Summary

The Virtual Physiological Human (VPH) encompasses a wide range of activities including; biomedical modeling, simulation and visualization, imaging, data mining, knowledge discovery tools and databases. The VPH research environment is developing from a relatively small, focused research community to one able to develop and translate the emerging technology to industry and the clinic. This process of evolution and potential expansion will require a highly-trained multidisciplinary workforce and strategies for training existing researchers in the use of emerging tools and technologies. The EU FP7 VPH Network of Excellence is providing a framework for the development of training initiatives. This paper reports the first steps in the implementation of a coherent VPH training portfolio.

Keywords; Virtual Physiological Human, Network of Excellence, training, multi-disciplinary

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’ (1). The VPH encompasses, biomedical modeling of all levels of complexity, simulation and visualization, imaging, data mining, knowledge discovery tools and databases (2), (3). Researchers have wide range of backgrounds. The majority come from the physical sciences, from engineering and from computer science with a small number coming from life science or medicine. The aims of researchers developing computational tools, infrastructure and models that form the fundamental components of the VPH are not solely those of academic enquiry. The future of the VPH lies in the use of computer simulation and modelling for the development of predictive tools and personalised healthcare, leading to better treatment outcomes and improvements in patient safety.

The VPH is a relatively new and highly multi-disciplinary initiative, gathering together expertise from a large number of different specialties. Based on the concepts of the IUPS Physiome (4), the VPH has its origin as recently as 2005, when an expert
workshop based on the Physiome\textsuperscript{1} was held as part of a conference, ‘Functional Imaging and Modelling of the Heart’, held in Barcelona. This resulted in the production of a of ‘White Paper’ that summarised the current status of Physiome activities, outlined a consensus on possible ways to progress Physiome research, driven by new, and complimentary, research initiatives within the EU, and identified mid- and long-term research goals. In parallel with this, the European Commission funded a coordination action ‘STEP’: a Strategy for the Europhysiome (5) to provide a roadmap to direct the coordination of a European initiative toward the development of the Virtual Physiological Human. The Europhysiome roadmap document, published in 2007 (1), was written by a consortium formed from the nine academic partner organisations within STEP through a consensus process involving over 300 contributing stakeholders from academia, industry and healthcare.

The Importance of Training to Success and Sustainability of the VPH

One of the issues highlighted by the STEP Roadmap was the importance of training, with the availability of specialist personnel with skills relevant to the VPH identified as an essential requirement. There was a particular focus on the need for integration of skills across different disciplines and for a training framework to foster the education of multidisciplinary scientists and specialists. Mobility of researchers is seen as a solution to facilitate the transfer of expertise between different research groups and a role was identified for multidisciplinary clinicians to facilitate the process of transferring VPH technology to the clinic.

The potential of the VPH has been recognized by the European Commission through the Research Framework Programme. ‘Predictive Medicine – Virtual Physiological Human’ one of the research priorities areas within the Information and Communication Technologies (ICT) work programme for Framework 7. A sum of € 72M was awarded to VPH projects in 2007, € 5 M in 2009, with a further € 63 M to be awarded in 2010. The main focus of this initiative is the development of new computational models and/or data processing techniques appropriate for clinical application. Access to suitably trained personnel and the ability of current VPH researchers to learn new skills and adopt the emerging technology will be essential to the success of these projects. In addition, a focus on clinical application increases the need for input from clinicians with an understanding of the VPH environment.

The European Research Landscape

The development of the VPH is set against the current EU research landscape. A number of visionary discussion papers and reports, emerging from both National (6),(7)
and European (8) (9) consultation activities and published within the last six years, collectively identify a developing issue; the threat to research, industry, and implementation of new technology by an inadequate supply of trained scientists, engineers and technologists within the European Community. This comes at a time when statistics for Higher Education in a number of larger EU States show changes in the student recruitment profile with a decline in the number undertaking traditional scientific subjects including mathematics, physics and chemistry and fluctuations in recruitment to engineering balanced by an increasing interest in the life sciences and computing. (9). Further compounding this situation is a declaration made at the EU summit in Lisbon in March 2000 setting ‘…a new strategic goal for the next decade: to become the most competitive and dynamic knowledge-based economy in the world…’ (10).

