Chapter 1
Mechatronic Futures

David Bradley and Peter Hehenberger

1.1 The Challenge

The period of over 40 years since the concept of a mechatronic system was introduced by Tetsuro Mori [1] to express the growing impact that the availability of electronic components was having on the control and operation of inherently mechanical systems has been, and continues to be, a period of significant and rapid technological change. In particular, there has been a shift in emphasis within systems from hardware to firmware and software, leading to the introduction of a wide range of consumer products structured around the use of smart devices, many of which remain essentially mechatronic in nature in that they bring together a core of mechanical engineering with increasingly sophisticated electronics and software. When combined with enhanced local and remote communications, this has led to the evolution of systems based around the ability of smart objects to communicate with each other, and hence to effectively self-configure according to context.

This in turn has led to the development of concepts such as Cyber-Physical Systems, the Internet of Things and Big Data [2–11] in which interaction is driven through the combination of smart objects and information. Referring to Figs. 1.1, 1.2 and Table 1.1, users access cloud-based structures through smart objects to draw on resources provided by a range of, often unknown or invisible, sources.

The growth of provision represented by Table 1.1 has also led to a growth in availability of sophisticated user systems where, for instance, smartphones increasingly incorporate high-quality still and video imaging capability to the point where they are now responsible for more images than conventional cameras. It has

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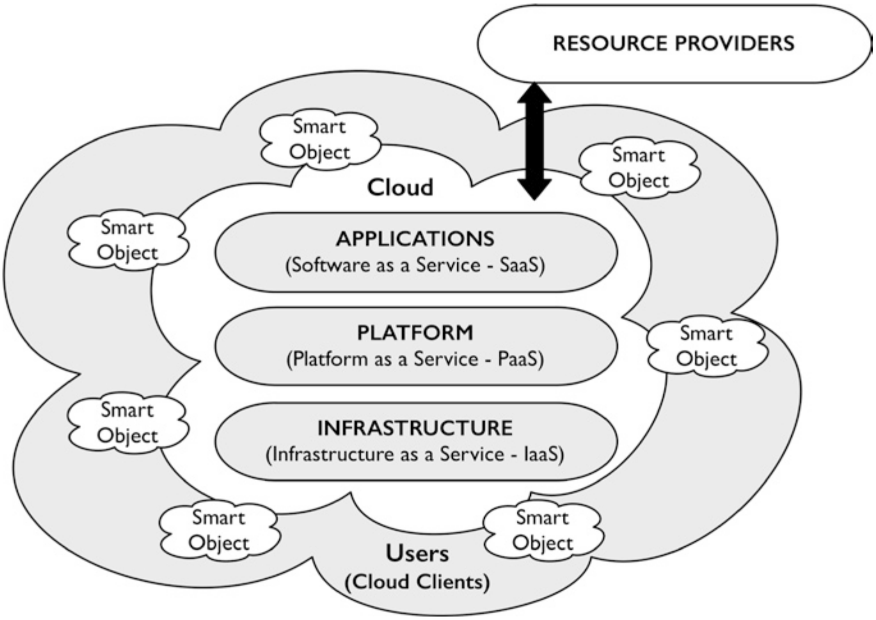


