Bioinformatics education in India
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Abstract
An account of bioinformatics education in India is presented along with future prospects. Establishment of BTIS network by Department of Biotechnology (DBT), Government of India in the 1980s had been a systematic effort in the development of bioinformatics infrastructure in India to provide services to scientific community. Advances in the field of bioinformatics underpinned the need for well-trained professionals with skills in information technology and biotechnology. As a result, programmes for capacity building in terms of human resource development were initiated. Educational programmes gradually evolved from the organisation of short-term workshops to the institution of formal diploma/degree programmes. A case study of the Master’s degree course offered at the Bioinformatics Centre, University of Pune is discussed. Currently, many universities and institutes are offering bioinformatics courses at different levels with variations in the course contents and degree of detailing. BioInformatics National Certification (BINC) examination initiated in 2005 by DBT provides a common yardstick to assess the knowledge and skill sets of students passing out of various institutions. The potential for broadening the scope of bioinformatics to transform it into a data intensive discovery discipline is discussed. This necessitates introduction of amendments in the existing curricula to accommodate the upcoming developments.

Keywords: bioinformatics; education; syllabus; computational infrastructure; certification; biotechnology information system; India

INTRODUCTION
The beginning of the era of bioinformatics is marked by early studies such as the compilation and analysis of large sets of protein sequences by Late Dr Margaret Dayhoff to study molecular evolution in the 1960s [1]. These efforts led to the development of one of the earliest databases in the area of biological macromolecules—Protein Information Resource, popularly known as PIR database. This was followed by the development of computer programmes, often written by the scientists themselves, for the application of quantitative methods to study biological data. History of bioinformatics in India dates back to the 1960s when Prof. G. N. Ramachandran and colleagues derived the famous Ramachandran plot that provided the foundation of modern structural biology/bioinformatics [2]. As a consequence of these and other discoveries, bioinformatics has grown into a full-fledged scientific discipline of knowledge discovery. It has become an essential and integral component of frontline research in life sciences. The problems addressed using bioinformatics range from simple analyses of single gene/protein data to modelling of complex data such as systems biology. Bioinformatics employs the principles of statistics, mathematics, physics and chemistry to address the problems in biology by using computational methodologies.

The early contributors to the field of bioinformatics were from either life sciences or physical sciences...
who had realized the potential of computational approaches in the study of biology. As the discipline evolved and its scope became broader, the demand for trained human resource started growing. This necessitated the establishment of formal training programmes. Initially, a few research institutes introduced short training programmes of a few days to few weeks in duration. The topics covered in these programmes varied from introduction to the field of bioinformatics to specialized themes like biological databases, algorithms and applications of bioinformatics. Formal long-term courses were subsequently launched by many universities/institutes world over [3–8].

**GROWTH OF BIOINFORMATICS IN INDIA**

Formalization of bioinformatics activities in India began in the early 1980s with the establishment of a nation-wide network of Distributed Information Centers (DICs) under the umbrella of the Biotechnology Information System (BTIS), by the Department of Biotechnology (DBT), Government of India (http://www.dbtindia.nic.in/; http://www.btisnet.gov.in/index.asp) [9, 10]. These centres were assigned the mandate to (i) carry out research in specialized areas and (ii) provide bioinformatics support and services to the scientific community at large. The BTIS network today includes six Centers of Excellence (CoEs), 10 DICs, 51 Sub-DICs and 61 Bioinformatics Infrastructure Facilities (BIFs) coordinated by the apex centre at DBT, New Delhi (http://www.btisnet.gov.in/index.asp). The geographic distribution of the centres ensures easy access of informatics infrastructure to maximum number of academic and R&D institutions in the country. The expansion of the network has also culminated in broadening expertise in various domains of bioinformatics, viz. structural bioinformatics, genomics, proteomics, immunoinformatics, etc. Researchers from these centres have significantly contributed to the development of a variety of primary and derived databases, a large number of algorithms to analyse data at different levels of bio-complexity and servers for prediction of various properties of biomacromolecules (http://btisnet.gov.in/writereaddata/12271108171_Publication_List.pdf) [11]. The BTIS network offers computing facilities as well as domain expertise, which have induced interest amongst a large number of life science researchers in the application of bioinformatics. This has successfully ushered in a new paradigm in India, through integration of bioinformatics approach with experimental research.