In a move towards achieving this, at the Barcelona summit in 2002, European heads of state called for an increase in the proportion of European GDP invested in research from 1.9 - 3.00% by 2010. In order to encourage investment in R&D by the private sector tax incentives were proposed (11). The level of new researchers associated with this level of increase is calculated to be 0.5 million; a total of 1.2 million if research-related personnel are taken into account. Whilst, at current growth rates, it is estimated that it will be many more years before the 3.00% target can be met (11), the decrease in numbers of physical scientists currently in training may prove to be a further pressure limiting this growth.

Whilst the full impact of the current economic recession on the scientific community is, as yet unclear, any effects on the employment market are likely to be temporary. The VPH must plan for the long-term and the possibility that the future expansion and translation of the VPH will have to take place in an environment with a shortage of scientists and technologists; an aggressively competitive employment market is a real possibility.

A 2007 report (8) on the identification of skill needs in the high income countries who are members of the Organisation for Economic Co-operation and Development warns that... "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."

The VPH community must be prepared for this by developing strategies for the recruitment, training and retention of highly skilled researchers.
The VPH Network of Excellence

A significant outcome of the first VPH Call in FP7 was the funding of a Network of Excellence – ‘the VPH NoE’ (12). This 54 month project started in June 2009 and has 13 academic partners from leading academic institutions across Europe. A major part of the NoE remit is to foster involvement across the VPH community and groups outside the core are encouraged to participate and become associate partners. There currently over 30 associate member organisations participating in NoE activities. Mindful of the importance of translation activities, the NoE is supported by Clinical and Industrial Advisory Boards comprising representatives from the major target end-users of the VPH. A Scientific Advisory Board includes key players from the wider international Physiome community.

Building on the community identified and the foundation provided by the ‘STEP' initiative, the role of the network is based firmly on community building. Service to the community of VPH researchers is its primary purpose. The aims of the NoE range from the development of a VPH ToolKit and associated infrastructural resources, through integration of models and data across the various relevant levels of physiological structure and functional organisation, to VPH community building and support. This includes fostering the development of new and sustainable educational, training and career structures for those involved in VPH related science, technology and medicine. Workpackage 4 of the NoE is dedicated to ‘Training and Integration Activities’

‘Training and Integration Activities’

Workpackage 4 is tasked with two major activities, or ‘Themes’;

Theme 1 is directed towards the creation of an interdisciplinary, European-wide study programme. A number of fact-finding activities have been instigated to enable the current training landscape within the VPH community to be defined. The scope of the existing training provision has been explored, and the expected long-term impact of an interdisciplinary training programme on policies, requirements and programmes within academic institutions is being evaluated.

An understanding of the needs of industrial and clinical stakeholders is essential to this process. Assessment is being carried out by means of surveys and questionnaires. The collated information will form the basis of policy documents on both "Industrial and Clinical Careers and VPH" and "Academic Careers and VPH" to be published towards the end of the project.
**Theme 2** is concerned with the organisation of interdisciplinary Study Groups and investigating staff mobility programs to support researchers who already straddle multiple academic disciplines and the publication of educational materials.

**Theme 1: Academic Policy and Integrated Studies**

The possibilities afforded by the NoE in support of VPH training are far reaching; providing a central focus for this rapidly developing area, and insuring that the needs of the VPH community are identified. One of the strengths of the NoE is that it provides an excellent forum for information gathering and formal consultation. One of the major challenges to be addressed by training providers in any subject area is how to obtain the essential background ‘market research’ required to establish the nature of the existing training landscape and to plan a business case for training delivery. A successful training course is correctly targeted, sustainable in terms of both student numbers and its value to employers, and cost effective. A number of key questions must be answered; what training is already available? is it delivered at the correct level and in the correct way (Undergraduate, Masters or Doctoral levels, fulltime study or short training courses) does it address the needs of students and employers? what are the gaps in educational provision? what is the likely demand for training, both now and in future years? what career paths are available? and, what are the employment prospects for successful students on completion of their training? For many traditional career paths, this information is gathered and collated by professional bodies. In the absence of such organisations this data is difficult and time-consuming to obtain.

Activities during the first year of the project have focused on the production of key strategy documents to underpin future effort. These include; reports on the academic policy and integrative studies strategy, a strategy for co-operation with clinical and industrial stakeholders and for the promotion of mobility and a plan for a (Masters level) early career pilot course.