Fig. 1.1 Cloud-based structures for the Internet of Things

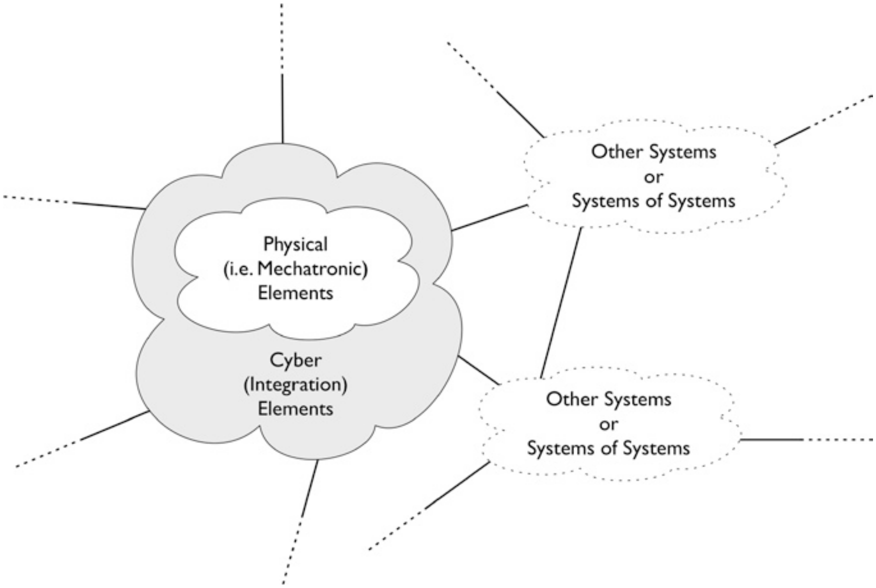


Fig. 1.2 Cyber-physical systems

Table 1.1 Cloud functions

Applications (software as a Service—SaaS)	Apps, Games, Mail, Virtual Desktop, Customer Management, Communications, Access, On-Demand Systems, …
Platform (platform as a Service—PaaS)	Runtime Operation and Management, Databases, Web Server, Tools, Computation, …
Infrastructure (infrastructure as a Service—IaaS)	Virtual Machines, Servers, Storage, Load Balancing, Networking, Communications, …

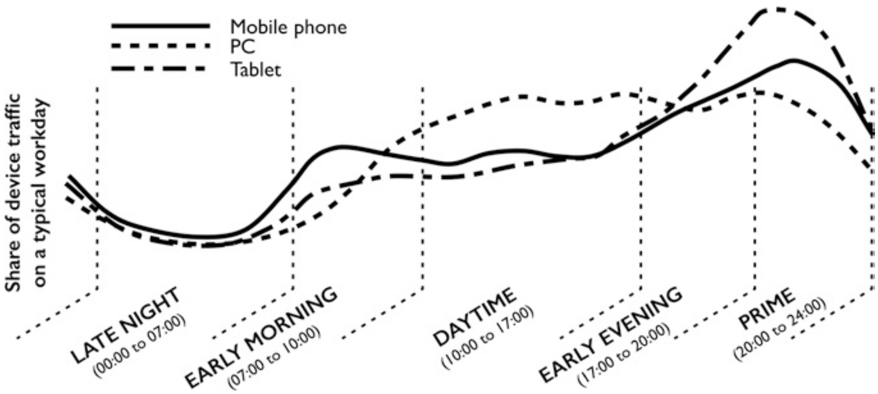


Fig. 1.3 Daily profile of use for mobile phones, PCs and tablets (after [12])

also led to the introduction of a range of user devices for behavioural monitoring, smart watches and tablet computers, all of which are capable of interacting with other smart devices through the medium of the Internet. Figures 1.3 and 1.4 together illustrate the daily profile of use for such devices [12–15]. All of the above have implications for the design, development and implementation of mechatronic systems, and for the future of mechatronics itself [16, 17].

In 2014, in association with the Mechatronics Forum Conference held in Karlstad in Sweden, a number of practitioners from around the world were asked to provide, in a single phrase, their view of the most significant challenges faced by mechatronics in coming years. The responses received are presented as Fig. 1.5 and will be discussed in more detail in the following sections of this chapter.

1.2 Challenges

Taking the above responses, the key issues can be summarised as:

- Design
- Privacy and Security

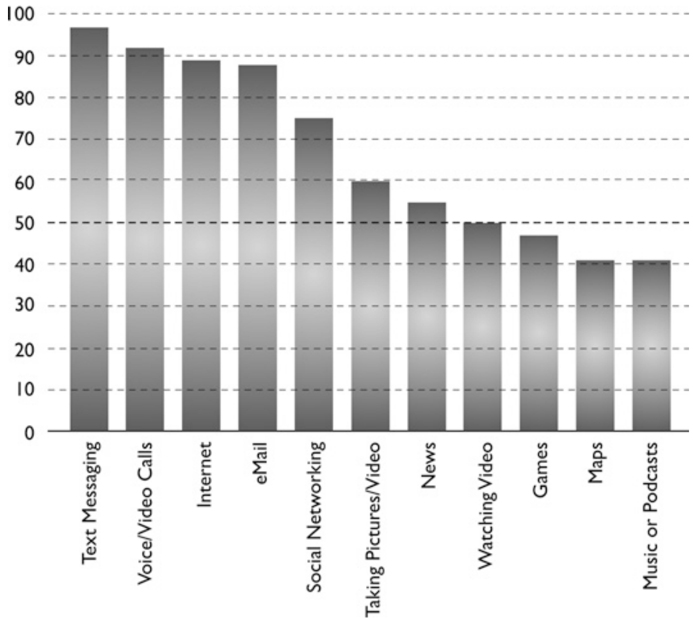


Fig. 1.4 Mobile phone use (after [13])

