Virtual physiological human: training challenges

BY PATRICIA V. LAWFORD1,*, ANDREW V. NARRACOTT1, KEITH McCORMACK1, JESUS BISBAL2, CARLOS MARTIN2, BINDI BROOK3, MARGARITA ZACHARIOU3, PETER KOHL4, KATHERINE FLETCHER4 AND VANESSA DIAZ-ZUCCARINI5

1 Medical Physics Group, Cardiovascular Science, University of Sheffield, Sheffield, UK
2 Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain
3 School of Mathematical Sciences, University of Nottingham, Nottingham, UK
4 Department of Physiology, Anatomy and Genetics, University of Oxford, Oxford, UK
5 Mechanical Engineering, University College London, London, UK

The virtual physiological human (VPH) initiative encompasses a wide range of activities, including structural and functional imaging, data mining, knowledge discovery tool and database development, biomedical modelling, simulation and visualization. The VPH community is developing from a multitude of relatively focused, but disparate, research endeavours into an integrated effort to bring together, develop and translate emerging technologies for application, from academia to industry and medicine. This process initially builds on the evolution of multi-disciplinary interactions and abilities, but addressing the challenges associated with the implementation of the VPH will require, in the very near future, a translation of quantitative changes into a new quality of highly trained multi-disciplinary personnel. Current strategies for undergraduate and on-the-job training may soon prove insufficient for this. The European Commission seventh framework VPH network of excellence is exploring this emerging need, and is developing a framework of novel training initiatives to address the predicted shortfall in suitably skilled VPH-aware professionals. This paper reports first steps in the implementation of a coherent VPH training portfolio.

Keywords: interdisciplinary; translational research; computer model; simulation; biomedical research

1. Background

The virtual physiological human (VPH) is defined as ‘a methodological and technological framework that, once established, will enable collaborative investigation of the human body as a single complex system’*

*Author for correspondence (p.lawford@sheffield.ac.uk).

One contribution of 13 to a Theme Issue ‘The virtual physiological human: computer simulation for integrative biomedicine II’.
In more practical terms, the VPH aims to make computer simulation and modelling an integral part of biomedical research and development, with the long-term aim of building predictive tools for personalized healthcare. This is hoped to give rise to improvements in disease prevention, diagnosis, treatment, and safety of pharmacological or device-based interventions (Fenner et al. 2008).

The VPH framework encompasses biomedical modelling across a broad range of levels of structural and functional complexity (‘from molecule to man’). This is a formidable challenge (Hunter et al. 2010) that involves databasing, data mining and knowledge discovery, modelling, simulation and visualization, experimental and/or clinical validation, and (if needed) additional experimentation to address particular shortcomings in available data (Viceconti et al. 2008a, b; Kohl & Noble 2009).

Given its scope, the VPH builds on the skills and expertise of a broad range of researchers and practitioners, with widely varying educational and conceptual backgrounds. However, at present, the majority of VPH-associated investigators come from a physical science, engineering or a computer science background, with a relatively small number of actively engaged experts with training or track records in the life sciences or medicine. This imbalance needs to be addressed, both via outreach and recruitment, but also through training activities.

Presence of expertise and goodwill of experts alone will not suffice, however, in generating a coherent VPH community. There is a clear disparity between integrative research needs and the compartmentalized academic landscape that is associated with structural divides into divisions, departments and institutes, where engineering, mathematics, computer sciences, bio-research and medicine (to name but a few) are conducted in administratively (and often physically) separate settings, linked to largely disconnected curricula for undergraduate and graduate training.

As a consequence, fragmented expertise and differing conceptual and terminological backgrounds have led to a situation where advanced integrative research increasingly depends on the availability of ‘translators’. Appropriate training efforts are few and far between (one of the notable exceptions is biomedical engineering, but this is less well-developed in Europe, compared with North America).