The report on the academic policy and integrative studies strategy examines the changing environment within medicine, and develops strategies for the phased introduction of educational systems matched to meet these needs. It does this by examining the current educational position within Europe, describing the available mechanisms that allow cooperative innovations to be introduced, and proposing an optimised set of strategies that build on existing strengths to meet the identified challenges by harnessing opportunities for interaction and change. It also identifies challenges that, in order to be addressed fully, may require policy decisions by the Commission or initiatives to be implemented at the level of the individual member states. Finally, it explores the practical steps that could be taken within the lifetime of the NoE to begin a process of educational development that will ensure that medicine and industry throughout Europe are appropriately equipped to meet the future demands of this new and important discipline. The document recognises that, as VPH technology progresses to maturity, there will be an increasing focus on translational activities, and
this may lead to a requirement for a more structured approach to training and a formalisation of the skills base. Key elements of the report are summarised below and the full report is accessible via a link on the VPH NoE website (13).

The formalisation of the Virtual Physiological Human (VPH) community that will emerge from the Network of Excellence will provide a foundation for the development of cross-disciplinary training and, offers exciting opportunities to establish initiatives jointly between Institutions across the European Union. The strengths, opportunities and challenges associated with the current VPH Training Landscape are summarised in figure 1 and further breakdown of the key conclusions is given in Table 1.

*Figure 1 here.*
<table>
<thead>
<tr>
<th>TOPIC</th>
<th>STRENGTHS</th>
<th>OPPORTUNITIES</th>
<th>CHALLENGES</th>
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<tbody>
<tr>
<td>Expertise</td>
<td>Excellent potential for 'Research-led' teaching; access to World Leading</td>
<td>Pooling of expertise/ resources</td>
<td>• Current training fragmented; wide range of courses offered in bioengineering, modellling etc but no common database.</td>
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<td>expertise - many pre-existing research collaborations</td>
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<td>Integration</td>
<td>NoE funding will provide the foundation for the future development of an</td>
<td>Bologna Agreement addresses pan –EU training issues</td>
<td>• Cross-disciplinary training takes effort: VPH is not a single speciality, how to address the many different strands?</td>
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<td>integrated VPH training strategy and raises the profile of VPH training</td>
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<tr>
<td>Collaboration</td>
<td>The NoE provides a structure for building teaching collaborations, provides a forum for discussion and opens up new opportunities.</td>
<td>Strong support available for Mobility of Researchers within the EU</td>
<td>• Increased effort associated with 'Distance Learning' options- alternatively mobility costs must be met.</td>
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<td></td>
<td></td>
<td></td>
<td>• Multi-centre training is intrinsically challenging to set up and administer</td>
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<td>Institutions</td>
<td>The VPH provides a powerful focus for ‘buy in’ at an Institutional level to</td>
<td>Rapid development of ICT -emerging support for new technologies for remote delivery of training.</td>
<td>• Inter-institutional differences (QA, regulations, fee structure, timetabling etc) must be identified and addressed for joint programmes</td>
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<tr>
<td></td>
<td>joint training initiatives</td>
<td></td>
<td>• Need to ensure Institutional ‘buy in’, allay concerns re ‘dilution’ of Institutional ‘brand’ but avoid oversell</td>
</tr>
<tr>
<td>Branding</td>
<td>Courses approved under the VPH banner carry the status and potential of</td>
<td>Increasing acceptance of Distance Learning</td>
<td>• Ensuring sustainability: no formal career structure, potential for mismatch between academic priorities and industrial/clinical needs.</td>
</tr>
<tr>
<td></td>
<td>the VPH ‘Brand’.</td>
<td></td>
<td></td>
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<tr>
<td>Funding</td>
<td>Clear ‘reward’ in terms of increased profile and increased access to new</td>
<td>Support for Programme Development from ‘Life Long Learning’ calls</td>
<td>• Encouraging engagement from funding bodies in Member States for matched funding and support of local students</td>
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<tr>
<td></td>
<td>funding streams and initiatives</td>
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<tr>
<td>World of Work</td>
<td>Strong links with Industrial, Healthcare and Clinical stakeholders</td>
<td>Potential for development of pan-European programme addressing industrial, clinical and academic needs</td>
<td>• Lack of data on background/needs of current researchers and current/projected skill shortages as VPH community expands</td>
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**Table 1:** Summary of the Landscape in which the VPH Training Initiative is developing
It is clear that there are major strengths afforded by the NoE and significant opportunities for education providers. Not unexpectedly, there are also some challenges which must be addressed.

The NoE presents an opportunity for the development of a world-leading training environment. With 13 core members and over 30 associated and general members, encompassing a wide range of experts from; clinicians to modellers, from biologists to mathematicians and physicists, theoreticians and experimentalists, including industrial and academic partners, the VPH NoE offers an incredible opportunity to translate world-class research into training efforts and common educational programmes.

