Genesis of
Interdisciplinary Subjects in Science
and their
Reflections in Classificatory Devices

Thesis submitted to the Faculty of Arts of Jadavpur University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Library and Information Science

by
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Certified that the Thesis entitled

Genesis of interdisciplinary subjects in science and their reflections in classificatory devices submitted by me for the award of the Degree of Doctor of Philosophy in Arts at Jadavpur University is based upon my work carried out under the Supervision of Prof. Udayan Bhattacharya, Professor, Department of Library and Information Science, Jadavpur University.

And that neither this thesis nor any part of it has been submitted before for any degree or diploma anywhere / elsewhere.

Countersigned by the Supervisor:

Dated:

Candidate:

Dated:

Declaration

I hereby declare that the thesis entitled “Genesis of interdisciplinary subjects in science and their reflections in classificatory devices” is a bonafide record of work done by me and no part of the thesis has been submitted for any other degree.

………………………………

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Dedicated

to my

beloved family

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List of Abbreviations

Abbreviation	Details
DDC	Dewey Decimal Classification
UDC	Universal Decimal Classification
CC	Colon Classification
i.e.	That is
etc.	Et cetera
No.	Number
ed.	Edition
et. al.	et alia

Chapter 1
Introduction

1.1 Prologue

Knowledge is imperative to mankind. Its growth is prerequisite for social, economic, cultural as well as individual progress. It is integral to innovation and creation. The frontiers of human knowledge are continuously expanded and reshaped through the persistent quest to discover what lies beyond the familiar. The pursuit of knowledge by human mind, its acquisition, storage, organisation, retrieval, dissemination, and transmission are therefore vital to ensure the advancement of a society.

As defined by Daniell Bell (1979) knowledge is an "organised set of statements of fact or ideas, presenting a reasoned judgment or an experimental result, which is transmitted to others through some communication medium in some systematic form" (p.168). The universe of knowledge is however vast and constantly growing. Ensuring an unhindered and systematic transmission of knowledge across time and organising and storing them in a manner that would cater to the information need of every individual is essential but challenging.

Libraries are widely recognized as custodians of knowledge. They have played crucial role in preserving knowledge across generations. Libraries employ various well-structured and systematic tools of organising knowledge. One such important tool is 'Library classification schemes' in which the universe of subject is arranged in accordance with the academic disciplinary demarcations. Traditional subjects that are already established as distinct disciplines have their well-defined boundaries with their respective areas of study visibly different from one another.

The dynamic nature of universe of knowledge however gives rise to new subjects at any point of time. Also, knowledge creation and gaining, technological developments and problem-solving, often necessitates these traditional subjects to interact by crossing their well demarcated disciplinary boundaries in form of shared theories, tools and techniques, expertise etc. What results from this is the emergence of a new area or field of study, which with time develops its own theories, principals, experts; and eventually gives rise to a distinct new interdisciplinary subject and sometimes even to a new discipline. This genesis, growth and development of an interdisciplinary subject require a substantial amount of time and involve multiple stages of interactions. In each of these stages their exist different typology of relation among the interacting subjects before its final consolidation into a new interdisciplinary subject. The different typology of relations or modes of subject formations for the development of any subject has been discussed in subsequent chapters. As the subject evolves a significant challenge is faced in effectively incorporating these new interdisciplinary subjects into the existing disciplinary framework. Over time, the existing disciplinary boundaries become less distinct, prompting the need to modify the traditional arrangements in which the universe of knowledge is organised. Consequently, for incorporating these subjects into any library classification scheme it becomes essential to understand their interactions, existing relationships, and developmental stages and ensure an appropriate place within the scheme.

Cases of such interdisciplinary interactions among disciplines have been observed several times in Science, Social Science as well as Humanities. Specially in science, interdisciplinary interactions have significantly contributed to the progress of knowledge. The world has witnessed the emergence of new interdisciplinary science subjects, few of which have already established themselves as disciplines.

Existing literary output shows very little evidence on study of genesis, growth, and development of interdisciplinary science subjects and the reflection of the stages of development in the classificatory devices or how far the library classification schemes have incorporated these changes with the course of time. Therefore, a notable knowledge gap has been found in this regard.

1.2 Statement of the Problem and Research Questions

For any interdisciplinary subject the relation between the interacting individual subjects evolves through different stages. This research focused on the genesis and development of selected interdisciplinary subjects in the field of science and its reflection in library classification schemes.

The problem of the proposed research can be stated as:

A study of genesis of interdisciplinary subjects in science and their reflections in classificatory devices.

The problem stated above along with some necessary and relevant research questions emerging therefrom are to be resolved in course of the investigation.

The research questions in this direction are as follows:

i. How the selected interdisciplinary science subjects developed? What are the major stages? How can they be determined? What methodology should be adopted to this end?

ii. What typology of relation existed in each of the stages of development of the selected interdisciplinary science subjects? How can they be studied? What methodology should be adopted at this point?

iii. How the stages of development and typology of relation of the selected interdisciplinary science subjects are reflected in library classification schemes? How can they be determined? What methodology should be adopted in this regard?

iv. Is there any difference in the coverage of the selected interdisciplinary science subjects in the latest editions of the library classification schemes? How can they be studied? What methodology should be adopted at this point?

v. How the literary warrant of the selected interdisciplinary science subjects have grown over the years? How can they be determined? What methodology should be adopted in this regard?

1.3 Objective

The main objective of the research is to study the genesis of interdisciplinary subjects in science and their respective reflection in classificatory devices. In doing so the study attempted:

i. to trace the major stages of development of the selected interdisciplinary science subjects;

ii. to identify the typology of relations existed at each of the stages of development of the selected interdisciplinary science subjects;

iii. to trace the reflection of the stages of development and typology of relation of selected interdisciplinary science subjects in library classification schemes;

iv. to compare the coverage of the selected interdisciplinary science subjects in the latest editions of the library classification schemes;

v. to study the selected interdisciplinary science subjects in terms of their growth of literary warrant.

1.4 Methodology

In order to reach the above stated objective suitable methodology has been applied at each stage of the research. A brief outline of the overall methodology is given below:

For the purpose of fulfilling the objective of this study a method of document research was adopted. Literature search revealed that interdisciplinary subjects are formed through three 'modes of subject formation' viz: Fusion, Distillation and Clustering. A thorough document search was conducted, and an attempt was made to identify interdisciplinary science subjects formed by either of the three modes of subject formation viz: Fusion, Distillation and Clustering. Extensive scanning and reading of various documents have been done to ascertain the interdisciplinary nature and final mode of formation of the subject. Such documents included general and scientific dictionaries, general and science subject-based encyclopaedias, various science abstracts, thesis and books. Also, specific web resources of respective subjects were consulted. However, as new interdisciplinary science subjects are constantly emerging, it was neither convenient nor possible to cover all interdisciplinary science subjects (formed by the three modes of subject formation) for the fulfilment of the objective. So, for selecting the sample interdisciplinary science subjects, the latest edition of three library classification schemes viz: Dewey Decimal Classification (23rd edition), Universal Decimal classification (standard edition) and Colon Classification (7th edition) were taken into consideration. The latest editions of all the three classification schemes were searched exhaustively, and a list of interdisciplinary science subjects was prepared. While doing so only those interdisciplinary subjects that were found to have an assigned class number in any of the three schemes under science; and was formed through either of the three already mentioned 'modes of subject formation' was considered.

All the listed subjects under the three modes of subjects formation were then tested in terms of their Literary Warrant and a Checklist.

- For finding literary warrant a web survey method was adopted. Number of books available on OCLC World-Cat was traced. Literary warrant on a subject descriptor in the format of 'Books' and in all languages have been considered for this data collection. While selecting the subjects the time range of 10 years i.e. 2012-2021 (latest development) and subjects having minimum 500 publications within the above time range was considered.
- The checklist was prepared on the basis of various definitions and developmental study of an interdisciplinary subjects found during the document search.
- The detail of the checklist is given below:

Table 1: Sample Checklist

Subject Name:	
Checklist	**Yes/ No**
Availability of Journals	
Availability of Research Article	
Available Research Group / Department/ Degree Course in Universities	
Conference / Seminar on the Subject or its sub-areas	

- *Availability of Journals:* Journals were traced on the selected interdisciplinary science subjects if indexed in the Web of Science/ Science Direct / Scopus.
- *Availability of Research Article:* Minimum 1000 published research articles on each of the interdisciplinary science subject were traced in Web of Science/ Science Direct / Scopus in last ten years i.e. (2012-2021).
- *Availability of Research Group / Department / Degree course in Universities:* Department or Degree courses (Graduate or Post-Graduate) available in a university / institute / college were traced. World University ranking of Times Higher Education (2021) was referred while selecting or validating the universities for conducting the search.
- *Conference / Seminar:* Seminars or conference regularly held on the selected interdisciplinary subject or sub-areas in last 5 years i.e., 2017-2021 were traced.

The data collection for the initial selection of the subjects (both for literary warrant and checklist) were done in February 2022 and the data were reverified throughout the course of study and final data was collected on 12-18th June 2024.

Only those interdisciplinary science subjects that were found to fulfil all the criteria of the checklist were considered and arranged in order of decreasing literary warrant.

However, as the list of subjects were still large so for the final selection of the sample, 8 subjects formed by fusion, 2 subjects formed by distillation and 2 subjects formed by clustering modes (constituting approx. 70% of each of the three list separately) were taken into consideration.

The list of the interdisciplinary science subjects along with their final mode of subject formation are given below in an alphabetical order:

Table 2: List of subjects

Interdisciplinary Science Subjects		**Mode**
1.	Astrobiology	Fusion
2.	Astrophysics	Fusion
3.	Biochemistry	Fusion
4.	Bioinformatics	Fusion
5.	Biomechanics	Fusion
6.	Biophysics	Fusion
7.	Geochemistry	Fusion
8.	Geophysics	Fusion

9.	Microbiology	Distillation
10.	Molecular Biology	Distillation
11.	Environmental Science	Clustering
12.	Oceanography	Clustering

After the selection of the interdisciplinary science subjects, a detailed in-depth document search was conducted to trace the history and landmark development of each of the selected subjects that contributed towards its formation.

For finding the growth in the literary warrant of each of the selected interdisciplinary science subjects a web survey of the number of books available on of OCLC World-Cat was done. Literary warrant on a subject descriptor in book formats and in all languages was considered for this data collection. For subjects found in more than one classification scheme the earliest inclusion date was considered.

Here while selecting time range two different criteria were followed:

- For subjects included in previous editions of the classification scheme: 10 years before the subjects first inclusion and 10 before the last published edition of the scheme was considered.
- For subjects included only in the latest edition of the classification schemes: 10 years before and after last published edition of the scheme was taken into consideration.

The three previously mentioned classification schemes were studied to find out inclusion and development of the selected interdisciplinary science subjects. For doing this all the twenty-three editions of Dewey Decimal Classification and seven editions of Colon Classification were investigated for the study. For Universal Decimal Classification three editions viz: 1985 Medium Edition; 1993 Medium Edition Revised; 2005 Standard Edition were examined. The twenty-three editions of DDC, the three editions of UDC and the seven editions of CC have been accessed and studied from Internet Archive; Jadavpur University Central Library; Departmental Library of Library and Information Science department, Jadavpur University; National Library of India and D-Space Repository of Gokhale Institute of Politics and Economics, Pune.

Keeping in view the objective of the study, the data collected were tabulated, analysed and interpreted.

The stages of development of the selected interdisciplinary science subjects were identified from the traced history and landmark developments of the subjects.

The different typology of relation that existed at the various stages of development for each of the selected interdisciplinary science subjects were identified and analysed. The modes of formation were identified after thorough interpretation of the landmark developments.

The identified stages and typology of relations of the selected interdisciplinary science subjects and their reflection through their inclusion and development in the previously mentioned library classification schemes were studied.

An analysis was made of the identified differences in the coverage of the selected interdisciplinary science subjects in the latest editions of the library classification schemes- DDC, UDC, CC.

The growth in the literary warrant of each of the selected interdisciplinary science subjects were studied.

1.5 Limitation of Scope

The proposed study had been kept restricted within the twelve selected interdisciplinary science subjects due to time constrain of the researcher. Also, the study was kept limited to three classification schemes namely Dewey Decimal Classification, Universal Decimal Classification and Colon Classification schemes. Due to unavailability of all the editions of Universal Decimal Classification (UDC) only three editions i.e., 1985 Medium Edition; 1993 Medium Edition Revised; 2005 Standard Edition were studied for the research.

1.6 Significance of the Study

This study will have significant implications to the understanding of the course of any subject formation and thereby evaluating the appropriateness of the inclusion of new subjects in classification schemes. As emergence of new subjects especially those interdisciplinary in nature is bound to happen, so it is pertinent to be able to accommodate those subjects within the disciplinary structure of a library classification scheme. However, to provide a new subject a justified position in the schemes, it is necessary to understand the typology of relations that existed between the interacting subjects. Also, it is inevitable that the nature of this relationship will change, and the core focus of a subject might also shift further necessitating a number relocation to suit the scope of the subject aptly. As this study identifies the significant developmental stages of the selected subjects and traces its corresponding reflection in classification schemes, this study will aid in the understanding of the concept of subject formation. Identifying the existing gaps in the process of incorporation will significantly help classificationists, those responsible for regular updation of classification schemes and anybody dealing with classification both in theory and practice.

1.7 Style of Reference

The American Psychological Association (APA) citation style is one of many different citation styles. Guidelines of American Psychological Association, 6th ed., 2009 was followed here for citation of print and non-print materials in the text and for making list of references.

1.8 Outline of Chapters

The research was presented in the following chapters:

Chapter 1 titled ‘Introduction’ deals with the problem of the research along with research questions, objectives. It also specifies the limitation of scope, and the methodology adopted to fulfil the objectives. It also discusses the significance of the study.

Chapter 2 titled ‘Literature Review’ provides a thorough review of the literature in relation to the problem of the research.

Chapter 3 titled ‘Interdisciplinary Subjects: An Overview’ discusses the concept of interdisciplinary subjects, its characteristics, emergence, modes of formation, and related terms like transdisciplinary, multidisciplinary, cross disciplinary.

Chapter 4 titled ‘Classification Schemes: A Brief Account’ deals with library classification schemes, its need and focuses on the structure and nature of the selected classification schemes for this study viz: Dewey Decimal Classification, Universal Decimal Classification and Colon Classification.

Chapter 5 titled ‘Interdisciplinary Subjects in Science: A Study’ gives a detailed analysis of the evolution of each of the subjects, its historical and landmark developments.

Chapter 6 titled ‘Reflections in Classificatory Devices’ identifies the incorporation of the interdisciplinary science subjects. It traces how far the classification schemes were able to accommodate the newly emerging subjects, how the number allocated to the subjects have been relocated to new class numbers in the course of the evolution of the subject.

Chapter 7 titled **‘**Data Analysis and Interpretation’ focuses on the analysis and interpretation of the collected data to reach the objective of the study.

Chapter 8 titled ‘Findings and Conclusion’ provides with a summary of the findings of the study. Areas of further research have also been suggested here.

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Chapter 2
Literature Review

2.1 Introduction

A literature review is an account of the existing publications on a specific topic, subject field, or research area. It is the process of critically analysing, evaluating and documenting works that are related to the research topic being studied. A comprehensive review allows to gain an insight into the present state of knowledge on the topic under discussion. This also aids to identify unsolved research problems in areas associated with concerned topic thereby allowing to find the research gaps and narrow down on topics on which further research can be carried out.

The purpose of this literature review is to throw light on the already existing literature that are relevant and pertinent to this current research. The present research aims to investigate the growth and development of different interdisciplinary science subjects, identify the modes of formation or the typology of relations between the collaborating subjects at different stages of its development and trace the reflection of these stages of developments in library classification scheme. With this study under consideration, works relating to interdisciplinarity, modes of subject formation and treatment of subjects in library classification schemes were therefore explored from various perspectives. An in-depth and thorough literature search was conducted from scattered information sources like journal articles, conference papers, thesis and dissertation, books, research reports etc.

The major sub areas under which this review has been conducted includes:

- Concept of 'interdisciplinary' in academics;
- Study of interdisciplinary interactions;
- Formation of interdisciplinary subjects;
- Interdisciplinarity and science subjects;
- Treatment of subjects in classification schemes.

2.2 Concept of 'Interdisciplinary' in Academics

The concept of 'Interdisciplinary' in academics encompasses various dimensions. Simply put 'interdisciplinary' refers to "involving two or more academic, scientific, or artistic disciplines" (Interdisciplinary, n.d.). Interdisciplinarity as put forward by Nissani (1995) is "bringing together in some fashion distinctive components of two or more disciplines" (p. 122). When practiced in academics such involvement can be witnessed in different context viz: education, teaching, curriculum, learning, research etc.

Thus, depending on the specific context in which the term is considered, it can have various usage and interpretations.

Studies that draw on techniques and viewpoints from a number of well-established disciplines or conventional fields are referred to as "*Interdisciplinary Studies.* Klein and Newell (1996) described interdisciplinary studies as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession . . . and draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective" (p. 3). The need for interdisciplinary study lies in the complex systems as understanding its structure and behaviour requires multifaceted approaches. Newell (2001) opined that the characteristics of complex systems justify the need for interdisciplinary exploration, offers new insights and reinforces established principles. Furthermore, complex systems play an important role in integrating somewhat unrelated methodologies employed in the interdisciplinary examination in case of both the humanities and the sciences. He focused on the significance of applying 'Complex

System Theory' to conceptualize the interdisciplinary process broadly and integration specifically. Klein (2005) examined links between integrative learning and interdisciplinary studies. She put forward that from the intersection of the two concepts emerged the ability to ask questions on complex issues; ability to locate multiple resources; the ability to compare and contrast them; to reveal patterns and connections; the ability to create a more holistic understanding. To Repko, Szostak & Buchberger (2017) interdisciplinary studies involve processes to solve complex problems, which are based on 'integration of disciplinary insights.'

Closely related to interdisciplinary studies are concepts like interdisciplinary curricula, interdisciplinary education, interdisciplinary teaching, interdisciplinary learning, and interdisciplinary understanding.