The difficulties are compounded by the geographical fragmentation of the VPH community, with expertise spread across institutions and countries, where researchers’ credentials may have different degrees of recognition. Europe-wide appreciation of this set of problems throughout the higher education system has given rise to the ‘Bologna process’. Today, the Bologna process unites 46 European countries and it also involves the European Commission, Council of Europe and the United Nations Educational, Scientific and Cultural Organization. It aims at building an integrated ‘European higher education area’, where increased modularity of educational contents supports mobility of students and graduates. The VPH training strategy will take full advantage of this process. The present paper gives a brief

1 The ‘Bologna process’ is named after the 1999 declaration (signed in Bologna) by the ministers of higher education from 29 European countries. See http://ec.europa.eu/education/policies/educ/bologna/bologna.pdf.
summary of VPH-related training needs, and highlights current efforts directed at addressing this crucial determinant of success and sustainability of the VPH initiative.

2. The European research landscape

The development of the VPH is part of, and contributes to, the ‘greater European Union (EU) research landscape’. A number of visionary discussion papers and reports, emerging from both national (Academy of Medical Sciences and the Royal Academy of Engineering 2007; Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine and the National Academies 2004. Facilitating Interdisciplinary Research) and European (European Commission Community Research High Level Group on Increasing Human Resources for Science and Technology in Europe 2004; Hilbert 2007) consultation activities identify the threat to academia, industry and society in general of an inadequate supply of trained scientists, engineers and technologists within the European community. At the same time, statistics for higher education in key EU member states show a decline in the number of students enrolling in traditional scientific subjects, including mathematics, physics and chemistry. This is partially off-set, however, by an increase in uptake of engineering, life sciences and computing (European Commission Community Research High Level Group on Increasing Human Resources for Science and Technology in Europe 2004).

Given the declared intent of the EU ‘[… to become the most competitive and dynamic knowledge-based economy in the world […]’ (http://www.europarl.europa.eu/summits/lis1_en.htm), significant efforts in training, research and development are needed, and are (partially) being implemented throughout the European Economic Community. Thus, at the Barcelona summit in 2002, European heads of state called for an increase in the proportion of European gross domestic product invested into research from a 2002 figure of 1.9% towards 3% by 2010. In order to encourage research and development investment by the private sector, tax incentives were proposed (http://www.euractiv.com/en/science/investing-research/article-117437). Associated training needs were projected to involve 0.5 million additional students, or 1.2 million, if postgraduate researchers are taken into account (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Human_resources_in_science_and_technology).

In 2010, it is clear that at the current rates of increase, many more years will be needed before the 3 per cent target will be met (http://www.euractiv.com/en/science/investing-research/article-117437). Certain trends, such as the decrease in numbers of physical science students and the current economic climate, are clear indicators of a negative trend in at least some of the required developments. However, the VPH must plan for the long term and be ready for future expansion in an environment where a shortage of scientists and technologists is contrasted with an increasingly competitive employment market, post-recession, for related professional specialties. Consequences of a failure to act are pointed out in the 2007 report on workforce skills needed in high-income countries of the Organisation for economic co-operation and development: ‘Proper
anticipation of how the skill content of occupations is evolving and the type of new skills required raises many challenges for policymakers, as failure to plan adequately could have potentially serious consequences for economic and social development’ (Hilbert 2007).

3. Virtual physiological human training needs

Identification of training needs, and the development of strategies to implement them, are tasks of the VPH network of excellence (NoE) (http://www.vph-noe.eu/home). The NoE is a 54-month project, started in June 2008, and has 14 core partners from leading academic institutions across Europe. There are currently over 30 associate member organizations. Mindful of the importance of translation activities, the NoE is supported by scientific, clinical and industrial advisory boards, comprising representatives from a broad range of VPH stakeholders. Activities of the NoE range from the development of community standards and ontologies, to the collation and sharing of tools, pooling of associated infrastructural resources and integration of models and data across the various relevant levels of structure and function. Most importantly, though the NoE aims to support VPH community building, which includes means of integration and exchange of knowledge between existing VPH experts (web portals, in-person meetings, symposia, etc.), and outreach into associated professional spheres and the general public (presentations, web-casts, interviews, etc.). A key task for long-term success and sustainability is training of the future generation of VPH-aware specialists via development of new and sustainable educational, training and career structures.