**BIOINFORMATICS EDUCATION IN INDIA: EVOLUTION & CURRENT STATUS**

The centres under the BTIS network, right from their inception, have been carrying out generalized as well as special theme-based short-term training programmes in different areas of bioinformatics. The training programmes in the 1980s focused on building awareness of bioinformatics among biologists, medical practitioners, statisticians, mathematicians and IT professionals. These were followed by detailed workshops on topics like biological databases, database searches, algorithms for sequence analysis and their applications, phylogenetic analysis, structural bioinformatics, molecular modelling and simulations etc. These activities proved to be extremely useful to a variety of user groups like researchers, academicians and industry professionals. The short-term training activities are now well coordinated across the BTIS network with DBT publishing an annual training calendar (http://www.btisnet.gov.in/uniquepage.asp?ID_PK=21).

In the 1990s, application of novel, high-throughput technologies and automated procedures in life sciences resulted in the generation of large volumes of biological data across the omics series. With the changing nature, volume and complexity of data (whole genome sequences, proteomics, structural genomics, transcriptomics, metabolic and signal transduction pathways, protein–protein interactions, etc.) specific and specialized technology became necessary for processing and analysis of the data. Approaches based on application of artificial intelligence methods, machine learning techniques, fuzzy logic, grid computing, parallel programming, etc were developed. With the changing scenario it became necessary to train students/professionals to be ‘bioinformaticians’. The field has been evolving so rapidly that the training programmes should empower the students not only to learn and apply the core tools and techniques but also inculcate a life-long learning ability that allows them to absorb and master new technologies/concepts as they emerge.
The full-fledged formal training programmes in bioinformatics were therefore designed with the following objectives.

- To train students in the fundamental disciplines relevant to bioinformatics
- To help them acquire the essential IT and bioinformatics skills
- To develop the competency in problem solving.

The students trained with these objectives are anticipated to meet the interests of stakeholders, viz. the funding agencies as facilitators, educational institutes as prosumers and academia/R&D laboratories/industry as employers.

**Advanced Diploma in Bioinformatics**

A 1-year Advanced Diploma course in Bioinformatics (ADB) was launched in 1997 in the five DICs viz., Jawaharlal Nehru University (JNU) (New Delhi), University of Calcutta (Kolkata), Madurai-Kamraj University (Madurai), Pondicherry University (Puducherry) and University of Pune (Pune). It was designed for students who completed their Master’s degree in basic sciences or Bachelor’s degree in medicine/engineering/pharmacy. The objective of ADB was to create human resource in bioinformatics to satisfy the growing need in various sectors. The ADB syllabus was designed to train students to achieve proficiency in the use of existing tools as well as the development of new tools. Indeed, the syllabus that was designed for ADB in 1997 was in congruence with the ‘dream’ syllabus proposed by Russ Altmann in 1998 [12].

The ADB course had to address the needs of students coming from different backgrounds. On one side, students with formal training in biological sciences needed to learn mathematics, statistics and computer science, whereas those from engineering/physical/chemical sciences required an in-depth exposure to biology. Such a mixed composition of students often proved to be an advantage as they complemented each other in understanding the multiple disciplines and significance of bioinformatics.

The ADB opened up opportunities for students to secure admission into the PhD programmes of reputed universities in India/abroad and jobs at various cadres ranging from technicians to scientists in academic institutions/industry. Several of these assignments included research projects having combination of computational and experimental components. A few of the ADB pass-outs also became entrepreneurs by establishing their own start-ups in the areas of bioinformatics, chemoinformatics and medical informatics.

Full-fledged Master’s degree programmes in bioinformatics started later have either replaced the ADB course or coexisted with it for a few years at the universities mentioned above.

**MSc programmes in bioinformatics**

Scientific and technological advances, viz. completion of full genome sequencing projects of important organisms including human, rise of omics series, availability of high performance computing facilities, in the early years of the 21st century further increased the demand for trained manpower. This called for institution of a full-fledged 2-year Master’s degree course (MSc) in bioinformatics. The first MSc programme in bioinformatics was started at the University of Pune in July 2002, with financial support from the DBT (http://bioinfo.ernet.in/). Subsequently, an MTech course in computational and systems biology was launched at JNU, New Delhi in 2006 and MSc in bioinformatics at Pondicherry University (Puducherry) in 2007. As a representative Master’s degree programme, a case study of MSc Bioinformatics at the University of Pune is presented below.