In addition, the EU is increasingly regarded as a world-class educational environment. By this year - 2010 - the European Higher Education Area (EHEA) is expected to encompass 16 million students and 4,000 universities. This huge education market enters into direct competition with those in the US and Asia. European Universities are seeking to position themselves as a “student destination” with added value achieved through mobility, and the possibility for students to undertake part of their Education in several Universities committed to the Bologna process. In this respect, the VPH NoE is in a unique position to offer world-class training through world-class expertise.

One of the major issues highlighted in the Bologna process is to increase “the international competitiveness of the European system of higher education”. The signatory countries explicitly express their goal to “ensure that the European higher education system acquires a worldwide degree of attractiveness equal to [Europe’s] extraordinary cultural and scientific traditions” (14). In this respect, the VPH NoE training converges fully with the expectations of the Bologna process by challenging the traditional training approach, where science is considered as fundamentally “vertical” specialties. This is no longer appropriate, for a new generation of researchers who must be able to succeed in a competitive and integrative environment. As a result, “horizontal science” training, focussing on multidisciplinary skills and research effort whilst retaining excellence in delivery, should be our goal. The ultimate aim of the VPH NoE training is to form well-rounded individuals, unlocking their potential and providing them with the skills necessary to succeed in an extremely changing area. To achieve this, the training must complement the existing background of each researcher in order to produce researchers capable of approaching a wide range of applications.

The potential instability of scientific careers and the need for scientists to move away from the traditional approach to careers and training is addressed in a recent article from Nature Careers (15). Introducing the concept of ‘career resilience’, the author predicts a future where the concept of specialisation, with scientists concentrating on developing a deep level of expertise in a single area, is not sustainable. To ensure employability, the future scientist will need to be adaptable, capping depth in one area
with ‘a broad set of interdisciplinary skills that allow scientist or engineer to solve problems in a wide range of applications’. - An obvious fit with our vision for the VPH researcher!

**Joint degrees**, supported by two separate Institutions, combining expertise in different areas in a single degree programme, provide a solution in terms of ‘horizontal science’. However, joint programmes been identified as potentially problematic (15). Besides the obvious practical obstacles and concerns about ensuring consistent quality of teaching, assessment and the outcomes of such degrees, Institutions are wary of the “dilution” of their brands. The focus could fall on the drawbacks of these joint efforts instead of the opportunities. The VPH NoE provides a framework to develop such programmes; VPH related institutions are committed to the success of the VPH NoE.

For the VPH, wider consultation on the development of European-scale training is of paramount importance. Ultimately, new or updated academic curricula may be required, encompassing emerging VPH technologies and conveying the VPH ethos and goals. Currently few European training programmes can embrace the necessary innovation and structure; such a programme must be as unique, innovative, international, multidisciplinary and as excellent as the VPH itself. The 'Lifelong Learning" programmes from the EC, could provide a suitable funding vehicle for such training.

New training initiatives, however necessary and exciting, inevitably face challenges which must be overcome if they are to flourish. Because it is such a complex venture, the VPH initiative inevitably attracts a larger proportion of challenges than a more straightforward evolution of technology. The breadth and depth of changes required will impact on the entire education delivery process; whilst changes to curricula might be expected to affect planning, administration and financial management, the requirement here is for a degree of collaboration between departments and across international institutions that has not been attempted previously.