In particular, VPH training and integration activities can be separated into two themes: (i) creation of an interdisciplinary, Europe-wide study programme and (ii) organization of interdisciplinary study groups and promotion of staff mobility programmes, to support researchers who already straddle multiple academic disciplines. Both are associated with the development and publication of educational materials.

4. Creation of an interdisciplinary, Europe-wide virtual physiological human study programme

It has been clear from the outset that VPH training activities need to be placed firmly in the context of the highly dynamic setting of the Europe-wide effort to improve undergraduate and postgraduate education. One of the major targets of the Bologna process is to increase ‘the international competitiveness of the European system of higher education’, to ‘ensure that the European higher education system acquires a worldwide degree of attractiveness equal to [Europe’s] extraordinary cultural and scientific traditions’ (the Bologna declaration; http://ec.europa.eu/education/policies/educ/bologna/bologna.pdf).

VPH NoE training concepts are fully compatible with the expectations of the Bologna process, by challenging the traditional approach where the individual sciences are considered as fundamentally ‘vertical’ specialties. This is no longer sufficient and should be complemented by a strong component of ‘horizontal’ training, focused on developing multi-disciplinary skills. This has been highlighted
VPH training framework

expertly in a recent article from Nature careers, which links ‘career resilience’ to adaptability of researchers, combining expertise in one area with ‘a broad set of interdisciplinary skills that allow a scientist or engineer to solve problems in a wide range of applications’ (Fiske 2009).

Nonetheless, development of an optimized approach to training for the VPH initiative is a challenging task. As an emerging field within biomedical research and application, the VPH community is still relatively small, and the actual scope of specializations needed across the community, and within individual areas, is still being identified. Consequently, when devising a strategy for VPH training, an additional core aspect is the built-in flexibility of content and operation.

Consultation with education providers and potential employers has shown that there are differing, sometimes conflicting, interests and needs. While the current community is very research-oriented, future VPH-related activities will increasingly focus on application to industry and clinics. Therefore, the concept of a ‘VPH-aware’ education has been developed. This will focus on

— provision of a strong scientific grounding, covering concepts and approaches of traditional sciences, engineering and biomedicine,
— a high level of competence in technology and information handling,
— a multi-disciplinary ‘problem-orientated’ approach with strong emphasis on practical application of knowledge and skills, and
— development of an ability to communicate across subject boundaries, with a focus on the acquisition of common terminology to foster understanding.

Within the common European education context, different levels of training can be distinguished: undergraduate (Bachelors degree), graduate (Masters degree) and postgraduate (PhD and other forms of ‘life-long learning’). In the following section, we will highlight how these stages contribute to the development of a VPH-aware generation of researchers, ready to tackle the broad range of related challenges (figure 1).

(a) Levels of training 1: undergraduate

At the undergraduate level, training is intended to provide students with a basic background of the field and the necessary (academic) skills to function in a professional environment. It should also identify and instill strategies that enable students to remain knowledgeable and competitive throughout their careers via life-long learning initiatives. This is already in place for the traditional degrees offered in existing Bachelor curricula at European universities.

Throughout the VPH and biomedical engineering communities, there are several opinions on when training in multiple, traditionally distinct, disciplines should start. The combination of engineering/sciences and biomedicine provides a specific challenge. This has resulted in the different types of Bachelors degrees, where either a traditional track is followed, concentrating on the disciplinary basics and going into great depth, while others offer mixed degrees, trying to provide a flavour of the different disciplines without going into very much detail or tending towards detailed subspecialization (e.g. tissue engineering) early on.
Given the multitude of skills and the broad background needed for successful research and applications within the VPH-related communities, there is no clear preference for any of these approaches when selecting an undergraduate degree. The only prerequisite is that each individual programme provides sufficient depth in specific basics and provides students with the skills needed for interdisciplinary collaboration.