Interdisciplinary Curricula according to Grady (1994) "present content across the disciplines by blending teachers' approaches and students' inquiry. Students examine the topic or issue through one of many complex reasoning processes selected by the teachers who had planned the interdisciplinary curriculum" (p. 6). Jones (2010) while studying advantages, disadvantages and future benefits of interdisciplinary studies put forward that creation of interdisciplinary curriculum requires collaborative teamwork and time.

Rhoten, Mansilla, Chun, and Klein (2006) defined *Interdisciplinary Education* as a "mode of curriculum design and instruction in which individual faculty or teams identify, evaluate, and integrate information, data, techniques, tools, perspectives, concepts, and or theories from two or more disciplines or bodies of knowledge to advance students' capacity to understand issues, address problems, and create new approaches and solutions that extend beyond the scope of a single discipline or area of instruction" (p. 3). While discussing impact of interdisciplinary education on curriculum Styron (2013) remarked that interdisciplinary education encourages creativity and allows to think, collaborate and communicate beyond a single disciplinary boundary.

Interdisciplinary Teaching on the other hand "involves a much broader kind of collaboration and integration, one in which a theme begins to encompass all curricular areas involved" (Sahay 2019, p. 86). Nikitina (2006) discussed three for interdisciplinary teaching. These approaches were 'contextualising', 'conceptualising', and 'problem-centring' which according to her must be dependent on the discipline being studied. She demonstrated that if the basic discipline involved in interdisciplinary teaching in humanities, then the approach to be involved is contextualizing; if the interdisciplinary interaction involves scientific method, in that case the approach involved will be conceptualising; if the teaching is that of the applied science the approach for integrating must be problem-centring.

Interdisciplinary Learning as pointed out by Ivanitskaya, Clark, Montgomery & Primeau (2002) "focuses on the methodologies, interpretive tools, and language of several disciplines on a central problem, issue, or theme" (p. 108). It involves "shifting the programmatic focus from memorization of facts to focus on a central theme, application of knowledge relative to this theme, and reflection on the thinking process" (Ivanitskaya, Clark, Montgomery & Primeau 2002, p. 98).

Boix Mansilla (2005) defined "*Interdisciplinary Understanding* as the capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement – for example, explaining a phenomenon, solving a problem, or creating a product, or raising a new question – in ways that would have been unlikely through single disciplinary means" (p. 16). Newell (2013) advocated the development of theory for growth and advancement of the interdisciplinary field. To him theoretical backup is necessary for greater acceptance of interdisciplinary studies.

The above-mentioned dimensions of 'interdisciplinary' although varies in their definition, however, at the core of all the concepts lies interdisciplinary collaborations involving two or more disciplines.

Interdisciplinary research is another major area where collaborations among subjects are frequently observed. It is through research that involves two or more knowledge domain, the interdisciplinary nature of a study gets manifested. So, interdisciplinary research has over the time emerged as a crucial part of the research landscape. By dismantling barriers, interdisciplinary research enables innovative findings that might not be achievable inside the boundaries of a specific discipline.

Karlqvist (1999) opined that interdisciplinary research "signifies a gap and lack of connection to be closed and fastened by additional means not yet available within the disciplines themselves" (p. 379). The National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (2005) defined interdisciplinary research as a "mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (p. 2). Aboelela et.al., (2007) in their work put forward a definition of Interdisciplinary research after conducting a systematic literature review, interviews and field tests with interdisciplinary researchers. They defined interdisciplinary research as "any study or group of studies undertaken by scholars from two or more distinct academic fields, based on a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requiring the use of perspectives and skills of the involved disciplines in all phases from study design through data collection, data analysis, specifying conclusions and preparing manuscripts and other reports of work completed" (pp. 339-341).

Research publications and their extent to which they integrate other disciplinary fields in terms of methodology, tools, theories, and data can also come under the purview of interdisciplinary research. Such process or research requires a number of steps to be carried out successfully. Klein (1990) put forward twelve steps interdisciplinary process which individuals must engage in to overcome the boundaries that exist due to differences in disciplines and world view; Szostak (2002) provided a twelve steps model of Interdisciplinarity; Newell (2007) came up with a fourteen steps model of interdisciplinary research process; Repko (2008) put forward ten steps for an integrated approach to the interdisciplinary research process.

A 'subject' that has not received enough focus or its interpretation is hindered to a large extent within the disciplinary structure necessitates interdisciplinary research. Gomez (2020) put forward the example of women's studies or ethnic area studies. The intrinsic complexities in the subject matters in such fields of studies requires 'perspectives combined from two or more disciplines' to comprehend the problems and bring solutions to it. He stated, "It is about creating something by thinking across boundaries" (p. 1).

The impact of interdisciplinarity on 'subjects' also resulted into the emergence of new 'Subject' that are itself interdisciplinary in nature. *'Interdisciplinary subjects'* therefore occupies a major area of research. Gopinath (1981) stated that 'the development of interdisciplinary subjects is determined by the connection established or focused on a specific issue or phenomenon; a conscious effort to motivate people from different fields to focus their attention on a particular issue, phenomenon, or mission’. Bhattacharya (2006) defined interdisciplinary subjects as those subjects that “emerge as a result of interaction between two or more traditionally known well demarcated disciplines” (p. 4). In an interdisciplinary subject, “students explore and integrate multiple perspectives from different disciplines, sub-disciplines and areas of expertise” (Golding, 2009, p. 3).

The emergence of a distinct interdisciplinary subject is however, preceded by a significant history of numerous interdisciplinary interactions and collaborations among the already established disciplines. Several studies have been conducted focusing on such interdisciplinary interactions among disciplines using different methods. The next section review works related to the study of such interdisciplinary interactions.

2.3 Study of Interdisciplinary Interactions

Chettiparamb (2007) stated that “the organisation of disciplinarity and interdisciplinarity is intertwined historically, with interdisciplinarity (most often) quietly flourishing within disciplines” (p. 15). A critical review of the literary search revealed that while studying interdisciplinary interactions researcher mostly focused on the collaborative works undergoing between two or more interacting subjects. Publications (research articles as well as journals) were found to be an important source to study such collaborations. It was also observed that there exists no well-defined methodology on how to evaluate the interdisciplinary nature of the interactions. Researchers therefore time and again adopted approaches and methods as per their perception and applicability.

A method widely seen to be used for assessing the interdisciplinarity in a subject was through ‘Citation Analysis’ and ‘Co-citation Network’. Chen, Arsenault & Lariviere (2015) analysed interdisciplinarity present in the one percent top cited papers and least cited papers published in the year 2000 and available in the Web of Science database using Simpson index and found that the top cited papers are more interdisciplinary than its counterpart; thereby suggesting that interdisciplinary research played a more important role in generating high impact knowledge. Karunan, Lathabai & Prabhakaran

(2017) opined the accumulation as well as flow of knowledge are best reflected through analysis of citation network of articles which in turn helps to identify specific developments that might cause interdisciplinary evolution. They in their study attempted to investigate interdisciplinarity of subjects at the level of published articles; formed an interdisciplinary assessment framework using both qualitative and quantitative methods and identified interdisciplinary interactions. Hammarfelt (2011) demonstrated the changes in interdisciplinary citation in monographs, made a comparison of the changing trends in citation of two different time periods and thereby attempted to show the 'potential citation analysis in providing insights into the interdisciplinary intellectual base in Arts and Humanities.' Hernandez and Dorta-Gonzalez (2020) focused on analysing interdisciplinarity on the basis of publication and citation link. They based their analysis on citation network comprising of selected papers and other papers that they have cited. A total of 30 research article published in 2018 were considered and Scopus database was used as a source of citation. The results according to them revealed that the disciplines to which the articles belonged are highly interdisciplinary. Leydesdroff, Wagner & Bornmann (2019) in their attempt to study interdisciplinarity analysed the citation pattern of 11,487 journals covered by the Journal Citation Reports 2016 of the Science Citation Index and the Social Sciences Citation Index as well as the citation patterns of 85 journals assigned to the Web-of-Science category "information science & library science". The analysis was made from perspectives of both cited and citing directions by using their new modified indicator DIV which to them prove a better result in understanding interdisciplinarity.

Closely related to citation analysis another frequently used approach found was study of 'Co-authorship Pattern' in published articles or any journal relating to a subject field. Using co-authorship pattern in analysis of interdisciplinarity are exhibited in works by Liu & Xia (2015). They studied the co-authorship network in the field of 'Evolution of Co-operation' based on Web of Science. They identified a giant component of its collaboration network.

Determining interdisciplinarity using multiple Bibliometric indicators were observed too. Morillo, Bordons and Gomez (2001) used bibliometric indicators to measure interdisciplinarity and conducted empirical research in the field of chemistry. In determining how far the nature of interdisciplinarity has changed between 1975-2005 by investigating over six research domains Porter and Rafols (2009) employed bibliometric indicators, a new index of interdisciplinarity (Rao Stirling diversity) and a Science Mapping Visualisation method. The new index of interdisciplinarity showed a modest (around five percent) growth in interdisciplinarity. Chang and Huang (2011) used three bibliometric methods: direct citation, bibliographic coupling, and co-authorship analysis, to investigate interdisciplinarity in Library and Information science (LIS) in the period 1978-2007. As the results of study revealed that each of the three bibliometric methods varies and provide different insights so they put forward that using single bibliometric indicator cannot reveal all aspects of interdisciplinarity.

Rafols, Leydesdorff, Hare, Nightingale and Stirling (2012) demonstrated the disadvantage of using journal ranking in evaluating interdisciplinary research. They used publication and citation data to study the degree of interdisciplinarity. They opined that the method of 'excellence-based' journal ranking is biased towards mono-disciplinary research. They moreover stated that such biasness would impact the interdisciplinary evaluation and thereby affect funding and even hinder the process of research on interdisciplinary nature of subjects.

'Social Network Analysis' was carried out by Leydesdorff (2007) on 7379 journals included in the Journal Citation Reports of the Science Citation Index and Social Science Citation Index 2004. It focused on set of centrality measures like degree, betweenness and closeness centrality and recommended betweeness centrality as the measure of interdisciplinarity of journals. In another study Leydesdorff and Rafols (2011) studied the importance of network indicators (betweenness centrality), Journal indicator (Shannon Entropy, The Ginni Co-efficient) and Rao-Stirling measure of interdisciplinarity. They used 8207 journals from Journal Citation Reports of the Social Science Citation Index 2008. The study revealed that although all three indicators were used but different indicators represented different levels of understanding of interdisciplinarity.

In his study "A study of interdisciplinary research collaboration" Qiu (1992) used the 'author's organizational affiliations' to understand interdisciplinary collaboration in published literature and found that quality of a journal is positively correlated with the number of interdisciplinary papers it contains.

Palmer (1999) investigated the 'structural and strategic' features of information transfer among interdisciplinary scientists and their intellectual domains. In the study, data collected from interviews demonstrated that scientists do both individual and cooperative boundary-crossing research. 'Boundary crossing' according to Pierce (1999) 'might result in complex patterns of interdisciplinary information transfer as it had the most potentiality as a means for interdisciplinary information transfer. The studied articles received more citations from the disciplines in which they were published than from the disciplines with which their first authors were affiliated, and more citations from other disciplines than from either the discipline of publication or the first author's discipline and hence were considered as capable of interdisciplinary information transfer.'

In the study of interdisciplinary nature of Library Science, Baradol and Kumbar (1998) employed a method of 'analysis of terms/concepts' belonging to other subject field than the subject matter of the review article in consideration. They found that the subject has interdisciplinary relations 29 other subjects.

Pratt (1977) put forward an 'index' for studying interdisciplinarity which came to be known as Pratt Index. The basic assumption was that the interdisciplinarity of a subject field relies on the proportion of cited reference belonging to different categories. Rafols and Meyer (2010) provided a conceptual framework for evaluating interdisciplinarity based on two concepts: 'Diversity' and 'Coherence' and suggested that combining these two approaches might be beneficial in comprehending interdisciplinarity. In a similar study Xu, Guo, Tue, Ru and Fang (2016) formulated 'Term Interdisciplinary (TI)' index for interdisciplinary topic mining in a given subject field.

Thus, from the above discussion numerous qualitative and quantitative approaches to study and assess the interdisciplinary interactions were recognised. These interdisciplinary interactions, gradually give rise to an interdisciplinary subject. However, the growth of an interdisciplinary subject is a lengthy process. As the interdisciplinary interactions continues the relation between the interacting subjects evolve through a number of stages. These stages of interaction can be identified with certain typology of relation or 'modes of formation' of interdisciplinary subjects.

2.4 Formation of Interdisciplinary Subjects

According to Binwal (1992) *modes of formation of subjects* "represent a typology of relations and act as guiding ideas in recognizing and formulating relations among concepts constituting a subject" (p. 197). Modes of subject formation has contributed "to the development of a typology of relation which has proved useful in designing schemes for classification" (Kumar, 1988, p. 201). Neelameghan (1967) opined that "a historical study of the pattern of development and the structure at different stages in the growth will help to recognize the modes of formation of subject" (p. 344). He also mentioned that as subjects would develop there might be an increasing inter-subject interaction which would become very much significant.

In his article 'Colon Classification Edition 7: a preview', Ranganathan (1969) had put forward twelve modes of subject formation namely Lamination 1, Lamination 2, Loose Assemblage 1, Loose Assemblage 2, Loose Assemblage 3, Fission, Dissection, Denudation, Fusion, Distillation, Partial Comprehension and Subject Bundle. While describing each of the modes he identified Loose Assemblage 1 as the mode where one subject is studied in light of another and Fusion as the mode where two or more subject gets fused together to form a new subject. In both the cases the subject that would emerge are bound to be interdisciplinary in nature.

Neelameghan and Gopinath (1972) discussed the idea of Fused main subject where a Primary Host subject (MS) and a Secondary Host subject (MS) are in a state of fusion. They illustrated the same with examples of interdisciplinary subjects such as Biolinguistics, Psycholinguistics, Astrophysics, Astrobiology etc. Neelameghan (1973) further studied the formation of Primary Basic Subject through fusion and discussed the arrangement of those subjects in Colon Classification. He pointed out that the increasing literary warrant gained by Fused primary basic subjects were result of the growing interdisciplinary research. Neelameghan (1974) recognised three interdisciplinary borrowings for interdisciplinary subject formation namely: Borrowing of techniques and tools; Borrowing of Data; and Use of principles and theories of one discipline in another discipline. Gopinath (1981) examined the interdisciplinary nature of Sociobiology and considered its mode of formation as Fusion. Binwal (1988) studied the modes of formation of subject and their role in information retrieval tool where he put together the modes identified by Gopinath, Neelameghan and Ranganathan for the formation of interdisciplinary subjects.

In studying Biochemistry as a case study Gopinath and Seetharama (1975) declared loose assemblage, lamination, fission and fusion as the modes of formation at different stages of its development. Binwal (1992) identified three modes of formation viz: loose assemblage, fission and fusion at different stages of development of the subject Biochemistry. So, studies show that formation of an interdisciplinary subject can even include modes like Lamination or Fission.

Sen (2009) associated the birth of a subject with the coming up of a segment in the Universe of Knowledge. However, he differentiated between what he termed as 'formation of a subject' and 'formation of a subject system'. Sen stated that Subject system is born when two or more segments join together loosely example Physics in 20th century. But when two or more segments join together firmly, another segment is formed, e.g., Biochemistry. Satija, Madalli and Dutta (2014) studied the growth of subjects under three categories: growth by specialization, interdisciplinary growth, and multidisciplinary growths. Under each category they put forward certain modes of formation of subjects. For Interdisciplinary growth they were in conformity with Ranganathan and hence identified two modes viz: loose assemblage and fusion.

A clear idea about the modes of formation of any particular interdisciplinary subject can be found by analysing the interaction among its collaborating subjects at the various stages of its growth and development. Tracing the growth and development of an interdisciplinary subject and its interdisciplinary interactions are therefore imperative for determining its position in Universe of Knowledge.

Keeping in mind the objective of this research the next section focuses on the available literature specifically related to interdisciplinarity and science subjects covering works on nature of interdisciplinary interaction or collaboration between science subjects, and historical development of specific interdisciplinary science subject.

2.5 Interdisciplinarity and Science Subjects

Identifying interdisciplinary subjects in science encompasses perceiving of the interaction between two or more Science subject. Smirnov (1994) identified three broad types of unity of Scientific disciplines- Ontological objective unity for subject matter; Common epistemological structures of different scientific modes; and Sociological forms. To him interdisciplinary interaction can begin in any of the three types of unity.

Interdisciplinary interactions can be found at a very local level. In science, collaboration of researchers belonging to different subjects with a 'problem solving' approach, facilitates research that cross the boundaries of the traditional subjects or disciplines.

The interactions and convergence as pointed by Alvargonzález (2011) “can lead to a practical and theoretical integration of the disciplines involved, which would be unified. Paradoxically, these convergences, on many occasions, give rise to new independent and sovereign disciplines, at least when they are considered in terms of their academic institutionalization” (p. 393).

These interactions however not necessarily always result into new interdisciplinary subjects.

The emergence of a new subject in science requires the integration of various elements from existing fields. This process often involves applying techniques or methodologies from one discipline to address unresolved issues in another (Darden & Maull, 1977). The combination of these diverse components is essential for the development of innovative scientific fields. The ability to synthesize knowledge across disciplines is a key factor in advancing scientific inquiry and problem-solving.

Interactions of Natural Sciences by crossing their own disciplinary boundaries contributed towards increasing its interdisciplinarity. Hackerman (1978) studied the interdisciplinary nature of chemistry and stated, “the tools of the physicist have given the chemist a far better interdisciplinary understanding of nature than ever before” (p. 332). The interdisciplinary nature of Physics was explored by Manolea (2014) focusing on the interaction between Physics and Mathematics; Physics-Chemistry-Mathematics; Physics and Biology. She was of the opinion that Physics borrows methods from Biology, Chemistry, Astronomy, Technical Discipline and Mathematics. Masanja (2008) examined the impact of modern mathematics in other disciplines like Material Sciences, Biology, Technology etc. Sujatha & Sharma (2016) identified the role of Mathematics in other disciplines like- Material Science, Biology, Chemistry, Physics, Technology, Statistics etc. Correlations of Mathematics with Chemistry, Physics, Geography, Social Science, Agriculture, History, Economics, Astronomy were highlighted by Kumar (2017). Yeasmin (2017) looked into the relation of Mathematics with other disciplines with the focus on how far application of Mathematics in curriculum is possible and on disciplinary integration. Burggren, Chapman, Keller, Monticino & Tarday (2017) studied interdisciplinary in Biological Sciences. They reviewed the interaction between Biology and Medicine; Biology and Chemistry; Biology and Engineering; Biology and Mathematics. Mickaelian & Farmanyan (2021) analysed the interdisciplinary interaction of Astronomy with other sciences like

Physics, Chemistry, Biology, Mathematics, Informatics, Geology, Meteorology etc. and its role in creating of new interdisciplinary areas.

