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ACROSS AND BEYOND THE DEVIDE: THE ROLE OF INTERDEPARTMENTAL TEACHING IN BIOINFORMATICS

Mohd Shahir Shamsir[1]
Zeti Azura Mohamed Hussein[2]

[1]**Universiti Teknologi Malaysia, Malaysia**
[2]**Universiti Kebangsaan Malaysia, Malaysia**

Abstract
Bioinformatics is a multidisciplinary field derived from computational and biological sciences. Its multidisciplinary nature has created a niche for specialists trained in both biology and computing, and it has required distinct teaching cooperation from experts in these two different areas. Consequently, teaching bioinformatics will require specialist educators with in-depth knowledge of the two different components -- biology and computer science. Because this is quite a daunting task, most universities lack the necessary specialists and experienced bioinformatics staff. They must therefore resort to the logical route of interdisciplinary and cross-faculty teaching. However, interfaculty teaching subsequently raises the issue of 'ownership', and consequently creates concerns regarding teaching and learning cultures, as it is obvious that each discipline has an its own inherent culture. In this article, we examined the curricula and their implementations at two Malaysian universities. Because both universities place their bioinformatics courses in opposing departments, we aimed to study how educators overcome the interdisciplinary barrier. In addition, we concisely explain the components that constitute the bioinformatics field, analyse the unique education criteria that are required to produce individuals with bioinformatics training and provide an overview of global bioinformatics education to further improve our implementation of bioinformatics education.

Keywords: bioinformatics, computational biology, interdisciplinary education, biological sciences, computer science

INTRODUCTION

Bioinformatics represents a new field at the interface between computer science and molecular biology. According to National Institutes of Health (NIH), bioinformatics can be defined as research, development, or application of computational tools and approaches for expanding the use of biological, medical, behavioural or health data, including those to acquire, store, organise, analyse or visualise such data. This definition has been adopted for the purpose of this paper. Demand generated by the expansion and development of bioinformatics has spurred the creation of bioinformatics courses in many countries (Zauhar, 2001). Many surveys of bioinformatics education and research initiatives have been published, representing countries such as the United Kingdom (Brass, 2000; Counsell, 2003; Hack & Kendall,

G. 2005), the United States (Hemminger & Anne Bauers, 2005; Zatz, 2002), Australia (Cattley, 2004; Littlejohn, 2000), Israel (Samish, 2003), France (Danchin, 2000) and Germany (Schomburg & Vingron, 2002). In addition, international workshops have been conducted to discuss aspects such as the shape, design and components of bioinformatics courses, as well as the integration of bioinformatics elements into conventional biological science subjects (Ranganathan, 2005).

There are two objectives of this paper. The first is to examine the curricula and their implementation at two universities in Malaysia that place their bioinformatics courses in opposing departments. We will further examine how institutions overcome the interdisciplinary barrier. The second objective is to study the current scenario, challenges, requirements and future trends needed to ensure the successful teaching of bioinformatics.

Concerns about the need for an undergraduate curriculum in bioinformatics were initially raised by Altman in 1998 (Altman, 1998), with guidelines presented by Luscombe (Luscombe *et al*., 2001) and Cohen (Cohen, 2003). Subsequently, a significant number of papers have discussed and described a variety of bioinformatics programs, curriculum contents and methods of delivery (Ai *et al*., 2002; Bednarski *et al*., 2005; Burhans & Skuse, 2004; Campbell, 2003; Centeno *et al*., 2003; Cohen, 2003; Cooper, 2001; Doom *et al*., 2002; Dubay *et al*., 2002; Dyer & LeBlanc, 2002; Fetrow & John, 2006; Friedman *et al*., 2004; Hack & Kendall, 2005; Hughey & Karplus, 2001; Johnson & Friedman, 2006; LeBlanc & Dyer, 2003; LeBlanc & Dyer, 2004; Maojo & Kulikowski, 2003; Sahinidis *et al*., 2005; Wickware, P. 2001). Overall, the emphasis of bioinformatics training can be divided into three levels: (i) teaching the use of pre-existing tools; (ii) teaching basic programming with algorithm design and in-depth theoretical foundations; and (iii) teaching the principles behind bioinformatics (Counsell, 2003; Dyer & LeBlanc, 2002).

BIOINFORMATICS IN CONTEXT: INSTITUTIONAL BACKGROUND & BIOINFORMATICS CURRICULA

Currently, bioinformatics education in Malaysia encompasses undergraduate and postgraduate programmes. Institutions that offer undergraduate bioinformatics courses are Universiti Teknologi Malaysia (UTM), Universiti Kebangsaan Malaysia (UKM), Universiti Malaya (UM), Management Science University (MSU) and Universiti Industri Selangor (UNISEL) (Yeo, *et al*., 2003). For the purpose of this paper, we will examine the framework and contents of Universiti Teknologi Malaysia (UTM) and Universiti Kebangsaan Malaysia (UKM). The teaching contents are defined as credit hours at institutions of higher learning in Malaysia. Each credit hour represents the number of contact or lecture hours per week in each corresponding semester.