From this evaluation, it was concluded that the VPH community should not seek to provide ‘an ideal’ educational track for undergraduate studies, but rather should encourage variety in the different degrees already available, provided they offer a solid scientific background and prepare the student for interdisciplinary curiosity and collaboration. VPH education should provide contact between different disciplines, paving the way for collaborative work in solving complex biomedical problems.

(b) Levels of training 2: graduate

The graduate (Masters) level, where (sub-) specialization and preparation for specific academic professional skills take place, is a prime area where appropriate content should be identified and made available. A wealth of Masters degrees are offered already within member institutions of the VPH NoE, all relevant to specific areas within the community and with a focus on one or more of the different disciplines involved. Most of these degrees build on local expertise and (research or professional) needs, and are therefore relevant, focused and quality assured.

In order to consolidate, enrich and fine-tune the graduate-level education, the VPH community can take two different approaches

— provide a specific, well-defined suggestion for ‘the ideal curriculum’ and offer this formally either as a single degree or as a joint degree through multi-institutional certification or
— participate in promoting, enriching and improving existing degree courses, offering information on relevance, quality and complementarity of the programmes and helping students in choosing (inter-institutional) tracks that fit their personal interests.

The first of these two approaches is, of course, the more challenging. Development of an ‘ideal’ curriculum should be based on a consensus after wide consultation with experts in academia, industry and healthcare, and should include the input of education providers and aspiring students. There are strong arguments to suggest that it is impossible to cover the breadth of VPH activities in sufficient depth within a single Masters programme or, indeed at a single institution. Thus, the educational framework developed must address these concerns.

The bioengineering community is taking a first step towards a multi-institutional approach to course delivery with the common European Masters course in biomedical engineering (http://www.biomedicaltechnology.eu/). Funded under the EU Erasmus mundus programme (http://www.biomedicaltechnology.eu/images/erasmus_mundus_programme_guide.pdf), a consortium of six EU universities is pooling knowledge and expertise to provide a 2 year Masters programme. Foundation modules that are delivered in semesters 1 and 2 are comparable across all institutions. After completing these at their chosen institution, the student moves to a second partner institution to complete specialist modules in semester 3, before undertaking an individual Masters project in semester 4. The final award is a joint degree from the two institutions. The first students will enrol on this programme in September 2010, and the VPH will observe this development with great interest.

One exemplar of a formal graduate training scheme in a broadly similar area that has successfully addressed these issues, is the UK training scheme for clinical scientists in medical physics and clinical engineering (http://www.ipem.ac.uk/docimages/2440.pdf). This comprises an accredited Masters programme, followed by a period of ‘on the job’ training based on prescribed major subject areas and core competences. Quality and standards for the Masters are the responsibility of individual universities, but the appropriate coverage in terms of content and skills is controlled by a professional body, the Institute of physics and engineering in medicine (IPEM) (http://www.ipem.ac.uk/). Learning outcomes for any Masters programme must map onto the defined core competencies. An element of flexibility is allowed, in recognition that a Masters syllabus must be linked to the expertise and interests at the awarding institution. The IPEM ‘syllabus content guide’ lists essential obligatory components and a number of specialist options. Accreditation of courses is the responsibility of the education panel of the IPEM accreditation and teaching committee, with one overseas and 14 UK universities currently offering accredited Masters degrees. Such a system should not be seen as a barrier to multi-institutional degrees, as it gives confidence to both prospective students and employers that a course is suited to purpose.

While the NoE is providing the forum for consultation and facilitates collaboration between the education providers in the short term, a credible professional body or other sustainable organization will be required to ensure that any syllabus is kept up to date, and to fulfil the essential role of overseeing an accreditation process. This could be the role for a future VPH institute (http://www.
Actions are already underway, under the umbrella of the NoE, to facilitate inter-institutional module sharing and to provide mechanisms for student mobility. A review has been undertaken of existing programmes at participating institutions and VPH-relevant modules have been identified. A consortium of European universities is already working to develop formal student exchange agreements, including proposed funding applications to support the preparation of materials and resources for core VPH training modules.

