The development and integration of Molecular Genetic and Cytogenetic modules in the Biomedical Technology curriculum

JOHANNA C A JAMISON
Department of Biomedical Sciences, Private Bag X680, Faculty of Health Sciences, Tshwane University of Technology, Pretoria

Abstract
The emerging diagnostic field of molecular genetics demands for appropriately and adequately trained medical technologists. The proposal for the inclusion of genetic and cytogenetic modules in the National Diploma and B.Tech Degree programmes has widely been accepted last year. This positive response lead to the development of these modules, but the integration of the proposed modules in the existing diploma programme remains challenging. Various factors will determine whether all or only some of the pro posed modules will be accepted and integrated.

Introduction

Medical research has gained new momentum as a result of the success of the Human Genome Project that involved the sequencing of the complete human genome[1,2]. This is evident from the pace of disease gene discovery and the molecular characterisation of clinical disorders due to increased understand ing of genetic networks and protein pathways, as well as clarification of genetic control mechanisms on gene function[3,4]. The provision of future health care will be profoundly affected by the information generated from this complex task as the molecular characteristics of any type of disorder/dis ease will influence its diagnosis, treatment and cure[5,6]. New therapeutic avenues, which include molecular and genetic medicine, are already being investigated worldwide. The number of private and para statal laboratories in South Africa that utilise molecular genetic and cytogenetic diagnostic and prognostic techniques continue to grow. These laboratories specialise in pathogen detection, pre and post natal disease gene detection, cancer sus ceptibility gene screening and DNA fingerprinting. Reliable, easy to use and cost effective tests/kits based on recombinant DNA technology, and spe cialised genetic techniques such as polymerase chain reaction (PCR) and denaturing high performance liquid chromatography (dHPLC) are widely used in developing and developed countries for diagnostic genetics, popula tion screening, pathogen detection, prognostic pathology and determination of cancer predisposition[5]. These techniques are employed in nearly all med ical technology disciplines such as haematology, chemical pathology, cytol ogy, microbiology and virology. The increased understanding of the genetic basis of disease and improvement of genetic diagnostic tools to determine the genetic profile of a patient, add a new dimension to clinical diagnosis.

Currently medical scientists are primarily employed in molecular labora tories in research institutions and clinical pathology laboratories due to their extensive genetic training and experience[7]. Biotechnologists are also employed but at a lower incidence. The majority of scientists and biotech nologists however, often lack a clear understanding of the general clinical pathology environment. In contrast, the multi skilled qualities of medical technologists and their knowledge of the major biomedical disciplines ensure effective functioning within the clinical pathology environment. However, they are currently ill equipped to meet the challenge of the changing work environment as superficial genetic training occur only in the fourth year of the Biomedical Technology programme. Furthermore, cytogenetic training at most training institutions is mostly limited to theoretical training. As a result, the opportunity exists to empower medical technologists even more by broadening their multi faceted understanding of clinical diagnostics and practical technological capabilities in the genetic environment[8]. The demand in the Pretoria area alone is currently so high that a shortage of skilled tech nologists and scientists with molecular genetic training is experienced due to the fast developing field of diagnostic medical genetics[7].

In 2004 it was proposed that future qualifying medical technologists should be equipped with molecular genetic knowledge and practical skills by providing training from the first year to the third year of the National Diploma course, followed by further specialised genetic training in the B.Tech degree[8]. The National Curriculum Development Workgroup (which includes representatives of the Health Professions Council of South Africa, Society of Medical Laboratory Technologists of South Africa (SMLTSA) and SMLTSA Subjects Advisory Committees (SACs), Universities of Techno logy and industry) accepted this proposal. The opportunity for the implemen tation of the proposed changes exists due to the current programme restruc turing process and new proposed model[9,10] of the Biomedical Technology qualification. The model proposes a 4 year professional degree with further discipline specific specialisation in the last year of study. Subject content are currently also being updated and re evaluated to eliminate duplicated infor mation over several subjects. This process is in response to an increased demand from industry regarding the need for technologists with a higher level of practical laboratory competence[11,12], as well as the impact of the Higher Education Act[13].

Problem statement

Currently no modules (units of learning) in genetics exist except for the sub ject, Molecular Biology IV, in the fourth B.Tech year. This subject is insuffi cient to introduce qualifying learners to clinical genetics and the applicable diagnostic techniques. Therefore, appropriate and extensive training modules are needed.