TABLE 1: List of subjects taught at Universiti Teknologi Malaysia Bioinformatics Degree grouped according to similar

UTM	
SUBJECT	Credit
BIOLOGY	
General Biology II	3
Cell Biology & Molecule	3
Cell Biochemistry & Metabolism	3
Genetic Engineering	3
Introduction to Bioinformatics	3
Biology Molecule Technique	2
Genomic & Proteomic	3
Gene Expression	3
Structure & Protein Function	3
TOTAL	**26**
CHEMISTRY	
Organic Chemistry	3
TOTAL	**3**
MATHEMATICS	
Linear Algebra	3
Algorithm Analysis	3
Statistic	3
TOTAL	**9**
COMPUTER SCIENCE	
Citizen & Computer	2
Programming Technique II	3
Computer Architecture	3
Data Structure	3
Discrete Structure	3
Software Engineering	3
Artificial Intelligence	3
Basic Computer Graphic	3
Database System	3
Operation System	3
Networking	3
Simulation & Modeling	3
Computational Biology I	3
High Performance Computing and Parallel Computing	3
Project 1	2
Project 2	4
Industrial Practical 1	4
Industrial Practical II – report	8
Programming technique I	3
Computerise in Biology II	3
TOTAL	**65**
*OTHER SUBJECTS	22
TOTAL	**22**
OVERALL	**125**

* Subjects that are not included in biology, chemistry, mathematics and computer science and offered by the university

Universiti Teknologi Malaysia, located near Johor Bahru (at the southern tip of Peninsular Malaysia), began offering a Bachelor of Computer Science in Bioinformatics in 2006. The university has a niche and a strong tradition in engineering and technology. This course was offered by the Faculty of Computer Science and Information Systems, with its pioneer cohort currently in its second year. It is a four-year program with 125 credit hours of lectures and a six-month industrial training during the third year (Table 1). The curriculum consists of 65 credits (52%) of computer science, 26 credits (20.8%) of biological sciences, 9 credits of mathematics (7.2%) and 3 credits of chemistry (2.4%), with the remaining general subjects totalling of 22 credits (17.6%) (Table 3). These 22 credits consist of various elective subjects offered by the university, such as English Language, Management and Ethics-related courses similar to those offered by other universities in Malaysia.

TABLE 2: List of subjects taught at Universiti Kebangsaan Malaysia Bioinformatics Degree grouped according to similar areas.

UKM	
SUBJECT	Credit
BIOLOGY	
Fundamentals of Molecular Biology	3
General Genetics	3
Fundamentals of Microbiology	3
Cell Biology	3
Biochemistry	3
DNA Recombinant Technology I	3
DNA Recombinant Technology II	3
Gene Expression	3
Microbial Genetics	2
Introduction to Bioinformatics	3
Bioinformatics Tools	3
Molecular Cell Biology	3
Genomics	3
TOTAL	**38**
CHEMISTRY	
General Chemistry I	3
General Chemistry II	3
TOTAL	**6**
MATHEMATICS	
Mathematics in Biology & Information Technology	3
Applied Statistics	3
Differential and Derivative Equations	3
TOTAL	**9**
COMPUTER SCIENCE	
Introduction to Microcomputer and Information Technology	3
C++ Programming	3

Programming Modeling Biology Graphic	3
Web Programming	3
Biological Database System	3
Artificial Intelligence	3
Software Engineering Methodology	3
Software Design in solving Biological Problems	3
Industrial Practical	2
TOTAL	**26**
*OTHER SUBJECTS	25
TOTAL	**25**
OVERALL	**104**

* Subjects that are not included in biology, chemistry, mathematics and computer science and offered by the university

Universiti Kebangsaan Malaysia is located in Bangi, 45 minutes from Kuala Lumpur. It also offers a Bachelor of Science in Bioinformatics. The program is based in the School of Biosciences and Biotechnology, Faculty of Science and Technology, and has graduated their fourth cohort of students. The course commenced in 2002 as a three-year undergraduate degree programme. This programme consists of 104 credits, with 38 credits in biology (36.5%), 9 in mathematics (8.6%), 6 in chemistry (5.7%), 26 in computer science (25%) and 24 in others miscellaneous subjects and electives (Table 3).