(c) Levels of training 3: doctoral and beyond

Postgraduate education consists of two major components: doctoral training, leading to a PhD, and continuing professional development, which in the current context is taken to encompass all aspects of further and continuous training of researchers and professionals in the field, potentially leading to chartered status. The VPH community provides an optimal forum to share information on the various initiatives. The VPH NoE will centralize and provide means to disseminate this information. Besides information sharing, the VPH community supports specific initiatives with focus on relevant VPH applications or domains.

This collaborative environment gives access to new opportunities for doctoral studies, such as the possibility of joint supervision for PhD studies involving subject combinations that may not normally be found in a single research group or institution. Initiatives such as doctoral training centres (DTCs), which were pioneered in the UK by the Engineering and physical sciences research council with a focus on the life sciences interface (http://www.epsrc.ac.uk/PostgraduateTraining/Centres/LSI/default.htm), offer another excellent example of the type of programme that could be developed within the VPH. DTCs have strong support from the industry, bringing together students with either a physical science or a life science background and jointly provide them with cross-disciplinary training in biological, mathematical and computational techniques.

Within the European education context, several countries offer PhD degree programmes that include a taught element, for which credits are awarded. Such credits are, by definition, associated with highly specialized topics and are closely linked to technologies and research expertise within the awarding institution. Once again, there is a role for inter-institutional collaboration, based on student exchange, for the provision and delivery of these short courses.

5. Continued integrative training

All professionals face the challenge of ‘staying current’ once they leave the formal education process. The 2002 article ‘What industry needs from universities for engineering continuing education’ (Paton 2002) draws attention to the half-life of engineering and scientific knowledge, which is predicted to continue to fall, with estimates dropping from 3–5 years at the turn of the millenium to currently nearer 2 years. This situation is likely to be even more acute in the context of emerging technologies where frontiers of a discipline expand.
As the VPH initiative progresses, and as tools are developed and adopted by industry and healthcare, access to training beyond the doctorate level will become increasingly important. From an employer’s point of view, it may not be possible to find applicants with the necessary expertise without on-the-job training, as skills needed may not be widely available. In addition, researchers will need to be able to assimilate new technologies and to adapt them to comply with industrial codes and practices or the constraints of the clinical environment.

Novel methods of knowledge delivery and acquisition will be needed. One vehicle that has already been tried and tested within the context of the VPH, is the use of study groups. These are intensive, carefully orchestrated workshops that are held over a period of one week. While study groups can be specifically tailored to target outcomes, there are a number of common and essential aspects. They have an overarching theme that must be amenable to mathematical/computational modelling and analysis and focus on bringing a modelling approach to bear in a specific context, for example, that of a particular tissue, organ or disease, or the application of multi-scale modelling techniques to complex biological problems. Participants are selected from a cross section of different fields (for example, experimental biologists, clinical researchers and modellers, from academia and industry) with balanced representation from life and physical sciences. Study groups can be extremely effective instruments for promoting interaction and communication across the ‘discipline divide’. Typical outcomes include new theoretical models, which may result in journal publications, and the initiation of multi-disciplinary collaborations that can be taken forward into applications for funding (see ‘Biology meets mathematics’ on YouTube for an example; http://www.youtube.com/watch?v=PtLnvwH4kuE).

6. Challenges and outlook

(a) Training

Within the different levels of education and training, several aspects are crucial for quality and sustainability. These include

— engaging senior experts, research groups and their host institutions, related industry and the clinical end-users,
— developing an educational framework and financial model to facilitate student exchange,
— providing facilities and accreditation possibilities for life-long learning and continuing professional development (e.g. chartered status),
— keeping in mind the employability of the graduates in the labour market and, where appropriate, providing the required professional accreditation,
— designing and maintaining ways to emphasize or judge VPH appropriateness of the content of each course, and
— ensuring the interoperability of initiatives and courses by clearly defining and communicating the entrance levels and background required.
Training is an essential component of the VPH research dissemination process, as relying on traditional dissemination paths, such as journal publications and conference presentations, will only partially address user needs. Within the NoE, training initiatives in the form of workshops and study groups will be offered as part of the process to promote the sharing of VPH models and the VPH ToolKit.