- Complexity and Ethics
- Ageing Population
- Users
- Sustainability
- Education

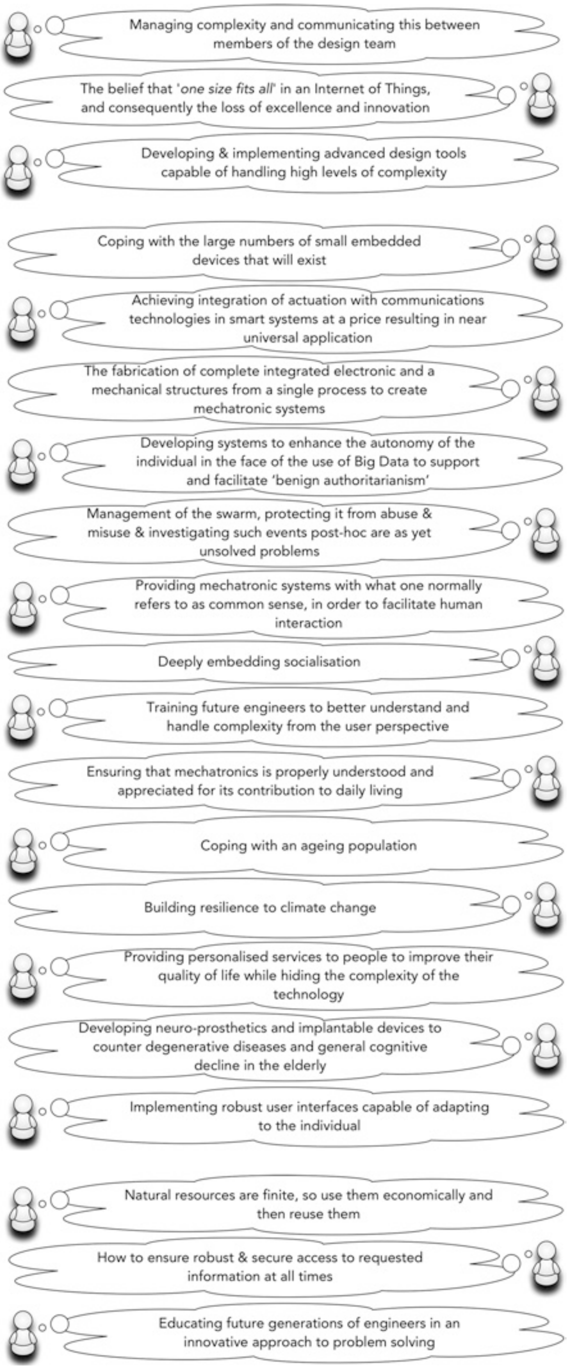
Each of which will be briefly discussed in the following sections.

1.2.1 Design

Conventional approaches to engineering design typically follow a path such as that defined by the simplified V-Model of Fig. 1.6 with integration being achieved through a structured system definition followed by a process of system development supported by appropriate testing regimes to support verification and validation. Individual modules and sub-modules, including those from external sources, are then tied into the design by a process of specification, test, verification and validation to ensure overall system functionality.

This approach has evolved over many years through the synergetic interaction between design theory and design practice. However, it is the case that design theory must inevitably lag behind practice where the possibilities afforded by new

Fig. 1.5 Practitioner responses regarding challenges facing mechatronics



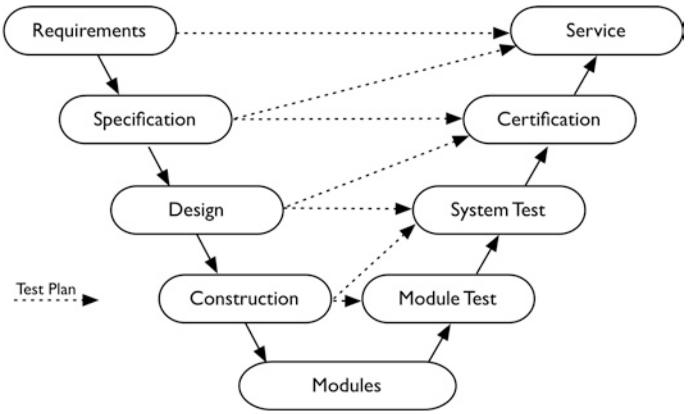


Fig. 1.6 Simplified V-Model

technologies are being explored, perhaps without necessarily a full understanding of their capability or implications.