Table 2 describes the key issues affecting the VPH training initiative, these indicate the need for a most careful introduction across the institutions that are candidates for VPH pilot activities.
<table>
<thead>
<tr>
<th>Challenge</th>
<th>NoE Action</th>
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<tbody>
<tr>
<td>Current training fragmented; wide range of courses offered in bioengineering, modelling etc but no common database.</td>
<td>A survey of current provision within the EU is underway. A pilot has been completed. A web-based database is proposed.</td>
</tr>
<tr>
<td>Cross-disciplinary training takes effort: VPH is not a single speciality, how to address the many different strands?</td>
<td>Virtual Academy will provide a forum for consultation and identification of training needs (see below).</td>
</tr>
<tr>
<td>Increased effort associated with ‘Distance Learning’ options- alternatively mobility costs must be met.</td>
<td>Current Erasmus programmes support the development of ‘Distance Learning’ infrastructure and mobility of staff and students.</td>
</tr>
<tr>
<td>Multi-centre training is intrinsically challenging to set up and administer</td>
<td>The NoE provides infrastructure to foster a collaborative training environment.</td>
</tr>
<tr>
<td>Inter-institutional differences (QA, regulations, fee structure, timetabling etc) must be identified and addressed for joint programmes</td>
<td>Bologna Agreement forms a basis for standardisation of some aspects. The Erasmus University Charter provides an exemplar of success in building Inter-university Programmes.</td>
</tr>
<tr>
<td>Need to ensure Institutional ‘buy in’, allay concerns re ‘dilution’ of Institutional ‘brand’ but avoid oversell</td>
<td>Institutions that are members of the VPH NoE have demonstrated their commitment. The proposed survey of clinical and industrial needs will identify skills shortages and training requirements.</td>
</tr>
<tr>
<td>Ensuring sustainability: no formal career structure, potential for mismatch between academic priorities and industrial/clinical needs.</td>
<td>The NoE will plan for sustainability of training; development of career structures will be prioritised. This will also impact on possible academic/industrial mismatches. The NoE will provide a consultation forum for these groups.</td>
</tr>
<tr>
<td>Encouraging engagement from funding bodies in Member States for matched funding and support of local students</td>
<td>Members of the NoE will seek to engage funding bodies based on the survey of the current funding environment.</td>
</tr>
<tr>
<td>Lack of data on background/needs of current researchers and current/projected skill shortages as VPH community expands</td>
<td>A pilot study reviewing the background and needs of existing researchers has been completed for 100 researchers at 5 institutions. This will be rolled out across the VPH community. The Virtual Academy will facilitate continuous update of this data.</td>
</tr>
</tbody>
</table>

Table 2: Summary of the Challenge context and associated NoE actions
Strategy for Training within the VPH

As we have seen, providing an optimised approach to training for the VPH initiative is a challenging task. As an emerging group within biomedical research and application, the VPH community is still relatively small, but is intrinsically characterised by its multidisciplinary nature and inter-institutional collaboration. Whereas many fields of research and industrial activity - and their associated training - are well defined and often self-contained, there is no such neat delineation of what exactly is required for well-matched functionality within the VPH community. Consequently, when devising a strategy for VPH training, the additional core aspects of flexibility and multidisciplinary operation must be taken into account, whilst preserving intrinsic quality and encouraging diversity.

Figure 3 provides a model illustrating the different levels of training that are relevant for higher education, life-long learning and careers within the VPH. Within the current common European education context, different levels of training can be distinguished. These are the undergraduate (Bachelor degree) and graduate (Masters Degree), and the post-graduate phase, which includes doctoral level and extended, indeed life-long, work-related education and knowledge maintenance.

Two-way arrows within this model indicate the flexibility of movement which is necessary for sustainable, resilient VPH careers. Consultation with employers shows that there is an intersection of differing requirements within the VPH community, with disparate and sometimes conflicting interests and needs. Whilst the current community is very research-oriented, VPH related approaches and technologies can ultimately only be successful if they are adopted by industry and can be exploited within the clinical environment. Ideally, therefore, the VPH initiative should facilitate mobility between these different areas of activity in the different sectors, and allow for and indeed encourage, a constant flow of ideas and technologies.

For each of the training levels, appropriate VPH-related components must be defined:

- Relevant training materials and courses must be available
- Students must be made aware that the disparate VPH environment will require them to make choices amongst the many possible training and career paths.
Defining a VPH Career and Training Track

As will be evident from earlier sections, a VPH career and training track needs to address a wide variety of complementary, potentially conflicting, requirements for skills development. Yet at the same time it must meet the needs of the employment market, covering the three principal aspects of the academic, industrial and clinical environments. Therefore, a VPH track needs to provide and maintain:

- A strong scientific background, covering traditional sciences, engineering and biomedical sciences.
- A high level of specialisation in technological approaches and information handling.
- An intrinsic multidisciplinary approach with a strong integrative nature.
- Skills of interdisciplinary communication with a common language and understanding.