The MSc bioinformatics programme at the University of Pune has earned a reputation as one of the best in the country. The course has been designed to ensure a balanced and comprehensive training in bioinformatics as well as related subjects. The course consists of a total of 100 credits distributed over four semesters of 15 weeks each. A theory course of one credit is equivalent to 15 contact hours while a practical course of one credit requires 45 h of laboratory work. The weightages for theory, laboratory courses and project work are 43, 37 and 20%, respectively. The learning process lays emphasis on hands-on experience and problem solving sessions. The syllabus is designed to impart training not only in bioinformatics but also in biology, mathematics, statistics and information technology, which form the foundation of bioinformatics. Figure 1 (A and B) depicts the allocation of credits for theory and laboratory components of these subjects, respectively.

The courses in these subjects run through the four semesters with increasing levels of complexity.
Basic biology and mathematics form optional courses to students who studied mathematics and biology, respectively, in their Bachelor’s degree. Biological chemistry and genetic information flow and processing (molecular biology) are offered in the first semester while cell biology, genetics and experimental laboratory techniques are taught in the second semester. For specialized areas of bioinformatics, viz. immunoinformatics, parasite bioinformatics and metabolic pathway engineering, the corresponding areas of biology (immunology, parasitology, metabolic pathways) are integrated with informatics. As depicted in Figure 2, statistics is taught in the first semester whereas advanced algorithms and techniques as applied to biological data mining are covered in the subsequent semesters along with pertinent topics in bioinformatics. Similarly, the courses imparting IT skills are introduced gradually during the first to third semesters. The IT training includes various operating systems, programming

**Figure 1:** Distribution of credits for the core subjects taught in MSc Bioinformatics. (A) Percent credit allocations for theory courses and (B) Percent credit allocations for laboratory courses. The credits allocated for project work are not included in this distribution.

**Figure 2:** Semester-wise distribution of topics in the major disciplines in the syllabus of MSc bioinformatics at University of Pune. Different colours as shown in tiles are used to indicate four semesters.
languages (C, java and perl), database management systems and computer graphics and visualization. The topics in bioinformatics are divided into four broad groups viz. databanks and sequence-based approaches, structural bioinformatics, genomics & proteomics, and biological data mining, which are spread over the four semesters (Figure 2). The course contents encompass biocomplexity from macro to micro levels and vice versa. For example, there are modules in biodiversity informatics on one hand and molecular phylogeny on the other, to enhance understanding at molecular level. Similarly, study of individual genes/proteins is followed by that of genomics and proteomics providing a perspective at the systems level. Chemoinformatics is an important area of research and is included as a separate course in the second semester.

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The students get an exposure to research methodologies in the project work during the fourth semester. Some of the projects carried out by the ADB and MSc students have led to publications in peer-reviewed journals [13–15].

Rapid growth and developments in bioinformatics call for revision of syllabus at regular intervals. Accordingly, the syllabus of MSc bioinformatics is periodically revised at the Bioinformatics Centre, University of Pune. It compares well with the syllabi of Master’s programmes offered at various universities world over. A few differences feature due to degree of details and weightages allocated to founding disciplines or areas of specialization. For example, bioinformatics programmes offered in the different universities/institutes in Germany are designed to focus on the main research area of the parent university/institute [5].

The ADB and MSc programmes in bioinformatics at the University of Pune turned out to be highly sought after professional courses leading to placements in academia as well as industry. To date, a total of 127 and 146 students have been trained in the ADB and MSc (Bioinformatics) programmes, respectively. Of the 69% of the students, who have successfully completed these courses, 80% found placement in academia or industries in India and abroad. These budding bioinformaticians are contributing to a wide range of academic and commercial projects not only in core scientific areas (drug and vaccine developments, clinical research, agrobio-technology, etc.) but also in technological aspects (software, database development and user support).

**Nationwide scenario of bioinformatics education**

Realizing the importance of bioinformatics as a career opportunity for the young generation, many universities and institutions are now offering Diploma, Bachelor’s and Master’s level courses in India. Since it is not possible to provide comprehensive overview of all of them here, some of the better known ones are mentioned below. In addition to the universities mentioned below, a few of those listed in the Table 1 also offer Bachelor’s and Master’s degree courses in bioinformatics.