TABLE 3: Comparison of percentages of subjects grouped within a specific

Subjects	Percentage (%)	
	UTM	UKM
BIOLOGY	20.8	36.5
MATHEMATICS	7.2	8.6
CHEMISTRY	2.4	5.7
COMPUTER SCIENCE	52.	25
OTHERS	17.6	24

Students are given preliminary work exposure through internship in industrial training (two credits) for eight weeks during the third semester of their second year. The majority of students are placed at bioinformatics companies and research institutes across Malaysia (mostly concentrated in the Klang Valley). During this period, students are given hands-on training and complete a mini-project within the duration of their training. During the second year, they are introduced to the fundamental principles of various bioinformatics algorithms. They also have hands-on, practical experiences during the sequential course in the next semester. Once they have completed these two core bioinformatics courses, they are able to apply the knowledge and techniques to sequence and protein structure analyses. They should also posses the ability to comprehend and infer the outputs of these analyses to answer the biological problems presented. The inclusion of computer science courses provides them with the knowledge of computer science applications related to biology.

INTERDEPARTMENTAL TEACHING

The challenges of teaching undergraduate bioinformatics are inclusion and depth. The inclusion challenge results from the difficulty in incorporating the breadth of knowledge created by the fusion of multidisciplinary areas within bioinformatics (i.e., biochemistry, molecular cell biology, genetics, thermodynamics, biophysics and statistical mechanics). The multidisciplinary nature not only transcends established areas of sciences; it also requires the integration of knowledge and the cross-field utilisation of techniques (Campbell, 2003). This requires specialist educators with in-depth knowledge of all of the different components of the field: mathematics, biology and computer science.

Another challenge in teaching bioinformatics relates to the breadth of information that should be included in the curriculum. Pevzner (2004) raised the issue of depth, commenting that a broad introduction to bioinformatics without the necessary depth would produce bioinformatics technicians rather than bioinformatics scientists. Along with Pevzner, Pearson (2001) highlighted the importance of teaching the principles of algorithms and statistics and creating a biologically motivated problem-based learning environment in order to effectively teach bioinformatics. From our observations, we found that most biologists are comfortable using software (e.g., BLAST) and are content simply to either finding a match or not, regardless of whether they understand the underlying principles. This treatment of bioinformatics merely as a set of computational tools is prone to erroneous assumptions if derived from a flawed understanding of the algorithms behind the tools. This is further compounded by an increase in the publication of cookbook-style, protocol-centric bioinformatics textbooks (Pevzner, 2004). Thus, failure to create a program with the necessary depth will produce students severely lacking in the skills necessary for pursuing careers in bioinformatics. These challenges compel university administrations to follow the logical route of interdisciplinary and cross-faculty teaching. This technique raises the issue of ‘ownership’ and the placement of the course within an institution. The university management must then determine which faculty or department (i.e., biology, mathematics or computer sciences) should house the necessary courses and facilities.

The use of interdisciplinary teaching is evident at each of the investigated universities. Both UTM and UKM utilise lecturers from opposing fields to complement their teaching. Lecturers from the Faculty of Bioscience and Bioengineering (FBB) in the Biological Sciences Department assist the faculty of Computer Science and Information Systems (FSKSM) at UTM. The FBB has a unit focusing on computational biology-based research, as well as its own teaching module for bioinformatics that is specifically tailored to biotechnology and biology courses. The FBB lecturers are responsible for teaching all core biology subjects (20.8% of total credits). The FBB lecturers are trained in a variety of bioinformatics tools that are utilised and integrated throughout their biology curricula. This embedded strategy for teaching bioinformatics to biology-based students has been practised at other foreign universities (Boyer, 2000; Cooper, 2001; Feig & Jabri, 2002; Gibbons *et al*., 2004; Honts, 2003; Ranganathan & Miyano, 2001). All of these implementations have obviously favoured the teaching of bioinformatics in FSKSM. The lecturers from FBBS are already familiar with bioinformatics tools and software, thus enabling the teaching of biological principles with bioinformatics concepts embedded. They are also aware of the requirements for computer-based students and make necessary adjustments and reemphasise the subject materials as needed. During their final year, students also have the benefit of direct and immediate support for their projects from the biology-based lecturers. Currently, there are no plans to hire biology lecturers in FSKSM and present arrangements manage to foster interdisciplinary cooperation between FSKSM and FBB.

Comparative studies of curricula in the US, for example, have shown a similar emphasis on the computer science element (Burhans & Skuse, 2004; Morrow & Wilkins 2004). Problems have occurred with regard to the teaching requirement of the individual lecturers. Additional teaching requirements are a contentious issue because the faculty prefers that its teaching staff focus on their own teaching requirements. The bioinformatics programme at UKM is based in the Faculty of Science and Technology (FST), with the first batch graduating in 2006. It also faces problems similar to those of UTM in terms of recruiting lecturers from the opposing faculty. However, a greater percentage of the biology lecturers are conversant with bioinformatics, at least at the level of tool utilisation. This allows for unhindered teaching and is reflected in the greater success of the course implementation in FST. Furthermore, the aim of UKM is to create researchers with bioinformatics knowledge to support wet lab research, rather than delving on the complexities of software design (as denoted by their shorter course duration and subject matter emphasis).