In the case of the Cyber-Physical Systems and the IoT, the system is a dynamic entity which smart objects, and hence users, enter or leave depending on context and need. In the majority of instances, the cloud-based components will be unknown to the user prior to their being adopted for use, and the same may well apply to any functional smart objects. This leaves the designer with the issue of ensuring that the system is not vulnerable to their inclusion, while recognising the ability of the system to self-configure as required.

Essentially, therefore the user specifies system function and content after which the system autonomously configures selecting required software and data components from cloud with information then becoming a commodity whose value is determined by user context. Where physical components are involved, as for instance in a smart home environment, identification and selection will be by the user with guidance. A challenge for designers is to provide tools to enable the implications of the dynamic system configuration to be explored at the earliest stages of the design process, and to integrate these outcomes into device functionality as appropriate [18].

1.2.2 *Privacy and Security*

Many of the devices associated with the IoT have the capacity to gather large volumes of personal data, much of which may be held in areas and ways unknown to the user. This data is then subject to the possibility of analysis, with associated risks of misinterpretation impacting on privacy [20–23]. However, this must be balanced against the potential ability to extract beneficial knowledge, particularly

Table 1.2 Perceived threats to system security (after [19])

Threat	Probability (%)
Data leakage	17
Employee error	16
Employee-owned device incidents	13
Cloud computing	11
Cyber attacks	7
Disgruntled employee	5
External hacking	5
All of the above	19
None of the above	8

within the context of IoT-based applications such as eHealth [24]. In the wider context of security, the ability of systems to protect themselves against intrusion is of increasing importance, both at the personal and the corporate level. Table 1.2 shows the perceived levels of threat based on a survey conducted by the Information Systems Audit and Control Association [19].

It is therefore clear that there is an increasing burden on system designers to place privacy at the core of their design process within the context each of the Internet of Things, Cyber-Physical Systems and Big Data, and that this must be reflected in the design process itself and the methods and tools to support this.

1.2.3 *Complexity and Ethics*

As systems become increasingly complex and begin to operate with greater autonomy, issues are raised regarding the ability of all stakeholders to understand their nature and function across a range of applications and environments from healthcare to autonomous vehicles [25–28]. This is particularly the case where responsibility for the wellbeing, or indeed the life, of an individual or individuals is being entrusted to the system [29]. Other issues include:

- Dual-use of technology—Technologies such as drones can be associated with beneficial applications, as for instance in crop management, but also for military and other purposes.
- Impact of a technology on the environment—The introduction of technologies into an environment can disrupt and change that environment in a variety of ways, even when the underlying intent is benign.
- Impact of technology on the global distribution of wealth—The use of technologies can increase the separation between differing societal groups, even within the same country [13].
- The digital divide and the associated socio-technological gap—There is an increasing separation between the ability to access and use the services provided through the cloud.

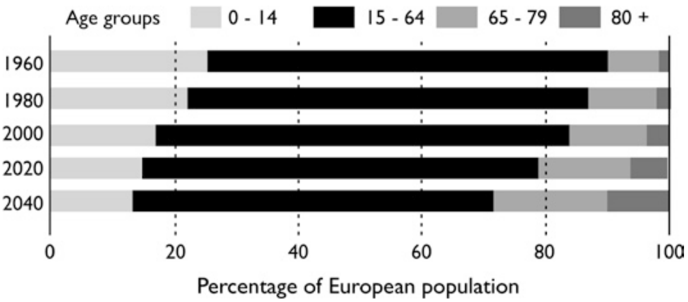


Fig. 1.7 An ageing population in Europe (after [32])

- Ensuring fair access to technologies—Controlling access to technology can act as a restriction on development.
- Technological addiction—Individuals becoming addicted to the technologies that they use [30].
- Technological lock-in—Individuals can become locked into specific technologies, a simple example being the choice between Apple and Android.
- Dehumanisation of humans and anthropomorphism—By taking away responsibility for their activities and wellbeing [31].

1.2.4 Ageing Population

Faced with an ageing population, Fig. 1.7 shows the past and predicted changes in the distribution of age groups within Europe,[1] questions are raised as to how best to use technology to support the elderly, and to try to provide them with increasing levels of independence in old age. In particular, there is a need to ensure appropriate levels of mobility within both the physical and information domains to prevent individuals retain independence and engagement with society [33, 34].