- **JNU, New Delhi**

  JNU introduced Advanced postgraduate Diploma in Bioinformatics in 2000 at the Centre for Computational Biology and Bioinformatics, which was later integrated into the School of Information Technology. In the year 2006, an MTech programme in computational and systems biology replaced the Diploma course (http://ccbb.jnu.ac.in/education.html).

- **Madurai Kamaraj University, Madurai.**

  The Bioinformatics Centre, School of Biotechnology, Madurai Kamaraj University offered a 1-year Advanced Diploma course in Bioinformatics during 1996–2006. The course was designed to provide an integrated outlook of biotechnology and bioinformatics (http://www.biotechmku.org/).

- **Pondicherry University, Puducherry**

  The Bioinformatics Center of Pondicherry University currently offers MSc and PhD programmes besides modular courses in bioinformatics (http://www.bicpu.edu.in/). Pondicherry University, Madurai Kasmraj University and Anna University (Chennai) are also due to start MSc in computational biology on a consortium basis from the academic year 2010–11.

- **Indian Institutes of Technology**

  Master’s level programmes in Bioengineering and Biotechnology offered by IITs include bioinformatics as core/elective courses.

- **Indian Institutes of Information Technology**
Indian Institutes of Information Technology (IIITs), Allahabad offers MTech in Information Technology with specialization in bioinformatics (http://bi.iiita.ac.in/index.html) whereas IIIT Hyderabad offers MTech in bioinformatics as well as MS by research in bioinformatics (http://www.iit.ac.in/academics/programmes/postgraduate/mtechbio).

- Institute of Bioinformatics and Applied Biotechnology, Bangalore

A postgraduate course of 18-month duration (three semesters) in bioinformatics is conducted by the Institute of Bioinformatics and Applied Biotechnology (IBAB), Bangalore, since 2002 (http://www.ibab.ac.in/prog_bioinformatics.html).

- DOEACC Society

The DOEACC Society, an autonomous body of the Department of Information Technology, Ministry of Communications & Information Technology, Government of India, is dedicated to education in IT in the non-formal sector. The society has designed bioinformatics courses at four different levels, ranging from basic diploma (‘O’ level) to MTech (‘C’ level). The courses are run at designated centres of DOEACC (http://www.doeacc.edu.in), e.g. a B-level programme, MSc (Tech) in bioinformatics, at the West Bengal University of Technology (WBUT), Kolkata.

PhD programmes in bioinformatics

Research work in the areas of computational biology and data mining leading to the award of doctoral degrees has been carried out in India since late 1960s. University of Pune was one of the first universities to have started a PhD programme in 1997 in bioinformatics per se and the first degree was awarded in 2000. Currently, PhD programmes in bioinformatics and computational biology are offered by several central, state and private universities, Indian Institutes of Technology (IITs) as well as research institutes (e.g. Indian Institute of Science, Bangalore; National Centre for Biological sciences, Bangalore; Centre for Cellular and Molecular Biology, Hyderabad; Centre for DNA Fingerprinting and Diagnostics, Hyderabad; National Institute of Pharmaceutical Education & Research at Mohali and other locations; various National Institutes of Technology; Institute of Microbial Technology, Chandigarh; Institute of Genomics and Integrative Biology, New Delhi, etc.). These programmes are mainly funded by the DBT, Department of Science and Technology (DST), Council for Scientific and Industrial Research (CSIR), Ministry of Communications & Information Technology (MCIT), Indian Council of Medical Research (ICMR), Indian Council of Agricultural Research (ICAR) and University Grants Commission (UGC). Availability of doctoral programmes has provided an impetus to research in bioinformatics.

CHALLENGES AND OPPORTUNITIES

Emergence of bioinformatics has ushered in new excitements in Life Science research and opened up new vistas in the career paths [8, 11, 16, 17]. Computational infrastructure is a crucial component for generating the human resource with desired skills and competencies. Through the establishment of BTIS Network, DBT has played and continues to play a significant role in this direction.

Bioinformatics being a multidisciplinary field, teaching programmes require experts from the core domain (bioinformatics) as well as from the basic areas of biology, mathematics, statistics, computer science and information technology. Only a handful of teachers with the necessary teaching and research experience in the field of bioinformatics are currently available. In most of the universities, the limited number of in-house faculty makes it necessary to invite experts from other institutions. With increasing numbers of courses all over the country, there is a growing demand for experts/teachers in this field. This opens up opportunities for the overseas bioinformaticians to return to India, facilitating brain gain.