Determining the nature of collaboration between the interacting science subjects were also carried out using different measures. Using cross-disciplinary citation flow Van Leeuwen & Tijssen (2000) provided 'macro-level data' on interdisciplinarity of modern science and identified disciplines like Meteorology and Atmospheric Sciences as witnessing increased interdisciplinary collaborations. Steele and Stier (2000) used citation analysis to study relation between citation rate and degree of interdisciplinarity in Forestry (Environmental Science). While analysing more than 750 articles of the journal 'Forest Science' they identified three types of interdisciplinarity namely: authorship, subject matter and cited literature. They indicated borrowing as an important method of interdisciplinary transfer of information. In measuring interdisciplinarity in Chemistry Morillo, Bordons & Gomez (2001) used a series of indicators based on Institute for Scientific Information (ISI) multi-assignation of journals in subject categories. The quantity and their quality of links were used to outline the research areas and categories. There were found significant levels of interrelationships between the categories. Rinia, Van Leeuwen, and Van Raan (2002), in dealing with interdisciplinarity in Physics research program investigated how far articles resulting from research programmes got published in journals that belonged to its main discipline and how many of them were published in journals of other discipline. 'Network analysis was used to map interdisciplinarity and determine the extent to which environmental science disciplines draw on other disciplines' (Hicks, Fitzsimmons, & Polunin, 2010). They found no relation between age and size of a discipline on measures of interdisciplinarity for papers published in 2006. For identifying interdisciplinary research in Nanoscience and Nanotechnology, Stopar, Drobne, Eler, Bartol (2016) used the method of citation analysis. To quantify interdisciplinarity in Physics Pluchino et.al. (2019) analysed articles and their authors belonging to a period of 30 years (1980-2009), using the Physics and Astronomy Classification Scheme. They opined that interdisciplinarity contributes to increasing success.

Similar studies focusing on the already recognised interdisciplinary subject were observed too. Hinze (1994) made a bibliometric analysis on the then emerging subject of 'Bioelectronics'. The evolution of a new discipline by fusion was illustrated with the help of bibliometric methods. The interdisciplinary facets of Bio-nanoscience were demonstrated by Rafols and Meyer (2010) by the means of Disciplinary Diversity and Network Coherence. Chen, Arsenault, Gingras, & Lariviere (2015) attempted to 'confirm that interdisciplinarity develops through interaction with neighbouring disciplines first and then diffuses toward cognitively more distant disciplines.' In doing so the study explored interdisciplinarity evolution of Biochemistry and Molecular Biology (BMB) over a period of one hundred years. Interdisciplinary collaboration in Astrobiology research was undertaken through a bibliometric investigation by Taskin & Aydinoglu (2015). A case for Bioinformatics to be included as a part of interdisciplinary curricula was put forward by Kang, Park, Venkat, & Gopinath (2015) after making a comparative analysis of its available published literature in PubMed with the amount of published literature present on Biochemistry in the same database. They also made a similar study for two other interdisciplinary subjects viz: Biophysics and System Biology.

Documenting the history of evolution of an 'interdisciplinary science subject' have also been attempted. As previously mentioned, Gopinath and Seetharama (1975) illustrated the typology of relation that they found to exist in the interdisciplinary fields of Biochemistry. Binwal (1992) elaborated the growing nature of universe of subject with the example of Biochemistry where he identified the structural changes that the subject had undergone at different stages of development. Gupta (1986) outlined the development of exploration Geophysics as a scientific discipline and discussed the factors responsible for its development. Tout (1987) dealt with the history of Biometeorology and the advances it has made. Dalgarno (2000) focused on the early history of Astrochemistry. Glaser (2012) in his book 'Biophysics' gave an introductory idea on how the interdisciplinary field of Biophysics came into existence. Cockell (2002) discussed the evolution of Astrobiology and how it existed in the then current scenario. He furthermore predicted the importance that the subject might enjoy in future. McSween, Richardson & Uhle (2003) gave a very brief historical overview on the rise of the subject Geochemistry. A similar outline on growth of Geochemistry was given by White (2013). The development of Biochemistry from eighteenth century to twentieth century was elaborated by Coley (2002). Singh, Batra & Naithani (2004) also gave a detailed account on the genesis and development of Biochemistry as an interdisciplinary subject. Longair (2012) explored how the different interdisciplinary interactions in Astronomy led to the emergence of Astrophysics.

Except for the two studies conducted by Gopinath and Seetharama (1975) and Binwal (1992) all the other works discussed above attempted to trace the historical timeline, mostly focusing on the major breakthroughs that had been witnessed in the course of its development. Those works did not identify the modes of subject formation at different stages of development of an interdisciplinary subject. Even the two studies mentioned above focused on only one interdisciplinary science subject that is ‘Biochemistry’. Thus, a research gap was identified.

Any attempt to identify modes of formation of a subject corresponding to its different stages of growth and development requires a detailed tracing of the subject’s evolution and interactions. This is where library classification system can play a significant role. Mitchell & Diane (2009) identified DDC as a potential source to map the evolution, growth, and development of subjects. “Classification systems for library collections, like any knowledge systems, are products of their times and cultural contexts.” (Searing, 1992, p. 8). They are not just a mere list of some subjects and corresponding class numbers. Rather, classification schemes are reflective of the knowledge structure existing in its time period. When new subjects emerge, they are expected to be included into classification schemes. As those new subjects further solidifies, their position in the structure of the classification scheme needed to be revised. So, the study of the treatment of a subject, its incorporation, and revisions, in a classification scheme can aid in picturing the growth and development of a subject. Keeping in view the objective of the study, literature found on treatment of subjects in classification schemes were reviewed next. The following sections therefore provides an overview of works done on different ‘library classification schemes’ relating to ‘treatment of subjects’ in such classification Schemes.

2.6 Treatment of Subjects in Classification Schemes

A thorough literature review revealed that the scope of works on ‘treatment of subjects in classification schemes’ are vast. Subjects belonging to Social Science, Humanities, Science or Technology all can fall within the purview of such study. These subjects can be monodisciplinary, multidisciplinary, cross-disciplinary, or interdisciplinary.

While conducting the review a number of initiatives taken to understand treatment of science subjects in classification schemes were found. Rajabhupathy in1944 (as cited in Shenoy, 1998) gave a brief account of treatment of 'Mathematics' in the Decimal and Colon Classification He opines that the Canon of Hospitality, Canon of Helpful order etc are well satisfied by the CC, while DDC violates it very much. Treatment of Physics schedule in DDC 14th edition and CC was examined by Ramabhadran (1944, as cited in Shenoy, 1998). Biological Sciences (Biology, Botany, Zoology, Medicine and Animal Husbandry including Veterinary Science) were compared in the Decimal and the Colon Classification by Sivaraman in 1944 (as cited in Shenoy, 1998). Rao (1944, as cited in Shenoy, 1998) explained the treatment of 'Agriculture' in CC and DDC and opined that hospitality in notation is more in CC as compared to DDC. Gopinath (1973) put forward a revision for the class 'E' Chemistry to accommodate all the subjects going with the primary Basic subject 'Chemistry'. Similarly, Neelameghan and Seetharama (1973) discussed about revising CC for subjects going with basic subject 'B' Mathematics. They were of the opinion that the existing schedule could satisfy classification of subjects of macro documents only when they are considered as a whole and not for micro subjects. Herla and Baradol (1997) made a comparison of Physics schedule between the seventh edition of Colon Classification and the twentieth edition of Dewey Decimal Classification on the basis of various characteristics, such as, placement of physics among other subjects, the neighbourhood relations, terminology used, the arrangement of schedules, notation, mnemonics, etc. They have pointed out efficiencies and drawbacks of both the schemes. Again Fraser (2017) discussed the position of Mathematics in the 'overall scheme of knowledge'. He observed that Mathematics in most of the classification scheme was placed under Natural Science. He also made a comparative analysis of how the subject was included in DDC, CC, Bliss and Library of Congress classification schemes. Tutu (2016) highlighted the way Pure Science subjects were recognised in Dewey Decimal Classification and Colon Classification. An attempt was also made to propose a model for a new classification scheme. Panda & Jana (2021) elaborated the changes in nomenclature of the class 570 in Dewey Decimal Classification Scheme. It showed the treatment of subjects under 570 and the terminological changes that took place in all the editions of DDC.

Works on treatment of Social Science subjects were also retrieved. Dasgupta in 1944(as cited in Shenoy, 1998) has compared the class of History and Political Science in DDC and CC. Parthasarathi (1944, as cited in Shenoy, 1998) made a similar comparative study between CC and 14th edition of DDC on the subject 'Economics' and favoured CC as a more helpful scheme for classification. Parkhi in 1944 (as cited in Shenoy, 1998) gave an overview of how far the subject 'Indology' can be classified in CC and DDC. CC came out as having better possibility of representation of all branches of the subject. Fosket (1971) analysed the structural problem of DDC, UDC, CC, LCSH and demonstrated their inability to represent new and emerging subjects in Social Science. He advocated the adoption of 'Facet Analysis' as a solution. Representation of complex subject in CC through multi-phased subjects was recommended by Satija. There can be two-phased or three-phased interactions among subjects. While citing the example of Geopolitics he enunciated that in CC 6th edition the class number of Geopolitics required number building through phase relation, and it was in CC 7th edition that it got listed as a main class (Satija, 1979). Pacey (1989) gave an account on classification of 'Literature' class in DDC. The study pointed out that except for 'American Literature' all other literatures were classified on the basis of language and not region. This to him made literature of certain regions subordinate to others whose mother tongue was of the language under which it was placed. Pathak (1995) evaluated the 'Sociology' schedule in DDC and recommended changes in representation of main concepts, filiatory sequence, structure etc. Jana (1998) showed the terminological development, class number modifications and how the sub areas of the basic class 'Anthropology' had been enumerated in the different editions of DDC. Shenoy (1998) made detailed research on treatment and arrangement of Social Science subjects in DDC and CC. Expansion of the class 200 i.e., Religion in DDC for the incorporation of Asian religions in more details were put forward by Dong-Geun & Ji-suk (2001). Their recommendation favoured the shrinking of the class 'Christianity' and allocation of separate class numbers to Asian religion like Buddhism. Fields and Connell (2004) highlighted the challenges faced in allocating class number to the subject 'Home Economics' and the changes it has undergone in due course. Satija (2008) thought the way in which the class Social Science is organised in CC is weak and inadequate. He identified that the placing of the classes is not satisfactory and also considered the terminologies used as dated. Nagapure and Paradkar (2018) discussed the revision and modification of notations and terminologies for the class 025 i.e., Library and Information Science from fifteenth to twenty-third edition of DDC. Saha and Hatua (2019) identified certain subjects mentioned under DDC's 000 and 700 class as sub-facets in Humanities which were not assigned as main class like Science and Social Science. In another work Saha and Hatua (2019) dealt with subject facets included in Humanities discipline and how they are treated in the twenty-third edition in DDC.

Studies on subjects that involve interactions beyond disciplinary boundaries mostly focused on accommodation of those subjects in classification schemes. Bulick (1982) opined that confusion occurred when disciplinary boundaries shifted and that some subjects received multiple classifications; interdisciplinary subjects received arbitrary classifications. Palmer (1996) stated "As research and knowledge become more interdisciplinary, the academic subjects represented in research libraries became increasingly ill-suited to the conduct of research" (p. 166). The need to respond to multidisciplinary literary warrant to accommodate multidisciplinary works appropriately was expressed by Beghtol (1998). Much earlier in 1926, Sayers expressed that a classification scheme "must enumerate the whole of known things, and permit the insertion of additions to them… A classification must be elastic, expansible and hospitable in the highest degree. That is to say, it must be so constructed that any new subject may be inserted into it without dislocating its sequence" (p. 44). Coates in 1957 while speaking of notations in classification schemes stated that about the necessity of notations to be infinitely capable of accommodating the growing universe of knowledge (as cited in Risk, 1959). Phase relation in Natural Sciences and Social Sciences, specifically focusing on Botany/Zoology/ Psychology/Economics/Sociology, were compared by Gopinath, Mohan, Bhandar and Saifulla (1983).

Gangu and Rao (2002) discussed the problems that librarians face due to formation of new subjects and in assigning a class number to documents on such subjects. In doing so they dealt with the limitations of the 18th edition of DDC and identified three reasons contributing to the changes in disciplinary structure – first expansion of existing subjects (environmental science), secondly invention of new knowledge (Diasporic study), thirdly formation of new subject with interlinkage of existing subject, that is interdisciplinary subject (Bioengineering). Developing a universal classification of the phenomena studies and the theories and methods applied by scholars for satisfying interdisciplinary needs was favoured by Szostak (2007). He went on to give suggestion that in place of "classifications suited to only narrow communities of scholars the goal is a universal classification to facilitate interdisciplinary inquiry" (Szostak, 2008, p. 21).

Mitchell & Diane (2009) stated that for topic scattered across DDC, an interdisciplinary number is given. It was elaborated with example like 'Holiday' and 'Garlic'. The concepts of 'Men', 'Women' and 'Transgender' people as depicted in DDC editions was evaluated by Fox (2016). Pal, Mondal and Bhattacharya (2019) identified the scattered placement of the descriptor 'Children' and its related concepts under various subjects and showed the development of the concept from the first to twenty-third editions of DDC. Balaji (2019) evaluated the domain 'Urban', its vocabularies and the disciplines where its concepts are scattered from its reflection in three classification schemes- Library of Congress Classification Scheme, Universal Decimal Classification and Dewey Decimal classification.

Works on specific cross-disciplinary, multidisciplinary, or interdisciplinary subjects were also found. Lalhmachhuana (2003) compared the representation and treatment of Social Science cross disciplinary subjects in three Classification schemes viz: DDC, CC, and Library of Congress classification scheme. Gopinath (1984) discussed the ways and means of development of multidisciplinary subjects, dealt with backdrop of emergence of new multidisciplinary and interdisciplinary subjects; categorised the modes of emergence of such subjects; highlighted the methods of development of such subjects. He also threw light on the various organisational supports that contributed to their growth. He also dealt with the accommodation of such multidisciplinary subjects by classification schemes like CC, DDC and Broad System of Ordering.

Neelameghan and Gopinath (1972) made a comparative study of the position of the Fused main subjects in CC, UDC and DDC. Gopinath (1981) in his thesis demonstrated the problems that arise in identifying Fundamental Categories viz Personality, Matter and Energy for Interdisciplinary Subjects viz: Sociobiology, International Relations, General Systems Theory and Solar Energy Study; and formulated a set of principles is to overcome it. Husain (1989) showed that how CC edition seven is more suited for the accommodation of newly emerging subjects than any other non-theory-based schemes. While elaborating he revealed that new interdisciplinary subjects are placed in CC seventh edition depending on the principal of 'Later-in-time'. If a number of such subject appear then they are arranged by applying the principal of Systematic Mnemonics and Scheduled Mnemonics. He elaborated with the example of BX Astronomy and BYC Astrophysics. Bhattacharya (2006) provided a comprehensive list of interdisciplinary Science and Technology subjects and showed how these subjects were placed in three classification schemes: UDC, DDC and CC. Bhattacharya (2012) studied the interdisciplinary subjects formed centring biological sciences identifying their core unity, final mode of formation, and coverage in UDC, DDC and CC. The study by Gopinath and Seetharama (1975) on the reflection of growth of interdisciplinary subjects like Biochemistry, Marketing and Survey Research Methodology in classification schemes focused on the changes of their positioning and class number in CC and DDC depending on their evolutional stages. Except for this study no other work were found to have attempted to trace the reflection of typology of relation existing during the evolution of an interdisciplinary subject in classification schemes. Thus, a research gap was again felt.

Given the growing importance of interdisciplinarity and at the backdrop of constant emergence of new interdisciplinary science subjects the need to conduct a study examining the typology of relations that existed at various stages of development of the various emerged interdisciplinary science subjects and how they got reflected in library classification schemes were felt here.

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Chapter 3
Interdisciplinary Subjects: An Overview

3.1 Introduction

Comprehending interdisciplinary subjects necessitates a clear understanding of the terms 'interdisciplinary' and 'subject'. The Oxford English Dictionary defines Interdisciplinary as “of or pertaining to two or more disciplines or branches of learning, contributing to or benefiting from two or more disciplines” (“Interdisciplinary”, n.d.). The word has two parts: inter and disciplinary. “The prefix Inter means ‘between, among, in the midst’. Disciplinary means ‘of or relating to a particular field of study’ or specialization” (Repko, 2008, p. 5). Interdisciplinarity can be distinguished from disciplinarity on the ground that disciplinarity ‘applies a constrained set of theories and methods to a limited set of phenomena in the context of tightly focused research questions’ (Szostak, 2015).

Subject’ in general indicates “any topic or theme of a work stated explicitly in the concerned text or title or implicit in its message” (Dutta & Dutta, 2014, p. 56). In academics ‘Subject’ is defined as “an area of knowledge that is studied in school, college, or university” (“Subject”, n.d.). To Ranganathan (1989) subject is “an organized or systematised body of ideas, whose extension and intention are likely to fall coherently within the field of interests and comfortably within the intellectual competence and the field of inevitable specialization of a normal person" (p. 82).

While traditionally subjects were well demarcated, the idea of 'Subject' was largely impacted due to interdisciplinary collaborations. Ranganathan (1944) had long remarked "knowledge all over the world is being diversified along one line and synthesised along another in a continuous almost bewildering flux in varied media" (pp. 21-22). Golding (2009) remarked that a range of critical and complex problems, phenomena, and concepts remain difficult to be understood or resolved when considered from the perspective of only one academic discipline. Investigators are needed to effectively engage in interdisciplinary translation and synthesis. Thus, along with disciplinary depth there must also exist what Gardner (2006) called a 'synthesising mind'. In the words of Gopinath (1981) such synthesis includes "a networking of several disciplines, sub-disciplines, fragmentations and atomisation to a new focal point. The focal point itself is a choice of the culture of society. Such an activity leads to problem-focussed research giving rise to what is called multidisciplinary and interdisciplinary subjects" (p. 34).