Working procedure

A small group of stakeholders were engaged in a process during 2004 to assemble possible modules. The exit level outcomes and specified outcomes identified in the SAQA qualification document for Medical Technology[14], as well as international trends in genetic education and research were taken in consideration during the development of the modules. Modules were devel oped and streamlined by identifying general and more specialised genetic knowledge required, as well as the inclusion of adequate practical technolo gy training. Modules were arranged sequentially at the different National Qualification Framework (NQF) levels in a progressive manner to ensure that prerequisite information would be dealt with before moving to the next level.

Results and Discussion

The working group identified the molecular and genetic knowledge medical technologists would need to attain in depth knowledge and understanding of the genetic basis of normal cellular processes, as well as abnormal events that lead to disease. Also, technologists should gain a comprehensive understand ing of applied diagnostic and research technologies and display a high level of practical competence in genetic and cytogenetic techniques.

Proposed modules and syllabi

The modules and proposed syllabi have initially been identified independ ently from the existing curriculum (Table 1). The reason for this approach was to identify the ideal level of knowledge and skills that were considered necessary by industry to fully equip medical technologists in the emerging field of molecular genetics and cytogenetics. The first year training includes three theoretical modules with a focus on fundamental cellular and molecu lar processes in the cell. The normal macro (cytogenetic) and micro (genet ic) organisation and activity of genetic material as well as finely tuned reg ulated and interconnecting cellular and molecular processes of healthy cells will be examined. This knowledge will form the basis for understanding the genetic basis of disease as a result of abnormalities in cellular processes and their regulatory pathways. The second year of training focuses on clinical genetics and cytogenetics, as well as basic genetic and cytogenetic sampling and diagnostic techniques. On the assumption that learners have understand ing of molecular normality of cells, these modules explore the general type of errors that occur in genes and chromosomes and consequential syndromes and diseases. At this level learners will also be exposed to the variety of ana lytical techniques and their appropriate applications. Comprehensive practi cal training in the sampling and diagnostic techniques should contribute 60% to the total credits of the second module to ensure practical competence. In the third year of training learners will be challenged to apply their molecular knowledge within the various medical disciplines by referring to specified examples of disorders with a known genetic component (Table 1). The Molecular Pathology module should therefore be fully integrated as sub modules (or themes) within larger discipline based modules to allow for the integration and interpretation of genetic and cytogenetic results in relation with existing non genetic diagnostic tests. The fourth year of training focus es on specialised/advanced molecular research and diagnostic techniques, as well as recombinant DNA technology principles and the genetic engineering applications in medical technology. These modules provide a sound basis for future research in applied genetics. However, diagnostic medical technolo gists will not be disadvantaged if the modules Recombinant DNA technolo gy and Specialised Molecular Technology are excluded from the programme or at least presented as elective modules, in contrast to the genetic training in the first three years which are fundamental to ensure the adequate training of technologists. In the fourth year future qualifying learners will be required to

Table 1: Proposed genetic and cytogenetic modules for the National Diploma and B Tech (Biomedical Technology) degree.