The biggest concern at both institutions is teaching style. It is obvious that each discipline has its own inherent culture; which can be overcome by instructors possessing an explicit understanding of the knowledge that are required in bioinformatics and the context in which it is taught. As long as the requirements for effective teaching of bioinformatics are followed, the courses are successful. Much of the literature surveyed has highlighted several requirements that ensure effective bioinformatics teaching. These requirements include fast Internet access, the use of a practical heavy curricula and the departure from traditional passive to modern learning by using creative instructional delivery; which have been fulfilled by both universities. Internet access is important in teaching bioinformatics. The changing of trends in information access, particularly over the Internet, has been shown to transform biological science education. Students now need to access online resources, usually from a free central depository for biology-derived data. There are more than a thousand online databases and resources available freely over the Internet (Galperin, 2007). Access is crucial, as fast Internet access would put researchers in a developing country on par with academic biologists in an industrialised country. The complexity of bioinformatics itself poses a challenge in determining suitable instructional methods for education (Ben-Dor *et al*., 2003). The hands-on nature of bioinformatics requires students to repeatedly perform standard sequence and structure analysis, thereby necessitating a practical heavy curriculum. A survey of the literature has revealed numerous proposed methods and examples, e.g., Instructional Design Theory (Shachak *et al*., 2005), Problem-Based Learning (Abbot, 2002; Ai *et al*., 2002) and Inquiry-Based Laboratory (Bednarski *et al*., 2005). Therefore, regardless of the placement of the course, interdepartmental teaching must incorporate an active learning, practical heavy curriculum in the course architecture; which both universities are trying to do so.

PAST & FUTURE TRENDS

Currently, bioinformatics is shifting away from a single discipline and into an integrative, multidisciplinary field - even within bioinformatics itself. This shift began after early investors realised that the yield obtained from isolated activities after 2001 did not meet expectations. This prompted anxiety over the sustainability of investments in the field of bioinformatics (Leite, 2004). The decline was signalled by the closure of bioinformatics companies, beginning as early as 2000 (Wickware, 2000). Some even consider demoting bioinformatics to a tools and application status (Black & Stephan, 2005; Counsell, 2003; Russell, 2006). As bioinformatics tools for biologists become more user-friendly, the applications become routine in laboratories, thereby eliminating a specialised need, akin to the commercialisation of kits used to standardise difficult laboratory procedures by biotechnology companies. The creation of bioinformatics workbenches as early as 1987 combined popular tools and further enhanced usability within the laboratory community (Bernstein, 1987; Oinn *et al*., 2004; Suter-Crazzolara, 2000). Universities offering bioinformatics courses have also declined in number due to decreasing demand from students. This phenomenon has been observed in Europe (Counsell, 2003) and the US (Black & Stephan, 2004; 2005). Studies have shown reductions in either the number of courses offered or in enrolment. Corresponding analyses on the number of bioinformatics vacancies advertised have also shown a marked decline. This consolidation and maturation of the education market mirrors the direction taken by the industry a few years earlier. Surprisingly, the opposite phenomenon is occurring in India; bioinformatics courses are ‘sprouting’ and becoming money-spinning enterprises that teach a mediocre curriculum (Balaram, 2002).

CONCLUSION

Both UTM and UKM have shown that fulfilling the teaching requirements of bioinformatics by recruiting teaching staff from opposing faculties is a feasible and adequate means of meeting each of programme’s goals. The placement of the course does not affect the delivery of the teaching material and will provide satisfactory learning outcomes. It is believed that the most critical aspect of interdepartmental teaching would be mutual research support between opposing faculties. Both faculties must reciprocate in order to ensure success in their bioinformatics courses. Only with this mutual support will interdepartmental collaborations not only survive, but thrive. Bioinformatics research has shifted from genomic sequences to integrative bioinformatics, such as proteomics, assimilated into areas like medical informatics and pharmacogenomics, and created new areas of interest, such as transcriptomics, metabolomics and systems biology. In the future, bioinformatics and the biological sciences will continue to become multidisciplinary fields that integrate approaches from engineering, mathematics and computer science (Tadmor & Tidor, 2005). The field of bioinformatics itself is very fluid; therefore, the curriculum must also be very adaptable and must be reflected by reciprocal teaching.

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Corresponding Author : zeti@ukm.my