The VPH community sits at the intersection of several traditional disciplines and areas of expertise, each of which requires a significant depth of knowledge and understanding. These include those tabulated below:

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Specific Expertise</th>
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<tbody>
<tr>
<td>Engineering</td>
<td>Biomedical</td>
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<tr>
<td></td>
<td>Computer sciences</td>
</tr>
<tr>
<td></td>
<td>Electronics</td>
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<tr>
<td></td>
<td>(Bio) Mechanics</td>
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<tr>
<td></td>
<td>Material sciences</td>
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<tr>
<td>Physical Science</td>
<td>Mathematics</td>
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<td></td>
<td>Physics</td>
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<td></td>
<td>Chemistry</td>
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<tr>
<td>Biomedical Sciences</td>
<td>Biochemistry</td>
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<td></td>
<td>Medicine</td>
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<tr>
<td></td>
<td>Biomedical Science</td>
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<td></td>
<td>Biology</td>
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</table>
It is clear that it will be impossible to concentrate all of these skills comprehensively in any single individual; consequently VPH-related activities will intrinsically be performed in a multidisciplinary environment, where strong communications using a common vocabulary and intersecting skills will link sub-specialised individuals from different backgrounds. Translating this into a training path emphasises how there can be no single route to suit all individuals, and the differing potential approaches, are an essential part of the training landscape.

**Levels of Training 1: Undergraduate**

At 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 instantiate strategies that enable them to remain knowledgeable and competitive throughout their careers through lifelong learning initiatives. This is already in place for the traditional degrees being offered in existing Bachelor curricula at European Universities.

Throughout the VPH and Biomedical Engineering community, there are several opinions on when training in multiple, traditionally non-related, disciplines should start. The combination of engineering/sciences and biomedicine provides a specific challenge. This has resulted in the different types of Bachelor 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 detail, or tending towards detailed subspecialisation (e.g. tissue engineering) early on.

Given the multitude of skills and background needed for successful research and applications within the VPH related communities, there is no clear preference for either one of these approaches when selecting an undergraduate degree. The only prerequisite is that each individual programme must provide sufficient depth in specific basics and prepares students with the skills needed for interdisciplinary collaboration.

From this evaluation it was concluded that the VPH community should not take a coordinated initiative to provide the ‘ideal’ educational track for undergraduate education, but rather should encourage the involvement and variety of the different degrees offered, as long as they provide a solid scientific background and prepare the student for interdisciplinary curiosity and collaboration. The idea is to provide contact between different disciplines, paving the way for collaborative work in solving complex biomedical problems.
Levels of Training 2: Graduate

The graduate, or Masters, level within the higher education, is where (sub) specialisation and preparation for specific academic professional skills is taking place. Therefore, this is the level where potential members of the VPH community can refine their knowledge and skills. This implies that the appropriate content should be identified and made available. There is a wealth of Master degrees 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 both relevant and quality assured.

To consolidate, enrich and fine-tune the graduate level education, the VPH community can take two different approaches:

- Provide a specific, well defined, suggestion on the ideal curriculum to be provided for future collaborators and potentially offering this formally either as a single degree or as a joint degree through multi-institutional certification.

- Participate in promoting, enriching and improving the existing degrees, offering information on relevance, quality and complementarity of the programmes and helping students in choosing (inter-institutional) tracks that fit their personal interests. This can include providing the framework for multi institutional exchange.

At graduate level, the VPH community could either provide an ideal curriculum (or several, curricula with a focus on the different disciplines involved) and organise its (multi-institutional) implementation, and/or participate in the existing wealth of degrees at the different VPH related partners by providing relevant information on the specific curricula and their complementarity and by promoting student exchange.

Levels of Training 3: Doctoral and Beyond

Postgraduate education consists of two major components, doctoral training, leading to the degree of PhD degree 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. The VPH community provides an optimal forum to share information on the various initiatives that are taken with regard to professional education and knowledge sharing. The VPH NoE will centralise and provide forums to disseminate this information. Beside information sharing, the VPH community can and will stimulate and organise specific initiatives, directly focussed towards some relevant VPH application or domain.

The Study Group (and described below) provide examples of this type of initiative, intended to provide opportunities for inter-disciplinary exchange of knowledge, technologies and ideas. This approach will, besides providing detailed information on specific initiatives, also offer an
opportunity for institutions, companies, organisations or individual (research) groups to profile themselves within the field and (co-) organise related educational or training opportunities

With regard to the doctoral training, within the European Education context, there is a tendency in several countries involved to link the PhD degree with formal training, where appropriate course credits have to be collected. Since these types of credits are, by definition, highly specialised and closely linked to available technologies and research expertise within institutions, providing the opportunity for students (from other institutions) to participate in these initiatives they could support the core ideas and competences of the VPH community. Therefore, similar to graduate level, the VPH community could take an active role in providing the relevant information on available initiatives, and, where appropriate, stimulate or (co-organise) specific training events and promote mobility and exchange programmes for students.