NQF LEVEL	PROPOSED MODULES/UNITS/THEMES		
5 (120 credits) FIRST YEAR	Biochemical genetics: • Flow of genetic information • Structure and properties of DNA • DNA replication • Mutation, DNA damage and repair • RNA structure and metabolism • Protein synthesis • Prokaryotic and Eukaryotic genome orga nization, gene expression (and its control) • Patterns of inheritance and genetic instabil ity	Introduction to Cytogenetics: • Chromosome classification • Homologous recombination • Transposons, Chromosome walks	Cell signalling pathways: • Transduction (membranes and cytoplasms) • Function, regulation and differentiation of cell proliferation • Role of proto oncogenes and tumour sup pressor genes • Ageing and apoptosis • Molecular networks of proteins
	*BIOCHEMISTRY II/ MICROBIOLOGY II	* CELLULAR PATHOLOGY III	
6 (240 credits) SECOND YEAR	Clinical Genetics and Cytogenetics: • Mutation types and nomenclature • Single gene disorders: Autosomal dominant/recessive/X linked • Multifactorial disorders (eg diabetes, asthma, hypertention) • Chromosome abnormalities • Disorders of autosomes and sex chromosome • Chromosome breakage syndromes • Malignancy and acquired chromosome abnormalities	Molecular and Cytogenetic Technology: • Specimen collection, processing and QC • Protein, DNA and RNA isolation, purification and quantification • Basic and advanced PCR (eg RT PCR, real time PCR) • Nucleic acid hybridization assays • DNA and protein sequencing • RFLP, RAPD • DNA fingerprinting (eg STR, VNTR approaches) • Specimen collection and tissue cultures (media, environment, QC) for chromosome analysis • Chromosome preparation and analysis (Giemsa, FISH, spectral karyotyping) • Practical: DNA isolation, PCR and agarose gel electrophoresis, DNA sequencing (demonstration), Giemsa staining	
	* CELLULAR PATHOLOGY III	*MOLECULAR BIOLOGY IV	
6 (360 credits) THIRD YEAR	Molecular Pathology: Molecular Blood Transfusion: • Immunogenetics • Molecular basis of bloodgroups • Sample collection, processing and QC procedures • Relevant genetic analytical procedure • Inherited and acquired immunodeficiency disorders Molecular Haematology: • Sample collection, processing and QC procedures • Relevant genetic/cytogenetic analytical procedure • Loss of function mutations (eg hemoglobinopathies) • Gain of function mutations (egCML) • Mutation quantification for cancer remission status (eg CML) Molecular Chemical Pathology: • Sample collection, processing and QC procedures • Relevant genetic/cytogenetic analytical procedure • Loss of function mutations (eg, haemochromatosis, errors of metabolism, hyperlipidemia) • Gain of function mutations (eg Prader Willi, Angelman syndrome, errors of metabolism) • Paternity testing • Tissue typing and HLA associated diseases Molecular Microbiology and Molecular Virology: • Sample collection, processing and QC procedures • Relevant genetic analytical procedure • Pathogen detection and quantification (eg TB, HIV, hepatitis C) Molecular Cellular Pathology/Molecular Cytology: • Sample collection, processing and QC procedures • Relevant genetic/cytogenetic analytical procedure • Cancer Genetics (multistep evolution of cancer, causative agents, genetic predisposition, cancer viral detection) Practical: Sessions for different disciplines should include at least one applied molecular/genetic practical		
7 (480 credits) FOURTH YEAR	Recombinant DNA Technology (Pro and Eukaryotes): • Restriction enzymes • Vectors • Transformation and selection of clones • Functional analysis of recombinant protein • Large scale production • Application of genetic engineering (eg vaccines, therapeutics) • Genome and cDNA libraries • Practical: Gene cloning experiment	Specialized Molecular Technology: • Screening of known/unknown mutations (eg DGGE, SSCP, Hetero duplexing) • Expression analysis (eg PPT, microarray, flow cytometry) • Molecular therapy Principles, ethics and approaches (mutation correction, targeted gene expression inhibition, ex vivo, in vivo therapy) • Gene mapping and linkage analysis • Basic Bio informatics • Introduction to Population Genetics	
	* MOLECULAR BIOLOGY IV	* MOLECULAR BIOLOGY IV	

engage in an appropriate research project[13] and a project with a genetic theme with application in a specified discipline can be identified. This will result in adequate practical exposure to genetic laboratory work.

Subjects in the current qualification with which some of the modules have limited content overlap are indicated at the bottom of each proposed module (Table 1).

