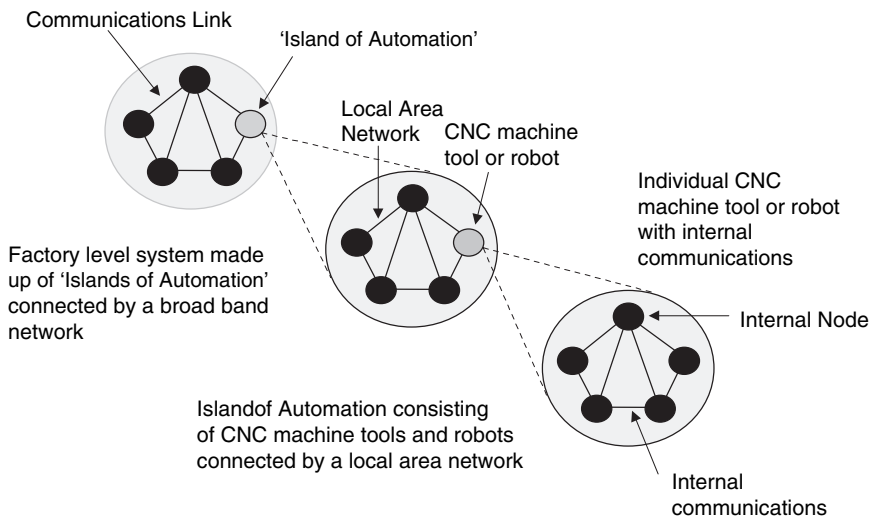


Fig. 8 A manufacturing system as a multi-layered mechatronic environment.

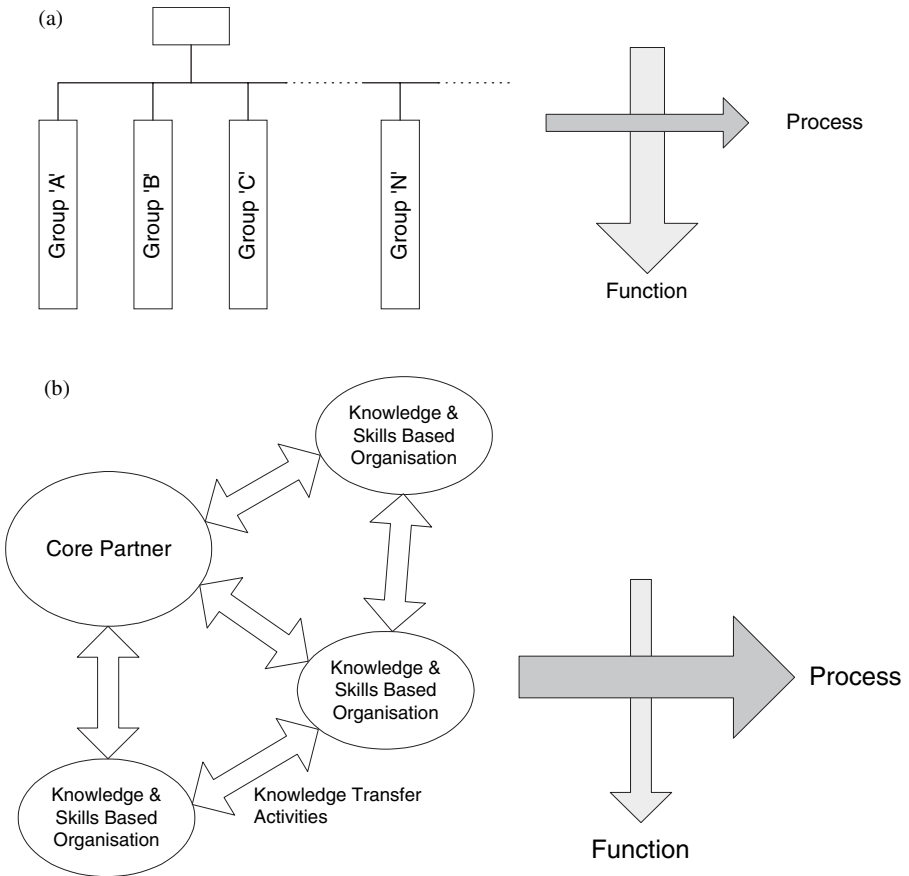


Fig. 9 Knowledge structures. (a) Hierarchical organisation; (b) Knowledge clustering.

### Mechatronics education

Faced with all of the above challenges, how might the designers of a programme of mechatronics education respond? What is clear is that they are faced with a number of questions, including:

- Should a theme be chosen or does it emerge as a result of local expertise and enthusiasms?
- How are the integration aspects introduced and managed?
- How are external requirements relating to factors affecting course structure, as for instance the Bologna Agreement in Europe, to be managed?<sup>23,24</sup>
- What is the local market for graduates and is the proposed course going to meet those requirements?

All of these questions must be balanced against meeting the academic requirements to provide a course which challenges and extends the students' perception of mecha-

tronics and which equips them to fit in to a wide range of professional environments on graduation.