(b) Careers

For VPH research and development to flourish, a critical mass of highly trained interdisciplinary researchers is required. Not all of these will find or want permanent academic posts. In order to allow significant uptake of research outputs, the VPH community must ensure that translational career paths to prepare researchers for careers in clinical/industrial areas are fostered and developed. This will be a key requirement for sustainability of both careers and VPH research. A qualitative and quantitative study of the current and future industrial and clinical needs in this research area is being undertaken to inform career structure and requirements for training. This involves consultation with industries (from pharmaceutical to medical-device design and manufacturing, research software and hardware development) and professional associations, with medical training institutions and health-care providers. Formalization of career structures and accreditation processes will provide benchmarks against which education providers, prospective students and employers can judge quality of training, suitability of learning outcomes and levels of competency.

For prospective academics, the VPH research is seen to be exciting and challenging, but the primary disincentive to establishing a career in this complex and inherently multi-disciplinary field is the perception that it is more difficult to obtain academic recognition in this type of research environment. Current performance metrics are more suited to producing rankings within traditional ‘narrow’ specialities. Here, the VPH community has a role in lobbying for a more equitable system, offering alternative solutions to academic career assessment.

7. Conclusions

The VPH NoE has a strategic role in developing the VPH training landscape, establishing a VPH community and brokering training collaboration between academic institutions and end users. It provides a forum for information gathering and strategic planning. Education is not only the most powerful tool to spread the VPH message, it is absolutely essential to the future success of the VPH mission. The NoE is well positioned to help develop a series of courses/modules/programmes that will carry on the VPH initiative.

This work is partially funded by the European community’s 7th framework programme (VPH NoE, grant agreement no. 223920, and preDiCT, grant agreement no. 224381).

References

Academy of Medical Sciences and the Royal Academy of Engineering. 2007 Systems biology: a vision for engineering and medicine.

Phil. Trans. R. Soc. A (2010)
VPH training framework


CORRECTION

Phil. Trans. R. Soc. A 368, 2841–2851 (28 June 2010)
(doi:10.1098/rsta.2010.0082)

Virtual physiological human: training challenges

BY PATRICIA V. LAWFORD, ANDREW V. NARRACOTT, KEITH MCCORMACK, JESUS BISBAL, CARLOS MARTIN, BINDI BROOK, MARGARITA ZACHARIOU, PETER KOHL, KATHERINE FLETCHER AND VANESSA DIAZ-ZUCCARINI

In the author list of Lawford et al. (2010), Jordi Villà I Freixa and Bart Bijnens were erroneously omitted.

The corrected author list is: Patricia V. Lawford1,∗, Andrew V. Narracott1, Keith McCormack1, Jesus Bisbal2, Carlos Martin2, Bart Bijnens3, Bindi Brook4, Margarita Zachariou4, Jordi Villà I Freixa5, Peter Kohl6, Katherine Fletcher6 and Vanessa Diaz-Zuccarini7.

1Medical Physics Group, Cardiovascular Science, University of Sheffield, Sheffield, UK
2Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain
3Institució Catalana de Recerca i Estudis Avançats, Universitat Pompeu Fabra, Barcelona, Spain
4School of Mathematical Sciences, University of Nottingham, Nottingham, UK
5Computational Biochemistry and Biophysics lab Research Group on Biomedical Informatics—Hospital del Mar Research Institute/Universitat Pompeu Fabra, Barcelona, Spain
6Department of Physiology, Anatomy and Genetics, University of Oxford, Oxford, UK
7Mechanical Engineering, University College London, London, UK