With time these subject fields develop their own theories, vocabulary and proponents. If the result is substantial and gains wide acceptance, then a distinct interdisciplinary discipline emerges which are accommodated in the organised structure of the universe of knowledge. Biochemistry, Geochemistry are two examples of such interdisciplinary subjects.

3.2 Definition, Characteristics and Related Concepts

Gopinath (1981) stated that interdisciplinary subjects "are products of the ontology of differentiation (analysis) and integration (synthesis)" (p. 37). Subjects that originate as a result of interaction within several related or even unrelated fields; draws knowledge from each other and represents knowledge beyond the demarcated traditional boundaries are known as interdisciplinary subjects. "Interdisciplinary subjects are those that emerge as a result of interaction between two traditionally known, well-demarcated disciplines" (Gopinath and Seetharama, 1975, p. 121).

Interdisciplinary subjects demonstrate certain common *characteristics* that go beyond specific academic disciplines and originate from interactions and collaborations that takes place between different fields of study. It can be witnessed in the realm of science, arts as well as humanities. Such characteristics are as follows:

- **Integration of distinct disciplines:** The integration of two or more disciplines is a fundamental requirement for a subject to be considered interdisciplinary. This integration can be a long-drawn process involving various real-life problems that cannot be resolved within a single disciplinary framework. The integration may involve theories, tools, methodologies and insights and in due course give rise to a new field of study or an interdisciplinary subject. For example, 'Biochemistry' integrates the distinct disciplines of 'Chemistry' and 'Biology'.
- **Focus on Complex Problems:** Interdisciplinary subjects emerge with a focus on ‘problem solving’. “The development of interdisciplinary subjects essentially depends on the linkage effected or focussed on particular problem” (Gopinath, 1981, p. 40). At the core of any interdisciplinary subject lies a challenge or issue that requires expertise from different perspectives. Interactions of the two or more disciplines provides with such approaches that results into effective problem solving. Many of these challenges arises out of the surroundings or the society. For example, public health issues, climate change all requires interdisciplinary approaches to understand the challenges better. Also, scientific phenomena and discoveries demands interdisciplinary perspectives. For example, understanding the possibility of life beyond earth requires insight from both biology and astronomy which has given rise to a new subject of ‘Astrobiology’.
- **Demands combined expertise:** Problem solving in interdisciplinary subjects requires expertise beyond a single academic discipline. Not just theoretical integration but professional collaborations are also necessary for problem solving. It “need expertise from divergent fields or disciplines and integrating results of studies from different disciplines” (Gopinath, 1981, p. 40). Interdisciplinary subjects not only involve such collaborations but also in due course gives rise to a new set of professionals who acquires expertise in the interdisciplinary subject itself. For example, Biochemists, Biophysicists, Astrophysicists etc.
- **Flexible and Broad in Scope:** As interdisciplinary subjects are born out of several other subjects, so the scope of such subjects is much flexible and broader than the traditionally known disciplines. They are more open in accommodating new

concepts and methods. As the interacting subjects develops the scope of the new interdisciplinary subject also broadens.

- **Facilitate Deeper Understanding:** Interdisciplinary subjects provide a common area of interaction for traditionally distinct academic disciplines having conceptual linkage. This enables a deeper understanding of the core concepts and issues related to the subjects and contribute to better decision making. It thereby creates a significant co-relation between the interacting academic disciplines and reduces possibilities of miscommunication.

The scope of the concept of interdisciplinarity is vast. It is often used to refer to any type of interactions across the boundaries of disciplines. Terms like multidisciplinary, cross-disciplinary, transdisciplinary and pluradisciplinary are often used interchangeably with interdisciplinary. However, a closer look at each of the terms reveals that although the basic idea underlying for each of the term involves disciplinary interactions beyond the decided demarcations but there exist certain differences in their actual connotation.

- **Multidisciplinary:** OECD (1972) defined Multidisciplinary is a "juxtaposition of various disciplines, sometimes with no apparent connection between them" (p. 25). It involves several disciplines each of which provide a different perspective on a problem or issue but continues to maintain their individuality (Stember, 1991). To Klein (1990) it is 'additive and not integrative'. Thus, in multidisciplinary subjects there are collaboration of individual subject but on integration takes place.
- **Crossdisciplinary:** According to Bhattacharya (2006) cross disciplinary encompasses two or more fields that are not conventionally related or connected. Cross-disciplinary interactions at times prioritise concepts of one field above another. It entails looking and examining any discipline through the lens of another (Stember, 1991). Unlike interdisciplinary no emphasis on integration is given and thus there exists little chance of giving rise to a new subject. The focus however is of solving a problem or a complex situation.
- **Pluridisciplinary:** Pluridisciplinary is a juxtaposition of disciplines assumed to be more of less related, for example, mathematics and physics (Klein, 1990). In contrast to cross-disciplinary, pluridisciplinary deals with subjects that are

somehow traditionally associated with each other (Bhattacharya, 2006). For example, Astronomy and Mathematics.

- **Transdisciplinary:** Klein (2005) explains that transdisciplinarity aims to create a comprehensive framework that transcends the narrow scope of disciplinary worldviews. Marxism, phenomenology, and general systems theory are examples of transdisciplinary interactions. It is "an umbrella term used to describe a theme-based on approach that spans or transcends or cross over several disciplines" (Bhattacharya, 2006, p. 23).

3.3 Modes of Interdisciplinary Subject Formation

Any subject is made up of different components. Even before a subject formally develops, these components interact with each other over a long period of time. These interactions, at the various stages of development of the subject, reflects a particular type of relations. "These relations can be formalised into a set of relations leading to a typology of relations" (Kumar,1988, p. 201). These are also represented as the 'modes of formation' of subject.

The relation existing between the components of a subject varies. It may display diverse relation at different stages of development or there might also be an overlapping of the relationships in the same stage. Ultimately a final mode of subject formation leads to the formation of a primary basic or a primary basic subject.

The idea of 'mode of formation of subject' have been represented by different specialists through various terminologies. As for the purpose of this research, Ranganathan's concepts of 'Modes of Formation of Subjects' have been taken into consideration.

Ranganathan (1969) identified twelve modes of formation of any subject. Each of these modes formed a particular type of subject viz Primary basic subject, Basic subject, Compound or Complex. The formation of an interdisciplinary subject as a primary basic subject may involve stages where a compound, complex or a basic subject is formed. Literature review (chapter 2) revealed that formation of any interdisciplinary subjects involved three main modes of subject formation viz: Fusion, Clustering and Distillation.

However, these three modes of subject formation are mainly found at the final developmental stage. Prior to that other modes of subject formation can also exist between the interacting subjects or its components viz Loose Assemblage, Lamination and Fission before it reaches its culminating stage.

Ranganathan (1967 as cited in Binwal, 1988) explains the progressive strengthening of relationship as "One Main Subject may be bonded to another in any of the following ways:

i. Loose assemblage by a phase relation;
ii. Indirect Lamination as a subdivision of an isolate in a facet;
iii. Direct lamination as an isolate in a facet;
iv. Fission or dissection/denudation yielding a canonical division of one of the Main Subjects; and
v. Fusion by which each Main Subject loses its identity, and a new Main Subject is formed."

Below is a brief discussion of the typology of relations or modes of subject formation, as propounded by S.R. Ranganathan involved in interdisciplinary subjects formation.

- Fusion: When "two or more primary basic subjects are fused together in such a way that each of them loses its individuality with respect to the schedule of isolates needed to form the compound subject going with it". (Gopinath and Seetharama, 1975, p. 124). This mode of subject formation gives rise to a primary basic subject. Example: Astrobiology, Geochemistry

- Distillation: Distillation mode gives rise to a "primary basic subject from its appearance-in-action in diverse compound subjects going with either different basic subject or one and the same basic subject" (Gopinath and Seetharama, 1975, p. 124). Neelameghan (1973) identified another type of Distillation (distillation kind 2) in which he stated that an isolate may become so specialised that it may give rise to a primary basic subject. Example: Microbiology, Molecular Biology, Cybernetics.

- Cluster: At times works relating to a particular 'phenomenon or an entity are brought together in a document and treated disjunctively… The document in which the preliminary results are brought together just as collection, taken as a whole, presents a subject field in which there is a core entity of study with inputs or viewpoints or works in it coming from specialists in subjects going with diverse basic subject. This is explained clustering around a nodal idea' (Gopinath and Seetharama, 1975, pp. 124-125). This mode of subject formation also gives rise to a primary basic subject. Example: Space science, Ocean science, Soil Science, Indology, Gandhiana etc.

The modes that are also observed in the process of subject formation are:

- Loose Assemblage: Ranganathan identified three types of Loose Assemblage viz Loose Assemblage 1, Loose Assemblage 2 and Loose Assemblage 3. In Loose Assemblage 1, 2 and 3 two or more subjects; two or more isolates of one and same schedule; or two or more isolates from one and same array are studied in their mutual relations respectively. Each of them involves five types of relations viz: General, Bias, Comparison, Difference, Influence and Tool. This mode of subject formation gives rise to a complex subject (Kumar, 1988; Gopinath and Seetharama, 1975).
- Lamination: Ranganathan identified two types of Laminations viz Lamination 1 and 2. 'When one or more isolate facets are combined with a basic subject' it is called Lamination 1. 'When two or more basic subject going with the same primary basic subject' or 'two or more isolates from the same schedule of isolates are compounded over one another' it is known as Lamination 2. This mode of subject formation gives rise to a compound subject or isolate (Gopinath and Seetharama, 1975).
- Fission: This mode of subject formation involves splitting or fragmentation of a basic subject or an isolate into subdivisions. Example Philosophy can be fissioned into ethics, Logic, metaphysics etc (Gopinath and Seetharama, 1975).

(Kumar, 1988) discussed about the formation of interdisciplinary subjects based on the above stated modes of subject formation in the following way:

Table 3: Stages of Development of Interdisciplinary Subjects

Stage	**Modes of Subject Formation**	**Resulting Subject**
First	Loose Assemblage	Complex subject
Second	Lamination	Compound Subject
Third	Fusion, Distillation, Cluster	Basic Subject

Before reaching the third and ultimate stage, any interdisciplinary subject undergoes either both or at least one of the stages where the different elements of the subjects interact to create a typology of relation.

In the context of library and information science understanding and evaluating the structure and development of a subject and the typology of relations at the different stages of development is largely depended on classificationists (Kumar, 1988). It contributes to determining their position in the universe of subject and helps in designing a classification scheme (Kumar, 1988) that can appropriately accommodate those subjects.

3.4 Emergence of Interdisciplinary Subjects

Interdisciplinary subjects, as defined in section 3.2 of this chapter, is a twentieth century phenomena. However, its emergence was not an abrupt one. It was a gradual process that involved the growth and development of individual subjects within their own scope as well as the evolution of the entire academic structure. Thus, the history of interdisciplinary subjects is intertwined with the history of interdisciplinarity.

The philosophers of the ancient Greeks were the earliest practitioners of the concept of interdisciplinarity. Many of their thoughts and ideas spanned over multiple subject area and exemplified interdisciplinary approaches. But interdisciplinarity as practiced then was significantly different from how it exists today. Subjects were not well demarcated. There was more of an all-encompassing approach towards solving any complex situation drawing perspectives from varied fields -philosophical, social, legal and most importantly religious. Such ancient Greek philosophers included Aristotle, Ptolemy, Eratosthenes, Posidonius etc. During the renaissance, the world has witnessed the coming up of eminent personalities who not only demonstrated affinity in more than one subject but also acquired mastery in them. They are regarded as polymaths. But these philosophers were mostly associated with scholarly societies. Unlike the present scenario it was not a part of the any structured or formal academic system.

As specialisations increased, subjects became more clearly demarcated which got reflected in the academic structure. Disciplines came up with growth of universities. There came up journals for specific subjects; seminars were conducted dedicated to a single specialised subject area; associations relating to the subject area were formed etc.

The professional demand for specialised expertise further accelerated the process of demarcating the boundaries of subjects.

While specialisation was at its peak, a support towards a more integrated disciplinary structure where synthesis of knowledge was possible was finding its voice. An increasing demand to transcend the boundaries of the specialised subjects was growing. This became the need of the time even more with the onset of the world wars. Various new circumstances - social, medical, environmental, technological - emerged that were beyond the scope of any specialised subject. Situations demanded solutions that must draw insights from multiple subjects.

The era of interdisciplinarity was initially reflected in the form of teaching and curriculum development. Gradually this was more and more accompanied by need for interdisciplinary collaborations facilitating interdisciplinary research resulting into interdisciplinary subjects. In the early 1980s, academically interdisciplinarity found support as the National Collegiate Honors Society declared that honours were synonymous with interdisciplinarity (Repko, Szostak & Buchberger, 2017).

The rise of interdisciplinarity and interdisciplinary subjects were facilitated by various factors.

Gopinath (1981) discussed the emergence of interdisciplinary subjects at the backdrop of World War II and how the conditions necessitated the coming together of experts of different fields together to bring solutions to various complex situations arising due to war. Klein (1990) in her book discussed four ways in which interdisciplinarity as a concept has developed which has ultimately contributed to the growth and development of new interdisciplinary subjects. According to her the ways included an increased focus on research and education; the expanding scope of traditional disciplines, the efforts to re-promote unity and synthesis; and coming up of distinct interdisciplinary movements. Klein (1996) opined that interdisciplinary activities were the result of historical and contemporary developments in disciplines, professions, and new interdisciplinary fields.

Similar reasons towards the emergence of interdisciplinarity and interdisciplinary subjects was highlighted by DeZure (1999), and Bhattacharya (2006). These included:

- Addressing complex social issues required an interdisciplinary approach rather than relying on a single disciplinary perspective.

- Students and faculty strongly opposed the artificial division of knowledge, advocating for a more integrated approach to learning and cohesion in the curriculum.
- Employers were in search of college graduates who were equipped to fulfil the diverse demands of the professional sphere by merging their learning from different disciplines.
- The goal of administrators was to optimize the utilisation of resources and equipment through interdisciplinary sharing.
- Dynamic shifts in knowledge construction had led to the blurring of disciplinary lines in fields like cultural studies. The evolution of disciplines such as neurosciences and bioengineering were attributed to scientific breakthroughs, changes in research practices, and funding allocations.
- Electronic knowledge and the Internet reshaped the way information was being organized and searched for, replacing linear models with hypertext links that could transcend disciplinary boundaries.

'Therefore, interdisciplinary knowledge was getting produced… and continues to form an important part of all currently produced knowledge' (López-Huertas, 2015).

The emergence of interdisciplinary subjects was clearly evident in science. A number of discoveries and inventions in specialised science subjects like Physics, Chemistry, Biology on one hand: and the increasing complex problems and demand for their solutions all contributed to the need of growth of interdisciplinary subjects in science.

3.5 Interdisciplinary Subjects in Science

Interdisciplinarity and Science co-existed from a period when neither of them were in shape how it exists today. The application of alchemy in medicine for treatment; the understanding of physiological activities in terms of chemistry; the belief in the idea of plurality of world; use of magnetic compass for navigation; invention of seismoscope for measuring earthquake and many more such activities across the world has represented the now demarcated science subjects as unified. From Copernicus to Galileo; Descartes to Eistein; Lavoisier to Newton all were polymaths whose area of interests were not confined to any specific specialisations. Science was then represented as Natural Philosophy (Physics, Chemistry) and Natural History (Biology).

This application of various scientific methods continued until scientific revolution came. The eighteenth and early nineteenth century witnessed specialisations in science. Astronomy, Physics, Chemistry, Biology developed into separate academic fields and evolved into its present structure. The rapid growth in each area made acquiring of knowledge across fields nearly impossible. Academic degrees, setting up of dedicated laboratories, carrying out of experiments leading to magnificent discoveries and inventions all led to science flourish in its specialised disciplinary structure.

Although science has been developing for centuries with a dominant discipline-based structure, there has always been the need to overcome the closed boundaries of varying science disciplines (Klein, 1990).

At the backdrop of the discussed scenario in above section the inquiry into real-world issues significant to the natural sciences has increasingly become more interdisciplinary in nature. Rather than addressing the issues through a single disciplinary framework, the incorporation of research and techniques from multiple natural sciences, such as physics, chemistry, biology, and earth science, along with insights from other relevant fields became the need of the time. (Repko, Szostak & Buchberger, 2017).

Increase in interdisciplinary research and promotion of interdisciplinary curriculum contributed largely to emergence of subjects that are by nature interdisciplinary. Klein (2010) discussed how 'application of knowledge of one discipline to another for its contextualisation'; 'application of complementary skills to solve complex problems'; borrowing methods or concepts across disciplines' have contributed to interdisciplinary developments in science, technology and engineering.

Such interdisciplinary interactions are visible in between biology and chemistry having implications on medicine and physiology; between biology and physics giving rise to methods like x-ray, radiation etc contributing to treatment; solving of environmental complexity by interaction between geology on one hand and physics, chemistry on the other; the study of microorganisms in various subject areas and in turn contributing to fields like food preservations, agriculture, vaccination; integration of tools and concepts in Astronomy with physics, chemistry, biology; the major developments of data science and computer science in understanding biological data; so, on and so forth.

All these interactions have resulted in coming up of major interdisciplinary fields of study many of which have now established themselves as distinct subjects having their own degree courses, departments, journals, societies etc.

Considering the objective and scope of this research a study of the genesis and development of selected interdisciplinary science subjects along with their typology of relations have been carried out in Chapter 5. Prior to that, the following chapter (chapter 4) provides with a brief account of three selected Library classification Schemes.