**Course content**

A review of the content of a range of mechatronics courses suggests that the balance between key (or core) subject areas, in that they appear in the majority of courses, and what are here termed secondary areas is as set out in Table 3. This not to suggest that these subject areas of themselves constitute a mechatronics course, rather that they provide an indicator as to the generality of material that such courses contain, and hence around which a course might be structured.

**Course structure**

The actual structure of any course will be determined by the academic structure of which it forms a part. Thus the division of the academic year into terms or semesters and the degree of modularity achievable, including flexible structures based around prerequisites, will influence the way in which a course is configured, as will the length of the course. 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. Similarly, within a modular 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.

**Group work and projects**

In the great majority of mechatronics courses it is through the use of group working and projects that the integrating aspects of mechatronics are introduced and there is significant evidence of the effectiveness of such an approach in engaging students, even if this is occasionally at the expense of some of their other studies.<sup>24,26</sup> Figure 10 shows an example of one such project in the form of the ‘*Formula SAE/Formula*

TABLE 3 *Mechatronic course subject areas*

Key subject areas	Secondary subject areas
Control systems	Engineering design
Embedded systems	Machine dynamics
Software engineering	Kinematics
Electronics (analogue and digital)	Manufacturing technology
Sensors and actuators	Hydraulic and pneumatic systems
Drives	Simulation and modelling
Mathematics	Artificial intelligence
	Robotics
	Human machine interface



Fig. 10 *Lancaster University Formula Student vehicle.*<sup>20</sup>

*Student'* vehicle constructed by students on the MEng and MSc programmes at Lancaster University.<sup>27,28</sup> In this particular case, students undertook both individual and group projects on different aspects of the vehicle system which would then be integrated onto the vehicle itself.

A question which is often raised in relation to projects of this nature is that of the marking scheme to be adopted in order to reward individual effort. Experience suggests that there is no one answer to this requirement, but that a combination of approaches which require the participating students to identify their contribution is necessary. This can range from project log-books and minutes of group meetings to the provision of individually identified and attributed contributions to the final report. There is also however an alternative view which suggests that in relation to many projects of this type, any attempt to provide a grade other than a pass or fail would inevitably force students to become conservative in their approach and would eliminate many of the more interesting options and solutions which would other-

wise be put forward, but which would perhaps fail to achieve the target levels of performance. While it could be argued that success in achieving design goals is a valid objective, perhaps in educational terms it is sometimes more worthy to encourage students to explore new and novel ideas and concepts than to penalise them for their adoption of such an approach.

### Undergraduate versus Masters programmes

A continuing debate when it comes to mechatronics education is that of whether it is a subject that can, or indeed should, be taught as an undergraduate programme in its own right or whether it is a subject which is best taught at postgraduate, and specifically Masters, level where it can build upon the more specialist background provided by courses covering a wide range of subject areas. Certainly, if the objectives of providing a sufficient depth of specialist knowledge to give credibility within a balanced programme which supports the effective communication of ideas (Fig. 3) are considered, it is becoming increasingly difficult to see how this can be achieved within the time constraints imposed on some undergraduate programmes. On the other hand, to provide a Masters-level programme which is capable of providing the broadening of experience required across participating students with a wide range of backgrounds requires a high level of flexibility in relation to the provision of options and the integration of courses from existing, specialist, undergraduate programmes which may be non-viable in terms of resources; particularly human and financial.

### Conclusions

Mechatronics has always suffered from an identity crisis both within the academic community and elsewhere, and indeed is likely to continue to do so given the diversity of approaches and emphases that are found within the community. Yet at the same time there is a need for graduate engineers with the particular integration skills that are provided by a mechatronic background and education. The challenge facing mechatronics course designers is therefore that of achieving the necessary balance between detailed knowledge and the ability to act in the integrating role in a wide range of environments.

The achievement of this balance is subject to a whole range of pressures ranging from the rapid advance of technology in some areas to external factors impacting on course management and design. At the moment, and providing it is recognised that there is no universal solution to the design of a mechatronics course, a balance between undergraduate and postgraduate programmes in mechatronics is probably just about achievable, though how long this will remain the case is open to question.

If mechatronics is to develop as an academic subject, then there is perhaps a need to rethink our approach to the provision of education in this area in a way which allows for a sharing of resources and skills between academic institutions and industry and which views mechatronics not just as an academic subject to be dealt with in three-, four- or five-year academic programmes but as a holistic approach to life-

long learning and education within engineering. Such an approach, in which students are able to integrate programmes from a wide range of sources to achieve their degree, will require a flexibility of view which perhaps does not currently exist.

It is however interesting to note that this sharing of expertise was something which was attempted in the late 1980s and early 1990s in the form of the Integrated European Course in Mechatronics which brought together a group of institutions throughout Europe,<sup>†</sup> each providing a specialist contribution to a broad-based post-graduate programme. That this attempt to provide a shared programme was not a success was probably due its being ahead of its time as it required the students to move from institution to institution, creating problems of timing and travel for the participants. Perhaps it is now time to resurrect the concept of a multi-centre mechatronics programme, but making use of current communications technology to support its provision.

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<sup>†</sup> Brunel University (UK), Dundee University (UK) University of Abertay Dundee (then Dundee Institute of Technology) (UK), Technical University of Denmark (Denmark), University of Leuven (Belgium) & Univeristy College Dublin (Ireland).

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