Teaching bioinformatics to students as a component of Master’s degree programmes in other disciplines

In view of the wide spread applications in life science research, a few universities have included bioinformatics as a subject in the curricula of Master’s degree programmes in zoology, botany, microbiology, biochemistry, biotechnology and bioengineering. Students of these subjects are the potential users of bioinformatics and hence need to be trained in an ‘application-oriented’ manner. Bioinformatics
training is adding value to some of the engineering and management degree programmes as well. We envisage that bioinformatics training will soon be incorporated into the curricula of medical sciences so that the medical fraternity would be adequately equipped to apply modern methods of molecular medicine in clinical practice & research in future. Based on our experience of teaching bioinformatics to a few students with background in pharmacy and our interactions with experts working in the area of drug design, we believe that formal training in bioinformatics would empower pharmacists with new tools & approaches for the entire spectrum of application areas, viz. drug discovery, delivery and metabolism. Similar views on the inclusion of bioinformatics in pharmacy curricula have been expressed by Thorn et al. [18].

Need for modular courses
Professionals from different domains of life, physical and computer sciences can effectively utilize bioinformatics resources for knowledge discovery. In view of this, there is a growing interest to acquire the requisite skills through short term, tailor-made modular courses in bioinformatics. To cater to this requirement, BTIS centres funded by DBT are organizing theme-based short-term training programmes (http://www.btisnet.gov.in/uniquepage.asp?ID_PK=21). MCIT, Government of India has also taken the initiative to identify and fund Centres of Excellence with a mandate to design and deliver modular courses of short duration for professionals (http://mit.gov.in/content/bio-informatics). Pondicherry University and IBAB, Bangalore have recently launched such courses.

BioInformatics National Certification Examination
Recent years have witnessed a mushrooming of bioinformatics training programmes in Indian universities and institutions, both from the public and private sectors, with a wide variation in the course contents, training period and methodology of training. In view of this, recognizing the need to define the minimum core competency of the trained manpower in this area, DBT has instituted the BioInformatics National Certification (BINC) examination in 2005 with the objective to certify the bioinformatics knowledge and skills of the students (http://bioinfo.ernet.in/binc). However, formal training in bioinformatics is not a prerequisite to appear for this examination. The examination is novel and unique in that it employs a three-tier system of testing, viz. objective, short answer and computational laboratory based assessments.

The objective and short answer components of the examination include sections on biology, basic mathematics, statistics, physics, chemistry, information technology and bioinformatics. The skills assessed in the laboratory based examination are: (i) application of the existing bioinformatics tools, (ii) ability to analyse and interpret data and (iii) competency in programming. A national committee of experts has framed the syllabus for BINC examination, which is compatible with Master's level teaching programmes.

Candidates, who qualify in all the three individual components of the examination, are awarded a certificate. This certification is intended to serve as a benchmark to facilitate industries and other potential employers in recruiting bioinformatics professionals. As a corollary to the BINC certification, fellowships are also awarded to the top 15 BINC qualified candidates to pursue PhD in Indian institutes and universities in the area of bioinformatics and computational biology. This examination is open to students from other countries as well, for the purpose of certification only.

BINC examinations were conducted five times during 2005–10. A total of 2374 candidates, from 27 states and union territories of India have appeared for these examinations, of which, only 50 candidates have qualified for certification amounting to a success rate of 2.1% (Table 1). While candidates from more than 150 universities/institutes appeared for the examinations, those who qualified came from only 18 of them. However, the representation of universities/institutes to which successful candidates belong is becoming wider every year (Table 1). Of the candidates who qualified for certification, 80% had formal training in bioinformatics reflecting that these candidates had a distinct advantage over those who had limited exposure to bioinformatics during their education or through self-study. Among the BINC certified candidates the proportion of those with Master’s degree is 88%, which is significantly higher than those with a Bachelor’s degree (12%). This underlines the importance of education in basic sciences at Bachelor’s level as a prerequisite for adequate and comprehensive training in bioinformatics at the Master’s level. Thus, the recent rush to introduce courses in
bioinformatics at the Bachelor’s degree level by several institutes/universities appears to be premature and ill-conceived since students do not get an opportunity to have a sound foundation in basic sciences. Similar views have been expressed by Natesh and Bhan [11] on the Bachelor’s degree programmes in biotechnology.