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Chapter 4

Classification Schemes: A Brief Account

4.1 Introduction

Classification in the most general sense involves the deliberate placing of things into classes or groups or categories. The term ‘thing’ may include anything and everything that exists in the world. (Hoffman, 2019). To Richardson (1901) classification is “putting together like things” (p. 1). He also considered it as a method of ‘sorting and grouping of things’. A similar kind of definition was given by Margaret Mann (1943) to whom classification is "the arranging of things according to likeness and unlikeness. It is the sorting and grouping of things, but, in addition, classification of books is a knowledge classification with adjustments made necessary by the physical form of books" (p. 33). Classification is something that is very commonly practiced in almost every sphere of life. The basic criteria of classification may vary depending on the situation and context. Different academic subjects have well defined classification system. For instance, Botany, Zoology, Music, Chemistry, Minerology etc. has their respective criteria and methods of classification that are most beneficial to them.

In a library, classification plays a pivotal role. Classification of library collections (books as well as non-book materials) have a consequential impact on the optimum utilisation of its collections and ease of service for the library users as well as library professionals. Sayers (1944) defined library classification as “the arrangement of books, on shelves or descriptions of them, in the manner which is most useful to those who read" (p. 1). Such arrangements, however, cannot be random and must be based on certain parameter and thereby maintain a sequence in the arrangement of the collection in a library. Ranganathan (1960) stated library classification “is the translation of the name of the subject of a book into the preferred artificial language of ordinal numbers, and the individualisation of several books dealing with the same specific subject by means of a further set of ordinal numbers which represent some features of the book other than their thought content” (p. 2).

Library Classification Scheme is “a system of coding and organising library materials according to their subject and allocating a call number to that information resources” (Singh, 2011, p. 117). To Ranganathan (1989) a classification scheme is “a scheme of classes fitted with terminology and notation” (p. 72). A class is denoted by a name and a corresponding ordinal number. In a classification scheme the entries are arranged by their class number and are accompanied by an alphabetical index. Thus, assigning of class number using a library classification scheme is core to fulfil the basic purpose of library classification. It is necessary to ensure an easy browsing and locating of library materials as well as a fast retrieval of documents. Kumar (1988) discussed the following purpose of library classification:

- *Helpful Sequence:* Bringing documents belonging to same or similar subject areas together increases the chances of their use as well as might be beneficial for the users. Any library classification scheme must aid in such sequencing of documents by separating the documents belonging to different subject areas. This would satisfy the inherent idea of helpful sequencing and benefit both users and staff.

- *Correct Replacement:* Documents in a library are prone towards getting lost unless kept in their original position every time after use. Library classification provides the scope to assign a class number to each document and thereby determine a specific position for each of them in a library. This in turn ensures its correct placement and reduces its chances of getting misplaced.

- *Mechanised Arrangements:* Assigning class numbers using a classification scheme assists in determining a fixed sequence for arranging documents within a library permanently. This sequence remains unchanged, even as new documents are added to the library collection.
- *Addition of New Documents*: The effective organization of newly added documents within the existing collection is facilitated by library classification. Furthermore, a classification scheme must also have the scope for accommodating new documents that are outcome of the ever-growing nature of the universe of subject.
- *Withdrawal of documents from stock:* Library classification is crucial not only during the inclusion of documents but also when withdrawing them. It ensures the exact location of the document to be withdrawn and also aids on any rearrangement.
- *Book Display:* Library classifications is also helpful in the arrangement of books or other documents in the shelf of a library to achieve user friendliness. Placing a material in its rightful place maximises the scope of its retrieval and use especially in open access libraries.

Library classification schemes are of different types depending on its structure and methods. Ranganathan (1989) categorised all classification schemes into five types:

- Purely Enumerative Classification: "An enumerative scheme for Classification consists essentially of a single schedule enumerating all subjects - of the past, the present and the anticipatable future" (Ranganathan, 1989, p. 95). Example: Library of Congress and Rider's international classification.
- Almost Enumerative Classification: "An Almost-Enumerative Scheme for Classification consists of a large schedule enumerating most of the subjects of the past, the present, and the anticipatable future, and in addition a few schedules of common isolates" (Ranganathan, 1989, p. 97). Example Brown's Subject Classification.
- Almost Faceted Classification: "An Almost-Faceted scheme for Classification consists of a large schedule enumerating most of the subjects of the past, the present, and the anticipatable future, and in addition a few schedules of common

isolates and also some schedules of special isolates" (Ranganathan, 1989, p. 102). Example: Universal Decimal Classification, Bibliographic Classification.

- Rigidly Faceted Classification: "In a Rigidly-Faceted Scheme for Classification, the facets and their sequence are pre-determined for all the subjects going with a Basic Class" (Ranganathan, 1989, p. 107). Example: Colon Classification edition 1 to 3.

- Almost Freely Faceted Scheme: A scheme is considered almost freely faceted when "the use of different Indicator Digits for diverse kinds of facets and the concept of Rounds and Levels removed the severe rigidity in the number and the sequence of facets that can occur in a Compound Subject" (Ranganathan, 1969, p. 205). Example: Edition 4-6 of colon classification.

- Freely Faceted Classification: 'In a freely faceted scheme for classification, there is no rigid, pre-determined facet formula for the compound subjects going with a basic subject. This is also called 'Analytico-Synthetic Classification guided by Postulates and Principles' (Ranganathan, 1989). Example: CC edition 7.

A Library classification schemes can also be categorized on the basis of its scope. A classification scheme can be general (accommodating the entire universe of knowledge) or special (for a particular area of knowledge) (Satija and Matinez-Avila, 2015). There are a number of general library classification scheme viz Dewey Decimal Classification (DDC), Universal Decimal Classification (UDC), Colon Classification (CC), Library of Congress Classification (LC), Bibliographic Classification (BC) etc.

Any general classification scheme has certain elements. This includes a schedule of classes and its facets representing the universe of knowledge; form division and other isolates that are used for synthesis of class number to bring more specificity; provisions for phase relations; an alphabetical index; notations representing the schedule of classes, facets and isolates using numeric, alphabets, signs and symbols. The scheme must have manuals and rules for building class numbers. There should be a governing body to look after necessary revisions from time to time. Any classification scheme must be hospitable and flexible to accommodate new classes; must have brevity and mnemonic qualities in its notation and must have scope for synthesis of class numbers.

Considering the objective and scope of this research, the following section provides a brief overview of three classification schemes: Dewey Decimal Classification (DDC), Universal Decimal Classification (UDC) and Colon Classification (CC).

4.2 Dewey Decimal Classification

Dewey Decimal Classification (DDC), one of the major general classification schemes, is a knowledge organisation tool, designed by Melvil Dewey and first published in 1876.

History: Before DDC was put into practice, materials in libraries were arranged according to a system of fixed location. Around 1873, Melvil Dewy, a student at Amherst College and a student library assistant observed the practical problems which this system of fixed location poses both to the users as well as staff. So, he came up with the idea of relative location and designed a scheme which he presented in front of the library committee of the Amherst college. Upon approval of the committee to rearrange their materials according to the new scheme of relative location, it was put to test and examined and ultimately culminated in the publication of DDC in 1876 (Kumar, 1988).

Developments and Editions: DDC is currently published by Online Computer Library Centre (OCLC). The Decimal Classification Division of Library of Congress is its editorial office. All the revisions and alterations are proposed by the editors whenever necessary and are finally decide by the Decimal Classification Editorial Policy Committee (EPC) (DDC 23 Summaries, n.d.). DDC has been continuously revised to accommodate new subjects. Methods used includes number relocation from one class number to another, expansion of class number through add instructions and complete revision of the edition or for any particular discipline in the main schedule. Such changes are also introduced through Phoenix schedule (Dhayani, 1998).

The first edition was published in 1876 titled ‘A Classification and Subject Index for Cataloguing and Arranging the Books and Pamphlets of a Library’. The name Dewey appeared under copyright on the verso of title page. One thousand copies were published each having 44 pages covering 12 pages of introduction, 12 pages of schedules and 18 pages of index (Dhyani, 1998).

DDC is published both as full edition and abridged edition. Till now 23 full editions have been published. The details collected from the various editions of DDC are given below in a tabular form:

Table 4: DDC editions details

Year	Edition	Editor	Pages/ Volume
1876	**1**	Melvil Dewey	44
1885	**2**	Melvil Dewey	314
1888	**3**	Melvil Dewey	416
1891	**4**	Evelyn May Seymour	466
1894	**5**	Evelyn May Seymour	467
1899	**6**	Evelyn May Seymour	511
1911	**7**	Evelyn May Seymour	792
1913	**8**	Evelyn May Seymour	850
1915	**9**	Evelyn May Seymour	856
1919	**10**	Evelyn May Seymour	940
1922	**11**	Jennie Dorkas Fellows	988
1927	**12**	Jennie Dorkas Fellows	1243
1932	**13**	Jennie Dorkas Fellows	1647
1942	**14**	Constantin Mazney	1927
1951	**15**	Milton J. Ferguson	716
1958	**16**	Benjamin A. Custer	2vol.
1965	**17**	Benjamin A. Custer	2vol.
1971	**18**	Benjamin A. Custer	3vol.
1979	**19**	Benjamin A. Custer	3vol.
1989	**20**	John P. Comaromi	4vol.
1996	**21**	Joan S. Mitchell	4vol.
2003	**22**	Joan S. Mitchell	4vol.
2011	**23**	Joan S. Mitchell	4vol.

DDC has been translated into over thirty languages – Spanish, Danish, Japanese and so on. An electronic version was created in 1993, and an online version named 'Web Dewey' is also available and updated regularly.

Arrangement: The arrangement of DDC has undergone changes many times. Initially it was of one volume, then it had two volumes (one schedule and one index) and then it became a four-volume classification scheme**.** The Twenty third edition of DDC is arranged in four volumes as described below:

- Volume 1: Volume 1 consists of an introduction, Glossary, Manual which acts as a guide where instruction is given to see manual in the main schedule, and most importantly the Tables that are added to the class numbers of the main schedule to construct a more specific class number. As of the twenty third edition there are six tables namely: Standard subdivisions; Areas, Periods, Biography; Subdivisions for the Arts, for Individual Literatures, for Specific Literary Forms; Subdivisions of Individual Languages and Language Families; Ethnic and National Groups; Languages.

- Volume 2: This is a part of the main Schedules having the class numbers from 000 (Generalia) class to 599 (Zoology)
- Volume 3: The second part of the Schedules having class numbers from knowledge from 600 (Technology) to 999 (History, Geography and Biography)
- Volume 4: This volume is the relative index in which almost all the entries in the main schedules are listed in an alphabetical order (Dewey, 2011)

Structure: DDC is a discipline wise arranged hierarchical scheme of classification. Arranged from general to specific it uses a decimal point for representing the subjects within the disciplines to the most specific level possible. DDC maintains structural hierarchy and "any note regarding the nature of a class holds true for all the subordinates classes, including logically subordinate topics classes at coordinate numbers" (DDC 23 Summaries, n.d., "Hierarchy", para 1).

At the broadest level, the DDC is divided into ten main classes, covering the entire world of knowledge. These are:

000 Computer science, information & general works

100 Philosophy & psychology

200 Religion

300 Social sciences

400 Language

500 Science

600 Technology

700 Arts & recreation

800 Literature

900 History & geography

Each main class is further divided into ten divisions, and each division into ten sections. The first digit in each three-digit number represents the main class. For example, 300 represents social sciences. The second digit in each three-digit number indicates the division. For example, 300 is used for general works on social sciences, sociology & anthropology; 310 for statistics, 320 for political science, 330 for economics. The third digit in each three-digit number indicates the section. Thus, 330 is used for general works on economics, 331 for labour economics, 332 for financial economics, 333 for economics of land & energy. After the third digit the decimal point is used and is further divided by ten continuing to the maximum possible specificity that is needed. For example, 331.1 represents labour force & market; 331.2 Conditions of employment.

There are six tables found in the latest edition of DDC (23rd ed.). They are:

Table 1: Standard subdivisions

Table 2: Areas, Periods, Biography

Table 3. Subdivisions for the Arts, for Individual Literatures, for Specific Literary Forms

- Table 3A for description, critical appraisal, biography, single or collected works of an individual author
- Table 3B for description, critical appraisal, biography, collected works of two or more authors, also for rhetoric in specific literary forms
- Table 3C for additional elements used in number building within Table 3B

Table 4. Subdivisions of Individual Languages and Language Families

Table 5. Ethnic and National Groups

Table 6. Languages

In DDC number relocation or discontinuation is indicated by putting the class numbers of the topics into square brackets. Also, there are notes give as ‘Class here’ ‘Class’ or Add instructions for interdisciplinary subjects and topics (DDC 23 Summaries, n.d.; Dewey, 2011). As the basic arrangement is discipline based so many subjects are found to be scattered across disciplines. It is the relative index that brings the scattered representation of a subject together. For example: ‘housing’ is scattered in many disciplines. Housing associated with animal husbandry is classed as 636.0831; in relation to armed forces in 355.12; in home economics with 643.1; in relation with psychological influence as 155.945; in respect to public administration in 353.55; and social services in 363.5 (Kumar, 1988; Dhayani, 1998; Dewey, 2011)

Notation: DDC uses Arabic numerals of 0-9 to represent each class in the DDC. Minimum three digits are used to represent the class numbers. Each of these digits have ordinal value and no cardinal value. It uses a decimal point however that decimal point "is a dot that follows the third digit in DDC number". (Dewey, 2011, p. lxxvi). Notational hierarchy is expressed by length of notation. "Numbers at any given level are usually subordinate to a class whose notation is one digit shorter; coordinate with a class whose notation has the same number of significant digits; and superordinate to a class with numbers one or more digits longer" (DDC 23 Summaries, n.d., "Hierarchy", para 2).

Below is an example from DDC 23rd edition:

300 Social sciences

330 Economics

332 Financial Economics

332.1 Banks

332.11 Central Bank

323.12 Commercial bank.

'Central bank' and 'commercial bank' are more specific than (i.e., are subordinate to) 'banks'; they are equally specific as (i.e., are coordinate with) each other; and 'banks' is less specific than (i.e., is superordinate to) 'central bank' and 'commercial bank'.

Number building: Not all numbers in DDC are enumerated. There is ample scope to construct new numbers through the various instructions. One of the major scopes is provided by the Tables given in Volume 1. Be it standard subdivision or tables like area, or ethnic group all can be added to the main classes of the schedules as and where permissible to make the class number much more specific. Also, in the main schedule there are different main classes where 'Add instructions' are provided to carry out synthesis of numbers. Example: Under the main class 760 Printmaking & Print; 769.564 represents 'Postage stamps depicting various specific subjects (Iconography). Here, class number for postage stamps of animals can be built by using the "Add instruction":

Add to base number 769.564 the numbers following 704.94 in 704.943-704.949

Postage Stamps of Animal

769.564 + ~~704.94~~32 = 769.56432

(Dewey, 2011)

Relative Index: The relative index of DDC is a word-by-word alphabetical listing of subjects having their related disciplines sub arranged under them. Therefore, it relates the scattered subjects to its corresponding disciplines. Each of the term entry is accompanied by a class number other than some exceptions. Below is an example from DDC 23rd example:

Death		306.9
arts		700.454 8
	T3C	-354 8
biology		571.939
customs		393
cytology		571.936
demography		304.64
ethics		179.7
religion		205.697
Buddhism		294.356 97
Christianity		241.697
Hinduism		294.548 697
Judaism		296.369 7
folklore		398.274 8
history and criticism		398.354 8
literature		808.803 548
history and literature		809.933 548
specific literatures	T3B	-080 354 8
history and criticism	T3B	-093 548

(Dewey, 2011)

The above discussion shows DDC has both enumerated class numbers and instructions for building new numbers. It displays important qualities that are absolutely essential for a classification scheme to be maximum useful. These qualities include Mnemonics, Hospitality, Brevity and Simplicity (Dhayani, 1998). However, even though it the most widely used scheme of classification there are certain limitations in its capacity to accommodate new emerging subjects. In case add instructions are not available constructing class numbers for any new subjects, especially in case of interdisciplinary subjects, is difficult. For example, although the subject Bioinformatics have no assigned class number, but it can be built using the standard subdivision table. But constructing a class number for subjects like Astrochemistry or Geobiology is not feasible in DDC. Moreover, even if a class number is constructed there remains an ambiguity in finding a rightful place for them in the universe of knowledge. In such cases those subjects cannot be accommodated unless the scheme is revised, and new numbers are assigned by the organising body itself.

4.3 Universal Decimal Classification

UDC is a general classification scheme and is a 'hybrid of two kinds of classification scheme namely enumerative classification scheme and analytico-synthetic classification scheme' (British Standards Institution [BSI], 2005).

History: The origin of the scheme can be traced back to 1889. The vision of two Belgians, Paul Otlet and Henri La Fontaine, of a universal bibliography on Social Science encompassing every relevant book and relevant articles, resulted into the emergence of a general classification scheme now known as Universal Decimal Classification. The creation of a universal bibliography required a method for arranging the entries. The then popular classification scheme of DDC (5^{th} edition) was found to be appropriate and hence a letter of permission to translate DDC into French along with suggestions of certain modifications was written to Dewey. Upon receiving the approval and a copy of DDC from Dewey in 1895 necessary modifications and expansions were made without altering the basic character of DDC. In the first International Conference on Bibliography held from 2-4^{th} September 1895 in Brussels two important developments took place. First of all, this project was given approval for further persuasion and secondly a new institute named Institute de la Bibluiography (IIB) was created to aid its future development. The initial publications were merely translation, but soon new ideas were incorporated to facilitate synthesis of class numbers- symbols were introduced, new tables and signs were added along with alterations in notational systems. From 1899 to 1905, fascicule publications were made and the first was entitled 'Classification Bibliographique Decimale: tables generales refondues'. UDC was originally issued under the title 'Classification Bibliographique

Decimale' in 35 parts. The first complete international edition was published in 1905 in French language titled 'Manuel du Répertoire Bibliographique Universel' having 33000 classes (Kumar, 1988; Dhayani, 1998; BSI, 2005).

Developments and Editions: The editions of UDC are of three types: Full Abridged and Medium editions. Also, editions of UDC are not in same language. The second edition of UDC was published in between 1927-1933. It was titled "Classification Decimale Universelle" and was published in French. The third edition came out in 1952 was in German language. Its work began in 1934 and is titled as "Dezimal Klassification". An International Museum Edition (IME) was published in 1985 in English. It also had a second edition of published in 1933. A special version, known as the British Version, was prepared by Bradford – the librarian of Science Museum library in 1928 titled 'Classification for works on Pure and Applied Sciences in Science Museum Library'. This version was also considered as basis of the first official abridged English edition published in 1948 by British Standard Institute. The latest UDC edition, known as the Standard Edition, came out in 2005 (Dhayani, 1998; Kumar 1988).