In was concluded that a similar approach to that proposed for graduate training should be promoted at the doctoral level. At the post-graduate level, the VPH community should actively support dissemination on existing VPH related training initiatives and should participate in the organisation of interdisciplinary and inter-institutional (including industrial and clinical partners') training events.

The phases of training and the integration of VPH activities within a potential VPH training scheme is shown in Figure 4.

*Figure 4 here.*

Within the different levels of education and training, several aspects have to be considered to ensure quality and sustainability of the initiatives. These include:

- Engaging senior experts, research groups and their host institutions, related industry and the clinical end-users.
- Providing facilities and accreditation possibilities for life-long learning and updating
- Focussing on a student centred approach,
- Keeping in mind the employability of the students in the labour market and, where appropriate, providing the required professional accreditation.
- Designing and maintaining ways to emphasise or judge VPH appropriateness in terms of the content of each course.
- Ensuring the interoperability of initiatives and courses by clearly defining/communicating the entrance levels and background required.
**Industrial and Clinical Needs Assessment (Careers)**

For interdisciplinary research to flourish within the VPH research community and beyond, a critical mass of highly trained researchers is required, not all of these will find or want permanent academic posts. In keeping with the need to have significant uptake of VPH research outputs supported by this FP7 objective (by industry/medical professions), we must ensure that translational career paths (those that are designed to prepare researchers to pursue careers outside of academia, in clinical/industrial areas) are fostered and developed: this will reinforce sustainability of both careers and VPH research output.

In keeping with the need for the VPH NoE to assess the clinical and industrial career potential for trained VPH researchers, therefore, 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 industry (from pharmaceuticals, to medical device design and manufacturing, to research software and hardware development), with professional associations, with medical training institutions and with health care providers.

**Theme 2: Tools and Materials for Integrative Training**

The main effort within theme 2 has been devoted to the organisation of the **VPH NoE Study Groups**. Study Groups are workshops which promote interaction between modellers and academic and industrial experimentalists working within medicine or the life sciences. Researchers from experimental and industrial laboratories are invited to present technical problems for study within working sessions with leading modellers from the academic community. The focus might be a general biological topic such as, a particular tissue, organ or disease, a modelling approach; the application of multi-scale modelling techniques to complex biological problems or some other over-arching theme. Whilst problems may be derived from a variety of subject areas, they must be amenable to mathematical/computational modelling and analysis.

Study Groups are held over a period of a week. A group of four to six different problems are presented on the first day and teams, comprising theoretical modellers and experimentalists, devote the rest of the week tackling a particular problem. A week of brainstorming and mathematical/computational modelling gives sufficient time to generate and assess many different approaches to solving the problem and also enables some of the ideas to be checked in more detail. Typical outcomes include new theoretical models, which may result in journal publications, and the initiation of multidisciplinary collaborations that can be taken forward into applications for funding.
The first VPH Study Group was held in June 2009 at the University of Nottingham. The subject for the prospective study group was regenerative medicine with a focus on epithelial cells across different organs (e.g. skin, bladder, gut, lungs, heart, breast etc). An interesting aspect of epithelial cells is the different properties they exhibit depending on their environment. Thus a novel additional feature of this study group was to promote discussion across the problems to explore the commonalities and differences of epithelial cells across the body.

We invited a number of academic and industrial researchers with interest in epithelial cells and regenerative medicine to participate by proposing a biological problem within this subject area. All the problems submitted were interesting, well–posed, amenable to mathematical modelling and within the remit of this Study Group’s focus. The final list selection was agreed by the VPH NoE Steering Committee.

Four problems were selected for study;

**Problem 1:** *Alveolar Epithelial Cell Injury and Repair in Fibrotic Lung Disease*

**Problem 2:** *Modelling doming in epithelial cells: physical properties of epithelial cells that permit doming and differences in cells in domes compared to non-doming neighbours.*

**Problem 3:** *Quantifying radiation-mediated damage to the gastrointestinal epithelium: Applications to cancer radiotherapy.*

**Problem 4:** *Tensegrity as a main determinant of tissue morphogenesis*

The participants were asked to complete an evaluation questionnaire. 29 out of 41 took part in the evaluation.