**Way forward**

The resources available for bioinformatics educational programmes have been enriched over the period of last 10–12 years. The easy and efficient access to scientific knowledge through specialized journals, e-learning material, international conferences, workshops, etc. has further augmented the development of these programmes. The time is now ripe to anticipate a perceptible impact of the educational programmes on research and developments in life sciences in general and bioinformatics in particular in the country.

The first decade of the 21st century has witnessed an unprecedented accumulation of biological data due to spatio-temporal studies involving technologies that allowed capturing data at mega- and milli-scales. The complexities and volume of resultant data posed new challenges for management and mining and are expected to have a far-reaching impact on bioinformatics research. Furthermore, new approaches are needed for cross-scale and cross-discipline integration of data from biodiversity informatics, ecoinformatics and enviroinformatics, which is critical to a wide range of scientific and educational purposes as well as for decision-making in the sustainable use of natural resources [19]. These emerging trends, which would widen the scope of bioinformatics, need to be incorporated in the curricula. For example, studies of interactions at levels beyond molecular, such as cell–cell, species–species and species–environment as outlined in phylodynamics studies [20] should find a place in the curricula. Mathematical modelling and simulations of these interactions should constitute an important component of bioinformatics training in future. The students should also be exposed to skills in scientific writing and presentation, knowledge of intellectual property rights, ethics, morals and socio-scientific attitude to ensure their overall development. We believe that with the inclusion of these aspects in bioinformatics education, bioinformatics as a discipline will move into ‘the Forth Paradigm’, facilitating data-intensive discoveries in biological sciences [21].

**Table 1:** University-wise distribution of candidates who qualified in BINC examinations (2005–10)

<table>
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<tr>
<th>Sr. No.</th>
<th>Year</th>
<th>Name of the University</th>
<th>BINC Qualified Candidates</th>
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<tr>
<td>1.</td>
<td>2005</td>
<td>Indian Institute of Technology, Kharagpur</td>
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<td>2.</td>
<td>2007</td>
<td>Mohanlal Sukhadia University, Udaipur</td>
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<td>3.</td>
<td>2008</td>
<td>University of Agricultural Sciences, Bangalore</td>
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<td>University of Pune, Pune</td>
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<td></td>
<td>West Bengal University of Technology, Kolkata</td>
<td>1</td>
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<td></td>
<td></td>
<td>Institute of Bioinformatics and Applied Biotechnology, Bangalore</td>
<td>2</td>
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<td></td>
<td>Jaypee Institute of Information Technology, Noida</td>
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<td></td>
<td>Manipal Institute of Technology, Manipal</td>
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<td>University of Pune, Pune</td>
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<td></td>
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<td>4.</td>
<td>2009</td>
<td>Chaudhary Charan Singh University, Meerut</td>
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<td>Indian Institute of Technology, Bombay</td>
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<td>Indian Institute of Technology, Kanpur</td>
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<td>International Institute of Information Technology, Hyderabad</td>
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<td>JNU, New Delhi</td>
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<td>Panjab University, Chandigarh</td>
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<td>University of Pune, Pune</td>
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<td>Vellore Institute of Technology, Vellore</td>
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<td>5.</td>
<td>2010</td>
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<td></td>
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<td>Total</td>
<td>50</td>
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journal Nature clearly brings out the need for trained bioinformaticians as well as application of latest technology of cloud computing for archival and processing of genomic data to maximize the discoveries based on genomic data [22].

**CONCLUSIONS**

Recognizing the potential of bioinformatics, India has taken the early steps to establish the necessary infrastructure and initiated the training programmes in this area. Efforts in this direction have resulted in perceivable growth of bioinformatics and biotechnology in the country. Several research projects have been funded and successfully completed, resulting in the development of bioinformatics resources and publications in international journals of high impact factor (http://btisnet.gov.in/writereaddata/12271108171_Publication_List.pdf) [11]. The HRD activity has also culminated in the development of core competency. Bioinformaticians placed at strategic positions in the biotechnology and software industries have significantly contributed to the value chain to generate IPR as well as revenue. India, with its strengths in information technology, increasing investments in bioinformatics infrastructure and human resource development, is poised to play a greater role in the global landscape in future.

**References**