In the beginning UDC was managed by International Federation for Information and Documentation (FID). However, from 1992 it came under the management of UDC consortium (UDCC) which included the five publishers of UDC included British Standard Institutions. FID continued to be a part of this consortium (BSI, 2005).

Arrangement: The latest edition of UDC has two volumes:

- Volume 1: Volume 1 is the main part consisting of both the Main Tables having all the main class numbers representing the universe of knowledge and Auxiliary Tables.
- Volume 2: It is the index where all the entries are alphabetically arranged (BSI, 2005).

Structure: Volume 1 has two parts. On one hand is *main table* having all the disciplines and sub-disciplines and on the other hand the *auxiliary tables* consisting of signs and symbols. Similar to DDC, UDC is also divided into 10 main classes.

The main classes are:

0	Generalities. Science and knowledge. Organization. Information. Documentation. Librarianship. Institutions. Publications
1	Philosophy. Psychology
2	Religion. Theology
3	Social sciences. Statistics. Politics. Economics. Trade. Law. Government. Military Affairs. Welfare. Insurance. Education. Folklore
[4]	[Vacant]
5	Mathematics and natural science
6	Applied sciences. Medicine. Technology
7	The arts. Recreation. Entertainment. Sport
8	Language. Linguistics. Literature
9	Geography. Biography. History

Main class 4 has been left vacant. Gap devices are used for future accommodation of class numbers. To denote a class UDC, unlike DDC, uses a single digit number. Classes are arranged hierarchically, and each main class is divided into sub-ordinate classes. For example: Main class 3 represents 'Religion. Theology'. This class number is followed by 30-39 and 39 is further followed by 391-398. Between 391-398 each of the class numbers are further subdivided using decimal points viz: 391.1-391.9 and then 392.1-392.9 up to 398.9. Only after that the next main class number 5 is filed.

Other than the main class there are the auxiliary tables. The auxiliary *tables* are of two types: Common and Special Auxiliaries. Common Auxiliaries are again of two types: signs and sub-divisions. The class numbers provided as common auxiliaries can be added to any number from the main classes.

These includes:

Table No	**Common Auxiliaries**	**Signs**
1a	Coordination. Extension	+ /
1b	Relation. Subgrouping. Order-fixing	: [ ] ::
1c	Language	=…
1d	Form	(0…)
1e	Place	(1/9)
1f	Ethnic grouping and Nationality	(=…)

1g	Time	"…"
1h	Subject specification by notations from non-UDC sources	* A/Z
1k	General Characteristics	-0…
	Properties	-02
	Materials	-03
	Relation processes and operations	-04
	Persons and personal characteristics	-05

Special auxiliaries are scattered throughout the Main Table and not listed at one place.

Special Auxiliaries	**Symbols**
Hyphen	-1/-9
Point Not	.01/.09
Apostrophe	'0/'9

These auxiliaries are specific to a particular main class and are mostly enumerated. Only the symbol apostrophe' is used to build new class number under which it is listed and can only be applied to that main class only (BSI, 2005).

Notation: Notation in UDC uses Indo-Arabic numerals, alphabets as well as symbols. UDC uses the following species of digits:

- Numerical from 0-9
- 26 Roman caps
- 26 Roman smalls
- Punctuation marks " " (double inverted commas)
  - (hyphen)
  ' (apostrophe)
  : (colon)
  :: (double colon)
  . (decimal)
- Mathematical Symbols ( ) (Parenthesis)
  [ ] (brackets)
  = (equal sign)

+ (plus sign)

/ (stroke or slash)

Similar to DDC it also uses decimal point. But in UDC the decimal point is used after every three digits. Alphabets can be used if and when instructed. For example, for construction of Biography class alphabetical extensions are used.

For example, the class number for Biography of Newton is 929Newton (Kumar, 1988; BSI, 2005).

Number building: Synthesis of numbers in UDC are mainly done using the common auxiliaries of signs and subdivisions. Some of the examples are given below:

- Class number for 'Foreign Relation between India and China' is

  327 (540 : 510)

  where 327 is Foreign Relation; 540 and 510 are India and China respectively taken from Common auxiliary of Place; and colon (:) represents relation as given in Table 1b of common auxiliary.

- Class number for 'Dictionary of Mathematics' is

  51(038)

  in which 51 is the main class representing Mathematics and (038) is dictionary as given in Common Auxiliary of Form (Table 1d).

- Two main classes are also joined by using Colon (:). For example: Ethics in Relation to Arts will have the class number

  17 : 7

  where 17 represents ethics and 7 is the main class of Arts.

Another important provision used for number building is *Parallel Division.* It represents same notation having same concepts that are allowed to be used in multiple places. For this the sign of 'sub-divide' is used (BSI, 2005).

Index: The entries in the index are alphabetical and word by word. It includes almost all the terminology used in the schedules. The entries indicate the possible locations of the terms in the main schedule.

From the above discussion it can be said that the structure of UDC displays hospitality, and its notations have brevity and simplicity. The auxiliary tables provide the mnemonic value and use of signs and symbols makes synthesis of numbers easier than DDC. In UDC accommodating new subjects is easier as compared to DDC. The use of relational symbol of colon (:) allows construction of class numbers that are even interdisciplinary in nature. For example, Astrobiology has no enumerated class number, but it can be built as 52: 57 where 52 represents Astronomy and 57 represents Biological Sciences. However again this does not provide with a rightful place for the subject in the universe of subjects.

4.4 Colon Classification

Developed in India, Colon Classification is a general classification scheme designed by S. R. Ranganthan in 1933. It is a faceted classification scheme having an analytico-synthesis nature of classification.

History: The ground for development of Colon Classification can be traced to around 1924, when Ranganathan, working as a Librarian at University of Madras, was sent to the University Library of London School of Librarianship to gain knowledge in the field. During his stay he made observations of the functioning of various libraries, studied the different classification schemes and also witnessed the major problems that the schemes having enumerated class numbers poses to library functioning. He thought that only an alteration of the nature of the library classification schemes can ease the situation. As a result, he brought a change in the foundational principles of his library classification schemes. (Kumar, 1988; Ranganathan, 1989).

The idea of the nature of the new principal came to his mind when he suddenly watched a Meccano set in a Selfridge Department store. He thought to design a synthetic or faceted classification scheme. The next important step was to choose a notational system that would aid the number construction in the faceted classification scheme. The need was to find a number having only ordinal value tying between zero of unity. Finally, the double dot or the colon was chosen as the alternative to zero and the first step for designing Colon Classification was taken in 1924. Gradually Ranganathan designed the framework for the new scheme, discussed with Sayers; and completed a draft of the scheme by 1925. The emphasis was on synthesis of numbers. The scheme was put to test in Madras University Library where their materials were classified using the new scheme; changes were made by observing the feedback from the users and finally in 1933 the first edition of Colon Classification got published. (Kumar, 1988).

Developments and Editions: The first edition was published in 1933. It had three parts: Part 1 had 127 pages of rules, Part 2 had 135 pages of schedule and Part 3 had 106 pages of index (Singh, 2006). The Second edition was published in 1939, and the idea of fundamental category was introduced along with other concepts like Facet, Focus and Phase. Eleven years later came the third edition in 1950, followed by the fourth edition in 1952. In the fourth edition the symbols representing the fundamental categories were changed to avoid ambiguity. Also, the use of Greek letters was introduced to facilitate interpolation of the newly emerging subjects. The fifth and the sixth edition were published in 1957 and 1960 respectively. Both the editions were updated based on the need and recommendations. The sixth edition was revised with published with certain amendments in 1963. Rules for the main classes were changed, the symbol for time isolate was also changed to inverted coma ('). The final edition that is the seventh edition was published in 1969. It was published under the editorship of Dr. M.A. Gopinath. However, only the first volume or the schedule was published. The index of the seventh edition has not been published till date (Dhayani, 1998; Kumar 1988).

The different editions of CC are recognised in three versions. In the first version the scheme was fully but rigidly faceted and these included CC editions 1, 2 and 3. In version 2 the scheme was made much more faceted but certain rigidity continued to stay. This included edition 4,5, and 6 of colon classification. CC7 is version 3 and is considered as the freely faceted scheme for library classification (Kumar. 1988). As edition 7 is incomplete so the revised sixth edition has been studied below.

Arrangement: Colon Classification edition 6 (revised) has three parts

- Part 1: Rules of Classification
- Part 2: Schedule of classifications
- Part 3: Schedule of Classics and Sacred Books with Special Names

Prior to these three parts the scheme also consists of an annexture which lists the changes that have been made for the edition. The seventh edition only have its schedule published. The index of this edition is not published even today (Ranganathan, 1963).

Structure: The structure of Colon Classification scheme is different from the other popular general classification scheme like DDC or UDC. Colon classification being an analytico-synthetic scheme has a theory of classification supporting the entire scheme. As a result, while there exists a structure that is visible in the form of schedule in colon classification; the synthesis of the class numbers demands the knowledge of the theory of classification that lies underneath its structure. The scheme consists of in part 1 certain rules. It includes rules relating to call number, class number, book number, collection number, foci and facet, discusses the canons and postulates as well as the different devices. The devices found in CC 6th edition includes Chronological device, Geographical device, Subject device, Mnemonic device, Alphabetical device, Superimposition Device, Favoured category device and classic device. Next rules were provided relating to the isolates, phase relation and rules that are given specifically for each of the main classes that are to be followed while constructing class number by combining of numbers from more than one facet. Next in Part 2 there are the Main classes that represent the universe of knowledge. The main classes here are represented by Alphabets. Below is a detail of the main classes as per CC 6th revised edition:

Main Class	Class Number
Generalia	9a
Library Science	92
Mathematics	B
Physics	C
Engineering	D
Chemistry	E
Technology	F
Biology	G
Geology	H
Mining	HZ
Botany	I
Agriculture	J
Zoology	K
Animal Husbandry	KZ
Medicine	L
Pharmacognosy	LZ
Useful Arts	M
Spiritual Experience and Mysticism	Δ
Fine Arts	N

Literature	O
Linguistics	P
Religion	Q
Philosophy R	R
Psychology	S
Education	T
Geography	U
History	V
Political Science	W
Economics	X
Sociology	Y
Laws	Z

(Ranganathan, 1963)

Part 3 provided with already enumerated class numbers for some selected classics and sacred books.

There are schedules for facets for each basic class and each of the facets are identified as either of the five fundamental categories identified by Ranganathan i.e., Personality, Matter, Energy, Space and Time (PMEST). Each of the categories is accompanied by an indicator digit.

There is facet formula for each of the basic class for construction of class number. Other than the Main classes there exists the Isolates. There are two types of isolates: Special isolates and Common isolates. Special isolates are specific to a basic class and appears under a main class in the schedule. Common isolates are those that are applicable to multiple classes and are identified in two categories viz: Anteriorising Common Isolate and Posteriorising Common Isolates. Schedules are also found for geographical division, chronological division, and Language division.

CC also have the ‘Systems’. Many main classes like Psychology, Agriculture, Medicine, Education etc. have been studied from different point of view which Ranganathan identifies as Systems and Specials. For examples in Medicine class Homeopathy is considered as a System.

Another significant feature is ‘Phase Relation’. Phase relation involves two or more basic subjects or a basic subject and a compound subject or two compound subjects brought into relation with each other. Phase relation can exist between Main Class level, Facet level, Isolate level known as Inter-Subject, Intra Facet, Intra Array Phase relations respectively. There are five types of phase relations identified in 6th edition of CC viz: General, Bias, Comparison, Difference, Influencing phase.

Each of the phase relation is indicated by an alphabet as shown below:

Intra Array	Intra Facet	Phase	Nature of Relations
t	J	a	General
u	K	b	Bias
v	M	c	Comparison
w	N	d	Difference
y	R	g	Influence

While the above discussed structure is apparent in the schedule there are also theories on which the facet formulas are based on. This includes the postulates of basic facet, postulates of facet sequence, rounds and levels. (Singh, 2006; Kumar, 1988; Dhayani, 1998; Ranganathan, 1963)

Notation: The use of different types of symbols alphabets, numbers have all resulted into a mixed notation in Colon Classification.

These include

1. 10 Indo Arabic numerals 0-9
2. 23 Small letters of Roman Alphabets (excluding i, l and o)
3. 26 Capital letters of Roman Alphabets
4. Numbers in Circular brackets
5. Indicator digits
6. Empty, Emptying and Empty-Emptying Digit

In CC the main subjects are represented by Alphabets. The Isolates and Speciators are also numbered using both Arabic numerals and Alphabets. The digit 9, Z, 0 (zero) z are used as empty digit. Digits T, V, X are used as Emptying digit. U, W, Y are used as Empty Emptying digit. Notations in CC have the Mnemonic quality- scheduled, seminal and Systemic mnemonics. Hierarchy of notation is followed by in Colon classification also. However, in some cases hierarchy is not maintained. This is mainly done in case of Telescoped array.

Some of the indicator digits of CC6 include:

, (comma)	Personality
; (semi colon)	Matter
: (colon)	Energy
. (dot)	Space
' (inverted commas)	Time
- (hyphen)	indicates spectator of kind 1
Arrows – both forward (→) and backward (←)	indicates backward/forward range
(*) Asterisk	Indicate Agglomerates
& (previously 0 zero in 6th edition)	indicates phase relation

Number Building: In CC numbers are constructed using the facet formula along with their symbols provided for each of the main classes separately. Also, common isolates are used to construct class number wherever applicable. Phase relation is used to construct class numbers depending on the nature of the relation existing between the interacting elements. An important feature taken into consideration while constructing class numbers is of Rounds and Levels. To Ranganathan any fundamental category might manifest themselves more than once. It is here the concept of Rounds and Levels are plays and important role while number building. Devices such as alphabetical device, subject device, chronological device, geographical device and super imposition device are often used in number buildings. In number of instances rules for number constructions have been provided in Part 1 of the classification system.

Below is an example of number built using facet formula. The facet formula for Library Science is 2 [P] ; [M] : [E] [2P] . The class for 'Classification of Manuscripts in National Library in India in 21st century' would be

213;12:51.44'P

where 2 is the class number for the main class 'Library Science'; 13 is the personality category representing national library; 12 is for manuscripts which is the category of Matter; 51 represents classification i.e. the Energy category; 44 is India (Space) and P represents 21st century that is Time. Each of the category is preceded by their respective symbols.

Index: In the 6th edition there are four indexes. All of them are alphabetically arranged. There is a general alphabetical index for the entire schedule. Other than that, there are three subject specific indexes: Geographical index, Index of the class Botany and Zoology. In CC7 there is no published index to the main schedule.

Colon classification is a faceted and analytico-synthetic classification scheme. This scheme although is used much less in comparison to UDC and DDC but has been adopted by many special libraries and documentation centres for arrangement of their library materials. The seventh edition of colon classification is also a freely faceted classification scheme. This scheme has the capability to accommodate the newly emerging subjects. Many interdisciplinary subjects are incorporated in colon classification edition seven. The scope for construction for class numbers have also been explicitly given.

4.5 Interdisciplinary Subjects and Classification Schemes

From the discussion on three classification schemes above it is evident that there are various methods to integrate new subjects into the existing structure of the scheme. The process involves assigning a class number to the new subject by following the 'add instructions' and utilizing the provision of gap device. But merely assigning a class number to the subject is not sufficient to meet the primary objective of a classification scheme. It is crucial to ensure that the subject is positioned appropriately within the schedule to accurately reflect the scope and core content of the subject matter. The ever-evolving nature of the universe of subjects presents a continuous challenge for classificationists to accommodate emerging or newly emerged subjects.

The challenge becomes more pronounced with an interdisciplinary subject, as traditional classification systems are discipline specific. Therefore, careful analysis and research are necessary to determine the most suitable broad discipline for the accommodation of the new subject, ensuring its scope is accurately represented.

Szostak, Gnoli, & López-Huertas (2016) highlighted the challenges faced in integrating interdisciplinarity into library classification schemes. They emphasized the challenge of determining the kind of relationships existing between the contributing subjects and identifying areas of interaction among subcategories of those subjects. The issue of possible ambiguity regarding terminology within interdisciplinary subjects was also addressed as vocabulary evolves along with the subject. The borrowing of terms from the various interacting disciplines adds to the complexity, making it challenging to understand the origin, context and meaning of terms. This uncertainty poses obstacles in deciding which terminologies to include in the emerging subject's schedule. The nascent stage of the subject even leads to taxonomical deficiency and lack of proper definition of the concepts.

But the growth of interdisciplinary subjects around the twentieth centuries made in necessary that these subjects are included within the disciplinary structure of the classification schemes.

Szostak, Gnoli, & López-Huertas (2016) opined “when addressing an inter-discipline, it is generally necessary to immerse oneself in the literature before one can establish the key subjects that are addressed by the inter-discipline” (p. 132). Their proper accommodation therefore requires a deep understanding of the shared areas of interest between the disciplines involved in order to establish a solid foundation for the new subject. Additionally, it is crucial to define the specific terminologies and subcategories that needs to be represented under the new subject.

Consequently, an in-depth analysis of the subject slated for incorporation into the classification scheme is imperative. Bhattacharya (1975) put forward a proforma that should be followed for gathering information on any subject that is to be studied. His recommendation included: Definition, Terminological development, Scope, Tool and Application Subjects, reflection in tools of document classification like thesaurus or subject headings; studying the development of the subject, and its reflection in both general and specific classification scheme. He further elaborated that study of development of subject should include its landmark development; trends of research; trends of education as well as its sources of information. The conducting of a developmental study for an interdisciplinary subject can have a crucial impact on determining the broader subject domain to which the new interdisciplinary subject could be associated. When considering the evaluation of interdisciplinary subjects within a classification scheme, it is essential to align this process with their developmental study. Evaluation of the reflection of the various concepts and areas of interaction between the main interacting subjects in the classification schemes, prior to its consolidation as a separate subject or discipline, will allow to understand the nature of interactions among the subjects as well as its alienation towards the interacting discipline and aid in determining its position. Once the position is determined number construction of the subject can be done through add instructions; use of symbols (in schemes having such provision); by reflection of the phase relation between the interacting subjects or its subcategories at different stages. Such subjects can also evolve to become a distinct discipline and can have application in various other disciplines.