When asked the main reason for attending the Study Group, the majority of participants reported that they were interested in the content (44%) followed by personal growth and development (41%) and networking (15%). With regards to the question “How well do you feel your team progressed in addressing the problem of choice?”, most of the participants (56%) responded “as expected” and “better than expected”(41%). 3% responded that the progress of the was worse team than expected and (94%) of participants reported that they would be interested in a follow up meeting, with their team, to discuss the problem further. We were also interested to obtain the participants’ opinion on which discipline benefited the most; life sciences, physical sciences or both. Interestingly, all the participants with a life science background considered the benefit to be equal for both disciplines. For participants with a physical science background, most agreed that both disciplines benefited (15) followed by those who believed that either life sciences (4) or physical sciences benefited most (3).
As part of the event’s evaluation, the participants were requested to specify which aspect of the event considered being the most valuable. Selected comments can be found in Table 2.

Table 1 Selected quotes from participants from life sciences and physical sciences regarding the most valuable aspect of the event.

<table>
<thead>
<tr>
<th>Life Sciences</th>
<th>Physical Sciences</th>
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<tbody>
<tr>
<td>“The meeting provided an opportunity to initiate an application of mathematical modelling to a disease state.”</td>
<td>“Exposure in new areas in biology and continuum mechanics and better understanding the way life scientists think.”</td>
</tr>
<tr>
<td>“To participate in the construction of a mathematical model of biological process.”</td>
<td>“Opportunity to see how researchers from other disciplines approach problems in related areas, approach to future training.”</td>
</tr>
<tr>
<td>“Exposure to “novel” and “unexplored” approaches to solve biological problems.”</td>
<td>“Time to think about modelling problems.”</td>
</tr>
<tr>
<td>“Learning how smart mathematicians are and how fast they can work.”</td>
<td>“Interaction with experimentalists.”</td>
</tr>
</tbody>
</table>

As part of the event’s evaluation, the participants were requested to specify which aspect of the event they would like to improve. The physical scientists had no particular suggestions. However, the life scientists had a few concerns and ideas for enhancing communication between the two disciplines. Selected comments from the Life Scientists can be found below:

“Absence of proper understanding between bioscientists and mathematicians.”

“We should have more discussions about the biological assumptions related to the mathematical model”
“It would help if the groups have a preliminary meeting where reliable premises on which the models are based be deeply discussed. This would prevent misleading conclusions”

Overall the participants were positive about their experience. Importantly, the promising results which were presented at the end of the meeting and the informal agreements formed to pursue further collaboration in terms of either paper submissions and/or grant applications are indicators of how fruitful this interdisciplinary event has been. Significant outcomes of the Study Group which lead to publications will also have the opportunity to be published in the VPH related special issue of Philosophical Transactions of the Royal Society A.

Two further study groups are proposed within the term of the NoE and will be publicised on the VPH NoE website (12).

The Next Stage

Current effort is directed to extending current Erasmus Agreements between two VPH NoE participant institutions to facilitate student exchange a post-graduate level. This will form the basis of the VPH Training Pilot. A funding application is being prepared for submissions to the EU Life-Long Learning Programme which, if successful will support the development of a prototype VPH training module. This would represent a first step towards the construction of a VPH MSc under the umbrella of the Erasmus Mundus Programme.

During the next year there will be an increasing focus on VPH models and the VPH toolkit and their use in training activities and the second Study Group, with a focus on Multiscale Modelling with be held in Barcelona.

Conclusions

The VPH NoE has a strategic role in the development of VPH training, in establishing a VPH Training Community and in brokering training collaboration between academic Institutions. It also provides an invaluable forum for information gathering and strategic planning.

Education is not only the most powerful tool there is to spread the VPH message; it is absolutely essential to the future success of the VPH. The VPH NoE is well positioned to develop a series of courses/modules/programmes that will carry on the VPH initiative. Training opportunities can also be expected to develop from new research collaborations forged by means of the VPH NoE Exemplar projects. Use of the VPH toolkit, will also provide a means to more integrative research and exciting training opportunities.
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7. **Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine**. *Facilitating Interdisciplinary Research*.


Figure 1. Strengths, opportunities and challenges identified within the current VPH Training Landscape.
Diagram 2: The VPH NoE effort on training will be based on the common objectives set up by the ERA, the Lisbon Strategy and the Bologna Process. Training will be informed by world-class research, through exemplar projects and tools developed by the VPH toolkit. The training aspects of the VPH NoE will be delivered through by study groups and a pilot study with the ultimate objective of create a Pan-European MSc. Additional training at PhD level will rely on Marie Curie Actions and other European initiatives.
Figure 3: A model for Life-long training and career flexibility in the VPH community.

Figure 4: Integration of VPH activities within a potential VPH training scheme