1.2.5 Users

As has been seen, the availability of Internet-capable devices has had a significant impact on social behaviour through the use of social media, but also allows a much more ready access to information than has historically been the case. Such devices also support increased levels of interaction with the environment, as for instance in the case of a smart home. Additionally, the introduction of wearable

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[1] Similar data can be found for other global regions.

devices provides opportunities for developments in areas such as eHealth and mHealth to support individual wellbeing [35], in turn raising issues of privacy and the control of personal data.

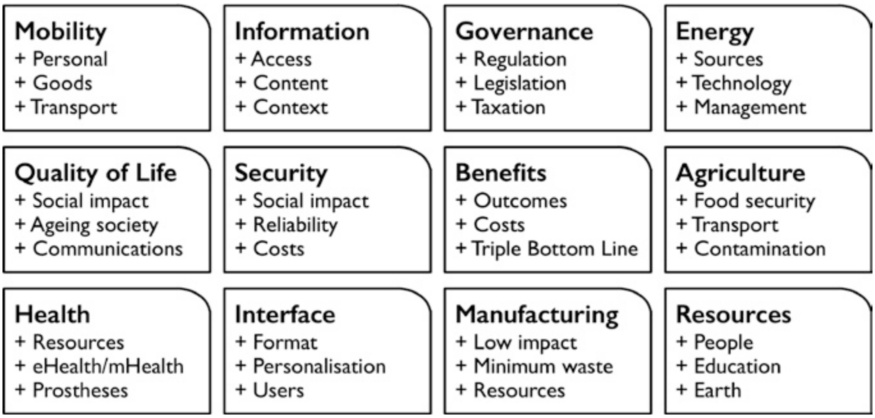
However, there is also a need to develop new forms of user interface to support a wider range of users in their ability to interact with such systems. In particular, there is an increasing requirement to be able to capture user intent and context in a way which does not require complex forms of communication or knowledge about the underlying technology.

1.2.6 Sustainability

There is a recognised need to move towards more sustainable forms of society-centred around the individual and their needs and structured around the effective management and use of all available resources as suggested by Fig. 1.8. In the context of mechatronics [36, 37], this integrates into concepts such as those of the smart home and the smart city where information is used to manage daily activities.

For instance, it is estimated that, on average, finding a parking place in a German city requires about 4.5 km of driving which for a vehicle emitting around 140 g of CO_2/km will generate at least 630 g of unnecessary CO_2, and significantly more in stop-and-go traffic. By linking knowledge of available parking spaces with the vehicle destination through appropriate communications, much of this excess could be eliminated [38]. Other sustainability issues impacting on cities are suggested in Table 1.3.

Overall, therefore there is a move towards the creation of sustainable societies with individuals and the core to address issues such as ageing populations, resource availability and management, climate change and resilience [40–44]. Referring to mechatronics and the Internet of Things, an underlying requirement



Mobility
+ Personal
+ Goods
+ Transport

Information
+ Access
+ Content
+ Context

Governance
+ Regulation
+ Legislation
+ Taxation

Energy
+ Sources
+ Technology
+ Management

Quality of Life
+ Social impact
+ Ageing society
+ Communications

Security
+ Social impact
+ Reliability
+ Costs

Benefits
+ Outcomes
+ Costs
+ Triple Bottom Line

Agriculture
+ Food security
+ Transport
+ Contamination

Health
+ Resources
+ eHealth/mHealth
+ Prostheses

Interface
+ Format
+ Personalisation
+ Users

Manufacturing
+ Low impact
+ Minimum waste
+ Resources

Resources
+ People
+ Education
+ Earth

Fig. 1.8 Sustainability domains

Table 1.3 City problems (after [39])

	US/Canada	Europe	Asia	Latin America	Africa
Average population (millions)	1.4	2.5	9.4	4.6	3.9
Population density (per km^2)	3100	3900	8200	4500	4600
Water consumption (litres per capita per day)	587	288	278	264	187
Water loss rate (%)	13	23	22	35	30
CO_2 emissions per capita (tonnes)	14.5	5.2	4.6	No data	No data
Waste volume (kg per capita per year)	No data	511	375	465	408

in achieving sustainability is the effective management and use of all resources; technical, physical and human, through the integrated use of information serviced by a range of smart objects.

This in turn implies the effective and appropriate use of information to support the engagement of individuals in all aspects of their lifestyle through the adoption of novel and innovative approaches to understanding, structuring and managing the physical and information environments, and the relationships between them, as part of a knowledge economy configured around the Internet of Things. Consider two different urban scenarios as follows:

Scenario 1: *New Build*—The aim is to achieve integration of the physical and information environments from the outset, supported by access to facilities such as high-speed broadband networks and the ability to deploy a full range of smart technologies within those environments.