The classification schemes discussed above have evolved over time to incorporate a variety of interdisciplinary subjects. Many of the already developed interdisciplinary subjects now have built-in class numbers. For areas that are emerging as interdisciplinary subjects, in UDC class number can also be built using the relational symbol 'colon' if necessary (BSI, 2005). Similarly in CC class number for interdisciplinary subjects are reflected through class numbers constructed by various phase relations. Edition 7 of CC have included several interdisciplinary subjects as either primary basic subject or basic subject (Ranganthan, 1987). In DDC numbers can only built through 'add instructions'. Also, there are numerous instances in DDC 23rd edition where 'Class here' notes are found.

"For example:

> 391 Costume and personal appearance
>
> Class here interdisciplinary works on costume, clothing (apparel, garments), fashion; casual wear (sportswear)" (Dewey, 2011, vol. 2, p. 907)

There are also notes that begin with the term 'class' which indicates interdisciplinary nature of any topic or term.

"For example,

> 370.15 Educational psychology
>
> Class interdisciplinary works on psychology in 150. Class psychology of a specific topic in education with the topic, plus notation 019 from Table 1, e.g., psychology of special education 371.9019" (Dewey, 2011, vol. 2, p. 806).

The relative index in DDC clearly represent the interdisciplinary nature of subject. "The first class-number displayed in an index entry (the unintended term) is the number for interdisciplinary works. If the term also appears in a table, the table number is listed next, followed by other aspects of the term. The discipline of the interdisciplinary number may be repeated as a subentry if the discipline is not clear.

For example:

Adult education	374
	T1-0715
federal aid	379.1215
law	344.074
public administrative support	353.84
public support	379.114
law	344.07685
special education	371.90475
university extension	375.175

Interdisciplinary numbers are not provided for all topics in the Relative Index.

For example:

Coagulation	
blood	573.159
human physiology	612.115
physiology	573.159
see also Cardiovascular system	
water supply treatment	628.162 2

They are omitted when the index entry is ambiguous, does not have a disciplinary focus, or lacks literary warrant. In such cases, there is no number opposite the unintended entry". (Dewey, 2011)

All the schemes have been revised to better suit the scope of these subjects whenever necessary. There has also been number relocation of a subject from one broad area to another due to change in the scope of the subject.

Thus, to cope with the challenges in integration of interdisciplinary subjects in a classification scheme, it becomes necessary that a dual process of 'developmental study of the specific interdisciplinary subject' and 'evaluation of its reflection in classification schemes' at various stages of development is undertaken.

Keeping in view the objective of this research, the following chapters aims at studying the development of selected interdisciplinary science subjects (chapter 5) and how the stages of development got reflected in the selected classification schemes viz DDC, UDC, CC (Chapter 6).

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Chapter 5:
Interdisciplinary Subjects in Science: A Study

5.1 Introduction

The present chapter deals with the growth and development of selected Interdisciplinary Science subjects. It highlights significant landmarks, stages of development, and identifies the typology of relations at each stage for all subjects involved. The subjects are organized alphabetically within each of the final modes. At first the subjects under Fusion are studied, followed by those under Distillation, and concluding with the subjects under Clustering. Fusion includes eight subjects: Astrobiology, Astrophysics, Biochemistry, Bioinformatics, Biomechanics, Biophysics, Geochemistry, and Geophysics. Distillation comprises two subjects: Microbiology and Molecular Biology. Lastly, Clustering consists of two subjects: Environmental Science and Oceanography.

The representation of developmental stages involves the identification of distinct time periods, each associated with a particular typology of relationships relevant to the subject under consideration.

5.2 Astrobiology

Astrobiology is "the interdisciplinary science that studies the origin, evolution, distribution and future of life in the Universe" (Farmer, 2011, p.73). Although Biology and Astronomy have little common in scope but the idea of plurality of world and the quest to identify life beyond earth gave them a common ground. The subject of Astrobiology involves various subfields of both Astronomy and Biology that interact and employs tools, methods and theories to search existence beyond earth; and also aims to understand the nature of environments required to sustain life beyond earth. Over the years the nature and focus of interactions between the subjects have undergone changes.

However, the search for life in other planetary world has created the need for collaboration between astronomers and biologists thereby creating a scope for interdisciplinary interactions, findings, development of new tools and formulation of new ideas and theories. With time such interactions gradually gave rise to a new interdisciplinary subject of Astrobiology.

Below are the stages of development of Astrobiology along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1934): At the core of Astrobiology lies the concept of 'life beyond earth' which is inherently related to the idea of 'Plurality of World'. Such ideas got reflected in the works of many Greek philosopher-like atomists Democritus and Leucippus who claimed that there exist several worlds that are either expanding, increasing or collapsing. The collapse to them can result from collision of the worlds with each other. Similarly, Epicurus also advocated the concept of 'infinity of worlds' similar to earth (as cited in Dick, 1982). Greek Philosopher Metrodorus of Chios in his book 'On Nature' wrote, 'it is unnatural in a large field to have only one stalk of wheat, and in the infinite universe only one living world' (as cited in Papagiannis, 1985, p. 5) thus expressing his conformity to the existence of infinite worlds in the Universe. Also, Roman philosopher Lucretius in his 'De Rerum Natura' (1BC) stated 'nothing in the universe is unique and alone, and therefore in other regions there must be other earths inhabited by different tribe of men and breeds of beasts' (as cited in Papagiannis, 1985, p. 5). The pluralist believed that there were numerous worlds full of intelligent beings. But the ancient pluralistic idea of the world and the contemporary understanding of extraterrestrial life are not similar. Also, inspite of support for cosmic pluralism, it was Aristotle and Plato's idea of single world that prevailed for centuries. People believed firmly on the uniqueness of Earth as the only planet with living beings and that it was the centre of the universe.

In the sixteenth century, renaissance astronomer Copernicus (1543/1995) challenged the geocentric theory of 'earth as the centre of universe' and put forward the heliocentric theory in his book 'On the Revolutions of the Heavenly Spheres'. Possibility of pluralistic world also got support from German astronomer Johannes Kepler. Favouring the possibility of worlds beyond the Earth, an Italian astronomer and philosopher, Bruno (1584/2014) wrote in his work titled 'On the Infinite Universe and Worlds' "So is the magnificence and glory of God magnified, and the greatness of his kingdom made manifest: not merely glorified in one, but in innumerable suns; not in one earth, one world, but in a thousand thousand, spoken in infinity" (p.28). He also stated that only suns are visible because they give light and that not one, but infinite earths move around sun. To him other planets are small and dark hence are not visible. Thus, there was a consensus to a great extent about the possibility of life beyond earth. However, still these theories were mostly conjectures about the existence of several worlds and was not backed by proper observational or experimental data that could testify the conditions of other planets and possibility of life; and was thus much different from the planetary system that exists at present.

The invention of the telescope in the seventeenth century and its use dawned a new era in Astronomy and also contributed to the theory of pluralism. It made it possible for astronomers to view new planetary bodies and moons. There was a surge of assumption on the existence of life on planets outside our solar system. The French author Fontenelle (1686/1715) a proponent of pluralism of world, published 'Conversations on the Plurality of Worlds' in which he discussed about the potentiality of extraterrestrial life and considered stars to be similar to Sun with a chance of having their own solar system. 'Cosmotheoros' the posthumously published book of Christiaan Huygens, a Dutch mathematician and physicist in 1698 included substantial writings about extraterrestrial life and the possibility of habitation in other planets (Huygens, 1698).

One of the major developments that contributed towards the beginning of Loose Assemblage between Astronomy and Biology came in 1687. The discovery and publication of Law of Gravity by Newton in 1687, as well as the rising acceptance of the heliocentric view of the universe by the mid-18th century, fuelled curiosity in extraterrestrial life. William Herschel, a British astronomer, was largely convinced by the evidence found to support the idea of life on the moon as well as in the existence of life in many parts of the planetary system. He discussed about the population of Saturn, Jupiter, Uranus as well as Mars. He was also a believer of plurality of planetary system and that some of these planets are habitable as well as inhabitable (as cited in Basalla, 2006).

Kant (1755/1969) in his book 'Universal natural history and theory of the heavens' speculated regarding extraterrestrials life and considered them as extraordinary. In the cosmic world of Kant, every entity has a centre and to him the creatures of worlds near to the centres are less refined and less intellectually developed whereas those away from the centre are "the most perfect classes of rational beings" (p. 166). These ideas further got support from works of French astronomer Camille Flammarion. He portrayed extraterrestrial entities as alien. His fascination for understanding life beyond earth got reflected in his books like La pluralité des mondes habités (1862), Les mondes imaginaires et les mondes reels (1864), Lumen (1887), Urania (1889), La Planète Mars et ses conditions d'habitabilité (1892) etc.

The speculation of extraterrestrial life got a further impetus in the early twentieth century when Percival Lowell claimed of observing canals on Mars and the prospect of intelligent beings on Mars further supported the possibility of extra-terrestrial life. He published his observations in three of his publications: Mars (1895), Mars and it's Canals (1906), and Mars as the Abode of Life (1908). However, this led to controversies as many of his contemporaries considered the observations as to be optical illusions.

Although curiosity to know and understand extraterrestrial life was clearly evident but lack of enough proofs to support the idea of other world in the planetary system made it difficult for astronomers to go ahead with any investigations. Also, Biologists had very little theoretical evidence to back up the claim of extra-terrestrial life. The ideas and theories were mostly observational and lacked proper scientific evidence. Any direct collaboration between astronomy and biology thus seemed to be distant at that point of time.

Loose Assemblage (1935-1974): At this backdrop however the concept of astrobiology began to appear in academic areas frequently. The term 'Astrobiology' appeared in many publications throughout the twentieth century. One of the oldest definitions of the term Astrobiology that is apt with the current meaning of it, can be found in Ary J. Sternfeld's 1935 article 'La vie dans l'Univers'' ("Life in the Universe") defining it as "the development of both the natural and astronomical sciences has led to the birth of a new science whose main objective is to assess the habitability of the other worlds, this science is called astrobiology" (as cited in Briot, 2012, p. 1154). A philosopher Lafleur (1941) in the essay titled 'Astrobiology' defined it as "the consideration of life elsewhere than on Earth" (p. 333).

In 1953 for the first time the term 'Astrobiology' appeared as a title of a book written by Russian astronomer Gavriil Tikhov where he discussed the study of life on other planets. He supported the potential use of spectral signature found in other planets to access the possibility of life in the extrasolar planet (as cited in Cockell, 2020). In 1955, American astronomer Otto Struve independently coined the word 'astrobiology' to describe the broad study of life beyond Earth. Flavio A. Pereira created, in 1956, the Brazilian Interplanetary Society and published in Brazil a book 'Introdução à Astrobiologia' in 1958 in Portuguese language on astrobiology. The term astrobiology was therefore beginning to gain academic popularity especially in the field of astronomy. (Rodrigues & et.al., 2012).

The space age dawned with launching of Sputnik 1 in 1957, This significant milestone prompted a heightened interest in investigating the possibility of life beyond Earth, as researchers began to delve into the new avenues created by the advancements in space exploration. This led to an increase in the study of the potential for life on other planets, as scientists began to consider the possibilities opened up by the new technology of space exploration. Thus, the scope for astronomy and biology to connect got a new dimension.

In June 1957, Albert G. Wilson, director of the Lowell Observatory, organized the first 'American Astrobiology Symposium' in Flagstaff, Arizona. Two leading scientific groups in the United States were engaged in coordinating research on extraterrestrial life- one was the 'Extraterrestrial Life of the National Bioastronautics Committee belonging to the Board of the Armed Forces' chaired by Melvin Calvin, with Carl Sagan as a key participant; the second was the 'Panel on Extraterrestrial Life of the National

Academy of Sciences', chaired by the eminent biologist and geneticist Joshua Lederberg. The focus centred around the quest for life on Mars and the advancement of devices essential for the planetary probes. This area of scientific inquiry was commonly referred to as bioastronautics (Lemarchand, 2000). Thus, the collaboration between astronomers and biologists got an initial footing to find answers to the questions of possibility of life beyond earth.

The creation of National Aeronautics and Space Administration (NASA) in July 1958, contributed to a large extent in furthering the understanding the possibility of extra-terrestrial life.

An instance of direct involvement of Biology came in 1960 when the term 'exobiology' came into the forefront specifically to mean the study of life beyond the Earth. Molecular biologist-turned-exobiologist Joshua Lederberg wrote in the journal 'Science' that "Exobiology is no more fantastic than the realization of space travel itself, and we have a grave responsibility to explore its implications for science and for human welfare with our best scientific insights and knowledge" (Lederberg, 1960, p. 399). He coined the term exobiology to mean 'the biology of extraterrestrial origin'.

In the same year (1960) Frank D. Drake, a radio astronomer in National Radio Astronomy Observatory performed an experiment to search extraterrestrial intelligence (SETI) using radio telescope. The detection of a signal that cannot be attributed to a natural source, according to Frank Drake, would reveal the existence of intelligent life beyond Earth (Ostovar, 2014). Use of Radio Astronomy to detect extra-terrestrial life started a phase which gradually led towards Radio astronomy as a separate subject.

Around 1965 microbiologist Dr. Harold P. Klein and others fellow exobiologists advocated for projects to send spacecrafts to investigate and detect possibility of life by examining extra-terrestrial environments. This resulted in NASA's Ames Research Centre (ARC) gradually pursuing various life science and exobiology programs, allowing for greater investigations in life throughout the universe, which subsequently led to the birth of the field of Astrobiology.

SETI studies were funded by NASA throughout 1960s and 1970s under which projects and programmes were undertaken to identify frequencies of radio signals of the electromagnetic spectrum from extraterrestrial life that could indicate life beyond earth.

Until this point it can be seen that the involvement of astronomers in understanding life in extraterrestrial world was mostly observational. The instances of collaboration between astronomers and biologists were also limited. The studies carried out were either research or observational and mostly were focused on 'biology of world beyond earth'. Thus, the relation between biology and astronomy was identified in a state of Loose Assemblage.

Lamination (1975 – 1997): One of the most important steps towards bringing Biology and Astronomy further close was NASA's Viking Programme in 1975under which two space probes (Viking 1 and Viking 2) were sent to Mars to probe the atmosphere and environment of Mars, to get high resolution images and to search for evidence of life in Mars. The idea was to study the possibility of life on Mars. Both of them successfully landed in 1976 and carried out biological experiments in Mars's soil to identify any traces of possible life. One of the experiments did show positive result in detecting Metabolism however the failure of the other experiments led to the conclusion that the initial positive results were due to chemicals that are non-biological in nature. Thus, the question of presence of life in Mars remained unresolved.

The failure resulted into abandoning of such experiments for certain time period. The developments in Biology however brought the focus once again back to the study of 'Life at Mars'. The focus now shifted from finding life to searching for conditions that can sustain life in the extraterrestrial world.

Around 1990 the discovery of organisms having the capacity to survive extreme conditions also gave hope that life might be possible in other planets. Rothschild and Mancinelli in their paper 'Life in extreme environments' while discussing about possibility of extraterrestrial life stated, "new data on the survival of microbes in the space environment and modelling of the potential for transfer of life between celestial bodies, suggests that life could be more common than previously thought" (Rothschild & Mancinelli, 2001, p. 1092).

Meanwhile the momentum to study 'life at mars' once again gained attention after the discovery of a Martian microfossils in a meteorite (ALH84001).

On the other hand, astronomical and planetary discoveries like 51 Pegasi in 1995 by Michel Mayor and Didier Queloz; dwarf stars; images of Jovian; identification of other extrasolar planets around stars also gave impetus and renewed interest in astrobiological investigations.

However, there was a lack of experts having enough knowledge on both the fields to answers queries on extraterrestrial condition necessary for life. Thus, the need of 'an interdisciplinary field that would allow the two groups to collaborate with one another was the need of the time for answering the question on 'life on Mars'-- the first question was how life begins and develops; the second question established by NASA asked whether there was life elsewhere; the third and final question identified in the astrobiology roadmap was to determine what the future of life is on Earth and beyond (Cockell, 2020).

In 1995, Dr Wesley Huntress, the then associate administrator of Space Science in NASA officially suggested the use of the term "astrobiology" to represent the new broad scope of study of life in the universe (Catling, 2013). This time the study was no more confined to the tracing of the signs for life in universe only but rather focussed on environment favourable for habitation for searching life beyond earth. In the same year Ames was declared as NASA's lead centre for the new field of astrobiology.

A group of researchers including NASA scientist Dr. David McKay published a controversial article about possible signs of life in a Martian meteorite ALH84001 in the Allan Hills region of Antarctica in 1984, (McKay & et.al, 1996). This is considered as an important juncture in the history of astrobiology.

In September1996, the first NASA Astrobiology Workshop was held at Ames, attended by scientists from a broad range of Earth, space, and life science fields (Dick & Strick, 2004).

By 1997 experiments were carried out that clearly showed the ability of microbes to survive extreme conditions. This was followed by a number of Mars missions.

Mars Global Surveyer Orbiter launched that captured images showing the strongest evidence that liquid water did exist on the surface of Mars. The Mars Pathfinder lander in 1997 aimed at finding extraterrestrial paleontological evidence of fossils of microbes. From 1997 a series of papers using the term astrobiology began to emerge coinciding with the formation of NASA's Astrobiology Institute.

By this time a mode of 'Lamination' is identified in the development of the subject. The concept of 'extraterrestrial life' may appear in subjects such as 'possibility of life at Mars'; 'microbial survival in extraterrestrial conditions'; locating of 'microbial fossils of living being in extraterrestrial world' etc. going with the primary basic subject of Biology and Astronomy.

Fusion (1998 onwards): The NASA Astrobiology Institute was established in 1998 with Baruch Blumberg (Nobel Prize winner in Physiology and Medicine) as the director. A programmes 'Astrobiology Science, Technology and Instrument Development Program (ASTID)' came up. Also to promote Astrobiological activities workshops were organised in regular intervals. In 1998 a NASA Astrobiology Roadmaps were designed to aid future research, planning, and conducting of programmes. It recognised four principles, ten goals, and seventeen objectives for astrobiology (Dick & Strick, 2004). A workshop on social implication of Astrobiology was organised in 1999 by NASA's Ames Research Centre.