Integration of genetic modules

Various factors influence the integration process of the proposed modules into the existing curriculum. The current re curriculation process for the Biomedical Technology programme seeks to improve the international com petitiveness and recognition of the qualification. More importantly, it seeks to improve the current inadequate practical training in the various disciplines due to a theoretical overemphasis in the programmes at some tertiary institu tions[11,12]. Another concern from employers and medical technologists is the composition of the current B.Tech (fourth year) qualification, which is gen erally considered to be irrelevant to the empowerment of technologists, espe cially regarding further discipline or technical specialisation[11]. As a result, several proposals have been considered for the restructuring of the whole programme. The inclusion of the existing internship required for HPCSA reg istration as part of only one medical technology qualification, namely the B professional degree (NQF 7, 480 credits) seems to be the most favoured pro posal but wider approval needs to be obtained[9,10]. At first glance the genetic modules seem to add a considerable amount of content to an already loaded curriculum. However, the current re curriculation process includes the eval uation of all present subject syllabi to identify and eliminate duplication. This creates an opportunity to include the proposed genetic syllabi as independent modules or as integrated content in existing to be streamlined subjects. The final amount of credits awarded for each module will determine the ultimate weight of these independent modules. These issues can only be considered at future national curriculum workshops with equal representation of all med ical technology disciplines. As proposed in this article, the module Molecular Pathology should be integrated in the major discipline modules. It may even in future be suggested that some of the other proposed genetic modules could also be integrated into larger credit bearing modules or could be excluded from the programme altogether to ensure that the appropriate exit level out comes are met. Some modules can be accommodated as elective modules in the programme such as the modules in the fourth year. This remains to be finalised in the re curriculated and improved medical technology pro gramme.

It should be emphasised that the purpose of the inclusion of these genetic modules is to empower technologists to expand their scope of work in the areas of medical technology, which is currently being dominated by profes sionals other than medical technologists. Ideally, learners should be exposed to the molecular genetic and cytogenetic work environment from the second year onwards. The inclusion of an improved level of work integrated learn ing in the future programme structure for all the medical technology disci plines was widely supported by representatives at the national curriculum workshops[10]. This however will require more innovative avenues of cooper ative education between the formal educational sector and accredited train ing laboratories.

Conclusion

The success of the Human Genome project, which led to an increased employment of genetic and cytogenetic technology in the clinical diagnostic and research environment, is having a marked effect on the field of medical technology[1,2,5]. The implication is that technologists should be equipped to explore new career opportunities in this emerging field[8]. The current medical technology qualification is limited in the amount of genetic training includ ed in the programme. In order to address this shortcoming, genetic and cyto genetic modules were developed for inclusion in the revised medical tech nology qualification. These modules should be seen as complementary to existing disciplines rather than in competition, as genetic and cytogenetic technology offers a wider scope of analytical techniques in clinical diagnos tics and research. Appropriate training will allow medical technologists to excel in the emerging fields of discipline specific molecular genetic and cytogenetics.

Acknowledgements

I wish to thank the representatives of the medical technology stakeholders for their valuable input in the development of the modules. Dr G Gericke and I Ferreira (Ampath, Pretoria), R Smart (NHLS, Cape Town) and J Hind (University of Johannesburg) made a significant contribution. A word of thanks to Dr Braam Hoffmann, senior lecturer in the department of Biomedical Sciences, Tshwane University of Technology for helpful com ments on the first draft of this paper.

References

1. Venter, J.C., Adams, M.D., Myers, E.W., et al. *The sequence of the human genome*. *Science 2001* **291**: 1304 1351.
2. International Human Genome Sequencing Consortium, *Initial sequenc ing and analysis of the human genome*. *Nature 2001* **409**: 860 920.
3. Peltonen, L. & McKusick, V.A., *Genomics and medicine: Dissecting human disease in the postgenomic era Science 2001* **291**: 1224 1229.
4. Jimenez Sanchez, G., Childs, B. & Valle, D. *Human disease gene Nature 2001* **409**: 853 859.
5. *Genomics and World Health*. *Report of the Advisory Committee on Health Research*. World Health Organization, Geneva *2002*: 7,10 13.
6. Collins, F.S., Green, E.D., Guttmacher, A.E. & Guyer, M.S., *A vision for the future of genomic research Nature 2003* **422**: 835 847.
7. Personal communication, Ampath Pathologist Group, Pretoria, 2004.
8. Jamison, J.C.A., *The education and training of medical technologists in molecular genetics: A challenge for the profession Medical Technology SA 2004* **18(1)**: 7 11
9. Minutes of the National Curriculum Workshop: Biomedical Technology, Cape Town, October 2004
10. Minutes of the National Curriculum Workshop: Biomedical Technology, Cape Town, September 2005
11. Minutes of the National Curriculum Workshop: Biomedical Technology, Cape Town, March 2001
12. Minutes of the National Curriculum Workshop: Biomedical Technology, Cape Town, April 2004
13. *Republic of South Africa, Higher Education Act*, Act 101 of 1997.
14. htt://www.saqa.org.za