Scenario 2: *Established Communities*—These represent the majority of the population and means that the introduction of infrastructure changes will need to take account of the impact on the existing environment, and the adaptation of that environment to the needs of technology.

1.2.7 Education

Mechatronics education has always faced the challenge of balancing appropriate levels of technical content with the understanding of the requirements for integration across the core disciplines of mechanical engineering, electronics and information technology [16, 17, 45–47]. Given the growth in the technological base over the last 40 plus years as suggested by Fig. 1.9 [17], the challenge facing mechatronics course designers in achieving that balance has become significantly more complex.

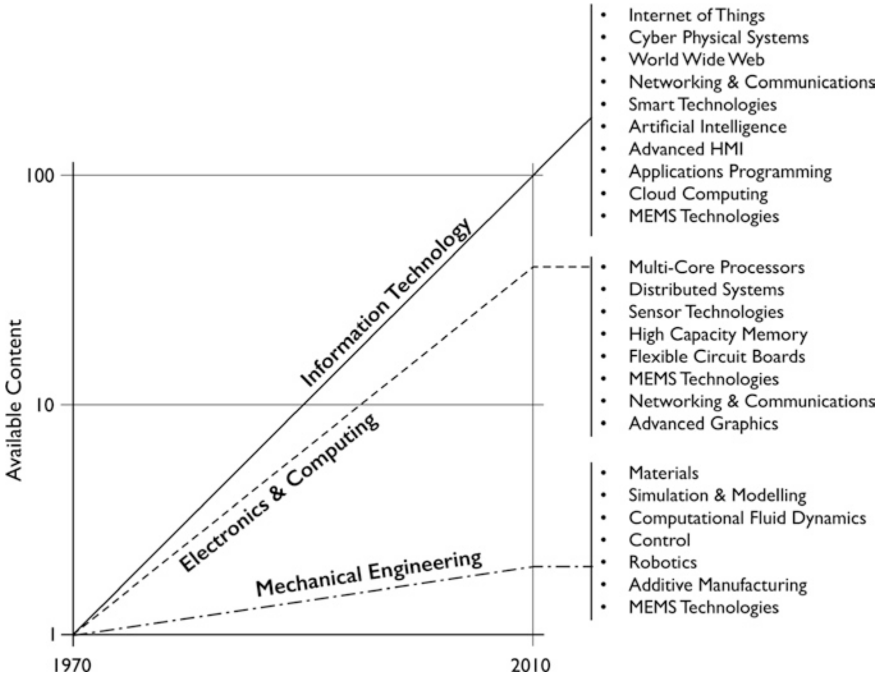


Fig. 1.9 Development and diversification of mechatronics technologies (after [17])

Fig. 1.10 The challenges of innovation

In addition to the challenges to course design associated with developments in technology a number of other factors need to be taken into account. These include:

- Changes in delivery
  - Massive On-line Open Courses (MOOCS) [48].
  - Tutorial and workshop based learning support.
  - Blended learning [49].
  - Impact of social media on learning [50].

- Structural Issues
  - Distributed learning resources.
  - Time value of content.
  - Collaborative working.

A key element for the future is therefore that of encouraging an innovative approach to mechatronics through education (Fig. 1.10).

1.3 Chapter Structure

The book is structured around a series of chapters from invited authors, each of whom is an expert in a particular area of mechatronics. In each case, the authors were challenged to establish the current state of the art using their own research or professional expertise as the starting point and then to try to isolate and identify those key areas in which significant development is needed or likely to take place in coming years. The chapters themselves are organised as set out in Table 1.4.

1.4 Summary

Though the core technologies and concepts remain essentially unchanged, the nature of what constitutes mechatronics has changed significantly since the concept was originally proposed, and that change is likely to continued at an accelerating rate. Some of the issues and challenges be addressed have been identified in the preceding sections, and will be developed and expanded in subsequent chapters.

Table 1.4 Chapter structure

Chapter(s)	Subject area
1	Introduction
2 and 3	Issues and Challenges
4–8	System Design, Modelling and Simulation
9	Manufacturing Technology
10–12	Internet of Things and Cyber-Physical Systems
13	Communication and Information Technologies
14 and 15	Mechatronics Education
16	Conclusions

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