Around the same time here came up an 'Astrobiology Academy' at Ames. Beginning in 2000, NASA sponsored postdoctoral degrees were being awarded. The University of Washington started the first graduate program in astrobiology, and a number of textbooks on the topic and related sub-topics were being developed. Furthermore, with a surge in global interest and research, astrobiology was increasingly becoming an international field, leading to collaborations with several institutions linked to the Astrobiology Institute (Dick & Strick, 2004).

Two journals namely 'Astrobiology' (https://www.liebertpub.com/loi/ast) (2001) and 'International Journal of Astrobiology' (2002) published by Mary Ann Liebert, Inc., and Cambridge University Press respectively came up which reflected the scientific progress of the field.

The year 2001 witnessed another important programme named "Astrobiology Science, Technology for Exploring Planets (ASTEP)" for development of exploration technique for enhancing study of Astrobiology. At the same time European Astrobiology Network Association (EANA) was created to act as a coordinator in Astrobiology research.

Thus, the interdisciplinary interactions reached a condition where clearly an interdisciplinary field distinct from Astronomy and Biology can be seen to emerge having its own set of practitioners and well-developed objectives.

Launched in 2001, the Mars Odyssey Orbiter gathered evidence through hydrogen spectral measurements that revealed the presence of extensive water ice beneath the surface of Mars. In 2004, NASA's Mars Explorer Rover confirmed the existence of significant quantities of liquid water on and beneath the Martian surface in its geological history. On 2005 signs of liquid flow on the surface Saturn’s moon ‘Titan’ was observed by Europe’s spacecraft ‘Huygens’. Such findings have greatly contributed to the development of astrobiology as a subject, expanding the potential for extraterrestrial habitats. In 2009, NASA revised its 1998 roadmap to include the 'Astrobiology and Society' initiative. It also became a basic theme for the European Astrobiology Institute (EAI). The humanistic and social aspects of astrobiology was put forward in 2011. A number of missions have since then been taken up to find answers to various astrobiology questions.

5.3 Astrophysics

Astrophysics in simple terms is “the study of the physical and chemical processes involving astronomical phenomena. Astrophysics deals with the stellar structure and evolution; the properties of the interstellar medium and its interactions with stellar systems, and the structure and dynamics of systems of stars and of systems of galaxies” (“Astrophysics”, 2017, p.725). It focuses on the physical properties of astronomical objects-density, motion, temperature, light etc. and employs the principles of physics to understand astronomical interactions. Astrophysics typically applies to many areas of physics, including mechanics, electromagnetism, statistical mechanics, thermodynamics, quantum mechanics, relativity, nuclear and particle physics, and atomic and molecular physics. Keeler (1897), said, Astrophysics "seeks to ascertain the nature of the heavenly bodies, rather than their positions or motions in space–*what* they are, rather than *where* they are” (p. 272). The two science subjects involved in this interdisciplinary subject are therefore Astronomy and Physics.

Tracing the genesis of astrophysics shows that astronomy has long been providing information that is based on concepts and scales that today are part of physics. Astronomy also provides data for investigations in physics that are not possible to be obtained on earth or in the laboratory. However, the interaction between Astronomy and Physics as distinct subject fields is much recent.

Below are the stages of development of Astrophysics along with the typology of relations as identified

Pre-Loose Assemblage (Till 1686): From ancient times the celestial sphere and the terrestrial spheres were considered as opposed to each other- the first being an example of perfection while the other full of imperfections. Thus, the governing principles for both the spheres were also thought to be distinct from each other.

The earliest works in Astronomy involving aspects of Physics are the works relating to Planetary motion. While the geocentric view was the general accepted idea of the planetary system; it was Aristarchus of Samos, a Greek astronomer who is considered as the first to put forward the notion that 'it is sun which is at the centre unmoved; and that earth and other celestial bodies rotates around the sun' (as cited in Heath, 1913). However, as his views were opposed to the general conception it did not find acceptance at that time.

It was astronomer Nicolaus Copernicus in the 16^{th} century who again brought the heliocentric idea of celestial motion into focus. His book 'De revolutionibus orbium coelestium' (On the Revolutions of the Heavenly Spheres) published in 1543 contains his idea and support for the heliocentric model scientifically (Copernicus, 1543/1995).

Significant observations were made by Danish astronomer Tycho Brahe from around 1575 to 1595. In 1572 Brahe observed a supernova and in 1577 observed comet. He also made positional observations of various celestial bodies (Dreyer, 1890).

The seventeenth century saw the emergence of proponents of the concept of unified physics. The notion of same rules of celestial world and earth found support in philosophers like Galileo, Descartes, and Newton. The invention of the telescope by Galileo Galilei and the discoveries made using it gave the heliocentric model a strong base. Moreover, his discovery of Jupiter (1610) and its four moons along with its planetary movements further supported the claims (Galilei, 1610/1880). But even after such findings the social environment was not conducive and hence his ideas were vehemently opposed.

The observations of Tycho Brahe provided the basis to Johannes Kepler, a German astronomer, to discover his three laws of planetary motion between 1609-1619 (Kepler, 1619/1997). In 1676 Ole Roemer, Danish astronomer, almost accurately calculated the speed of light. Roemer stated, "the speed of light was of such magnitude that it would require about 22 minutes to traverse the diameter of the annual orbit of the earth". (as cited in Roemer & Cohen, 1940, p.328)

Thus, the 17th century saw advancements in observational methods that led to more and more accurate observation of the motions of sun, planets and other celestial bodies. Such data was used for keeping time as well as for navigational purpose. But even then, these studies were mostly observational and did not involve Physics directly.

Loose Assemblage (1687-1919): A significant step forward came when Isaac Newton published 'Philosophiae Naturalis Principia Mathematica' in 1687 and put forward his three laws of motion including gravity, dynamics and mechanics, and in turn explained Kepler's laws; for the first time it was established clearly that the law governing the celestial and terrestrial world are one and unified. Thus, for the first time a clear ground of unity between the two subjects was observed where astronomy was studied in the light of laws of physics.

Another important observational area was measuring the distance of the stars, sun and earth. The observational measurement of the distance between starts was carried out throughout 18th century. However, the most accurate evidence of large distance in between the stars came from James Bradley in 1728 (Bradley, 1728).

The relation of physics with astronomy became further evident when spectroscopy was used to carry out astronomical investigations. William Hyde Wollaston, a chemist, is credited with discovering dark lines while examining a beam of sunlight in a dark room through a prism in 1802. His observations revealed the presence of dark lines along with other four colours- Red, Yellowish Green, Blue and Violet in the beam (Wollaston, 1802). Joseph Fraunhofer, a German physicist, in 1814 came forward with his observations after conducting a somewhat similar experiment using a prism infront of a telescope and passing sunlight through it. He also identifies dark lines while observing the strong lines which he labelled as A,a,B,C,D,E,b,F,G and H; and also stated "the two bands of H are most remarkable; they are almost exactly equal and each consists of many lines; in the middle of each there is a strong line which is very black." (Fraunhofer, trans, 1898, p.6). This also led the foundation of another interdisciplinary interaction that is of Astronomy and Chemistry.

Another area of interaction was astronomical parallaxes and its measurements. The following period saw several initiatives for measurement of distance of earth, sun, against the fixed stars. The method used for the measurement was trigonometric parallax. Friedrich Bessel around 1837 made an attempt to measure the parallax of a fixed star. For the same he used Fraunhofer heliometer and investigated the motion of 61cygni star in respect to the distant fixed stars and put forward its parallax as one third of an arc sec (Bessel, 1838). Scottish astronomer Thomas Henderson claimed to have measured parallax movement of Alpha Centauri star from 1832-1833. Similarly, astronomer Friedrich George Wilhelm von Struve measured the parallax for the star ‘Vega’ in 1835 which he published in 1837 in a monograph titled “Stellarum duplicium et multiplicium mensurae Micrometricae”. His measure showed a 2.3 arc value (Reid and Menten, 2020).

As photography developed John William Draper took a first photograph of the moon in 1840 and in 1845 Leon Foucault & Hippolyte Fizeau took the first photograph of Sun.

French physicist Hippolyte Fizeau in 1848 put forward his idea of Dopler shift that is shifting of the spectral lines in stars. He stated “…all the rays will thus replace each other in such a way that the lines will no longer be in the same places but are all displaced towards the red or towards the violet, according to the direction of motion of the luminous body” (as cited in “Hearnshaw, 1990, p.145). In France it is sometimes known as the Doppler–Fizeau effect.

In 1849, Léon Foucault, a French physicist made a study of spectrum of sunlight- one after passing the sunlight through a sodium arc and another without it. He made observations that the solar spectrum after passing through the arc emits bright lines that are much stronger than the emitted lines without passing through the arc. He also reflected light from glowing charcoal, although there was spectrum but “the D lines were now seen in absorption in this spectrum, just as in the sun, whereas using arc line alone they had been in emission” (as cited in “Hearnshaw, 1990, p.42)

By 1860, physicist Gustav Kirchhoff and chemist Robert Bunsen put forward that coloured bands are created when selected substances are heated. They concluded that “the solar spectrum, with its dark lines, is nothing else than the reverse of the spectrum which the sun's atmosphere alone would produce. Hence, in order to affect the chemical analysis of the solar atmosphere, all that we require is to discover those substances which, when brought into the flame, produce bright lines coinciding with the dark ones of the solar spectrum” (Kirchhoff & Bunsen, 1860, p.108). It became evident that the chemical elements found in the solar atmosphere are therefore similar to those found on the earth.

In the 1860s, James Clerk Maxwell stated that the apparent shifting of the position of stars and the observer's position on the earth along with Earth's motion are correlated. He put forward an equation to calculate the velocity of light for which he considered the earth's orbit almost circular along with velocity of the earth carrying the observer from the radius of the orbit and the length of the year (as cited in Simpson, 1997).

During the same time Italian astronomer Angelo Secchi attempted to classify stars which he initially did into two groups in 1863; but later extended it to three in 1866 based on the colors of stars. He also observed the type of absorption lines and other details (as cited in "Hearnshaw, 1990). The classification was further extended to four groups.

Also, in 1860s English astronomer William Huggins made important observations. On one hand he observed almost seventy nebule and their emissions; and in 1868 put forward the method to determine the velocity of stars both in case of moving towards or moving away from the earth (Huggins, 1868; as cited in "Hearnshaw, 1990).

In 1868 Norman Lockyer and chemist Edward Frankland took up the task of analyzing the elements in the spectrums that are present in different conditions. While doing so Lockyer stated, "I saw a line the yellow, which I found very much like hydrogen, thought I could prove that it was not due to hydrogen; for laboratory use the substance which gave rise to it I named helium" (Lockyer, 1900, p.38)

In 1885, astronomer Edward C. Pickering and his colleagues carried out a 'stellar spectral classification' at the Harvard College Observatory. They classified it on the basis of the photographs which they captured using a prism in front of lens of the object telescope. The result was the publication of the 'Henry Draper Catalogue' covering huge number of spectral classifications.

German astronomer Hermann Karl Vogel provided photographs of Sirius, Rigel, Arcturus and Procyon for carrying out spectral study of stars. Further with Scheiner he observed Doppler shift of stars and calculated the radial velocity of the five stars, which he further corrected in 1892. The results of measurement of Siricus in 1892 were almost accurate and close to what was found in later investigations (as cited in "Hearnshaw, 1990, p.87). Annie Jump Cannon developed the Harvard Classification Scheme, which was later on accepted for worldwide use.

Meanwhile in 1890 the Smithsonian Astrophysical Observatory was established. "The Astrophysical Journal: An International Review of Spectroscopy and Astronomical Physics" was founded in 1895. The journal was created to provide a space to those interested in astrophysics and physics both. It involved publication on various dimensions of the application or use of physics in astronomy.

American astronomer Henry Norris Russell in 1911-1913 came up with the catalogue of stellar spectra involving use of scatter plot. Similar use of scatter plot was also made by German astronomer Hans Rosenberg and Danish astronomer Ejnar Hertzsprung. The outcome was the publication of the Hertzsprung-Russell diagram of scatter plot.

In 1919 to observe the total solar eclipse under the guidance of the Royal Astronomical Society, Astronomer Eddington, Geologist Davidson and Sir Frank Dyson, the astronomer royal, carried out two expeditions. One of them was to Brazil and the other, led to Principe Island (west coast of Africa). Photographs of Stars near the Sun before and during the eclipse were captured and compared. But Eddington and Dyson confirmed “the results of the expeditions to Sobral and Principe can leave little doubt that a deflection of light takes place in the neighbourhood of the sun and that it is of the amount demanded by Einstein’s generalised theory of relativity, as attributable to the sun’s gravitational field” (Dyson, Eddington, & Davidson, 1920).

Thus, there was a clear development of observational astrophysics. The interactions between Astronomy and Physics included the use of tools or theories of Physics to understand different astronomical phenomena. Therefore, Astronomy was being studied in relation to Physics or Physical theories were being tested in terms of astronomical objects and phenomenon. Thus, a mode of Loose Assemblage can be identified.

Lamination (1920-1962): Although the basis of understanding astronomy in terms of physics was well developed, the investigation of specific astronomical objects soon became more organized.

One of the significant advancements was stellar astrophysics. The composition, structure and positions were being investigated using physics. Studies were being undertaken to predict the process of nuclear fusion in stars. Arthur Eddington made such predictions in his paper “The internal constitution of the starts” in 1920 (Eddington, 1920). In 1925, the doctoral dissertation of Cecilia Helena Payne at

Radcliffe College covered the study of linkage between spectral categorization and star temperature using theory of thermal ionization. She identified the elements of hydrogen and helium in stars (Payne, 1925). In 1929, based on Gamow's theory, Robert Atkinson and Fritz Houtermans studied the hot regions of stars to evaluate nuclear reactions in them. In 1938 Hans Bethe, a physicist opined, stars can generate energy and showed nuclear fusions that turn hydrogen to helium (Hans Bethe, n.d.).

The increasing focus on radioactivity brought a new phase in astrophysical study. There has been a long prediction that the sun emits radio waves. In 1932 radio waves emission by astronomical objects was identified by American physicist Karl Jansky. He published his findings in an article 'Electrical disturbances apparently of extraterrestrial origin' in 1933. In 1942 the fact that the sun emits radioactive waves was detected by radio engineer George Clark Southworth. Soon the study of detecting radioactive waves from different astronomical objects flourished. Thus, radio waves emission of astronomical objects became an important area of study. This also later lead to the establishment of radio astronomy as a separate subject field.

Another significant area of development was research in Nuclear Physics in the 1930s. In 1937 the discovery of CNO cycle and its further study; the application of nuclear physics in various astronomical studies provided astrophysics with a strong new area of further research.

In 1948 research was also being carried out to identify x-ray emission of sun. In 1949 the x-ray solar study was initiated by Herbert Friedman. Later, this led to the development of x-ray astronomy. It was in 1962 x-ray emission was detected by a rocket flight that successfully made the observation.

In 1955 Martin Ryle identified approximately two thousand radio sources that according to him were beyond the galaxy.

Joseph Weber in 1961 published a book 'General Relativity and Gravitational Radiation', where he put forward the idea of detecting gravitational radiation by cosmic objects.

The first gamma-ray detection was done in 1961 using a gamma-ray telescope carried by the Explorer II satellite

Around 1962 the first interstellar molecule hydroxyl radical OH was detected by Sandar Weinreb, Allan Barrett and their colleagues. Several interstellar molecules have been identified since then.

This period witnessed direct application of various sub-areas of physics (Radio waves, X-ray photography, nuclear physics, etc.) thus giving rise to new areas of astronomy viz stellar astrophysics, solar astrophysics, nuclear astrophysics, molecular astronomy and so on. A mode of 'Lamination' can be identified at this phase in the development of the subject where the concept of Sun may appear in subjects like x-ray solar emission; radio wave emission by Sun going with the Primary Basic subject Astronomy and Physics. Similarly, the concept of Star may appear in compound subjects like Stellar emission of X-rays; Nuclear fusion in Stars; measuring radial velocity of star etc. going with the Primary Basic Subject Physics and Astronomy.

All these almost simultaneous developments at a rapid pace gave rise to a distinct interdisciplinary subject of Astrophysics. A completely new group of scientists came up who were solely dedicated to astrophysical investigations. Diverse astronomical research was taking place. At this point the Department of Astronomy at Princeton University was renamed as Department of Astrophysical Science in 1962.

Fusion (1963 onwards): In 1963 the 'First Texas Symposium on Relativistic Astrophysics' was held in Dallas. Observatories were being set up exclusively for astrophysical observations and programmes under various universities. Significant Gama ray emissions were detected throughout in 1965 as well as in 1967. The Indian Institute of Astrophysics was set up in 1971 in Bangalore. In 1973, the centre for Astrophysics at the Harvard and Smithsonian was established. NASA's X-ray space telescope was placed for capturing images between 1978-1981. In 1984 the Astrophysical Research Consortium (ARC) was formed to provide large telescope to carryout research work to the members of the consortium (ARC agreement, 1984). The Chandra X-ray observation was launched in 1999 to capture X-ray images. Many space science programmes were undertaken to study the various aspects viz gravity, wavelength, temperature, motions, light, chemical composition etc as well as to investigate the other planets, galaxies, extra-solar planets, cosmic rays, cosmic microwave and origin of cosmic world. The year 2012 saw the establishment of Astrophysics Science Division of NASA. Most of the astronomical activities now encompasses astrophysical investigations.

5.4 Biochemistry

Biochemistry is the "study of the chemical substances and processes that occur in plants, animals, and microorganisms and of the changes they undergo during development and life. It deals with the chemistry of life, and as such it draws on the techniques of analytical, organic, and physical chemistry, as well as those of physiologists concerned with the molecular basis of vital processes" ("Biochemistry," n.d.). As evident from the above Biochemistry is an interdisciplinary science involving the interaction between different sub-fields of Biology and Chemistry.

Binwal (1992) identified two roots of origin of Biochemistry-one from medicine and physiology and the other from organic chemistry. Below are the stages of development of Biochemistry along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1751): The history of biochemistry can be traced back to around 16th century when chemistry was practiced in the form of Alchemy. Paracelsus (born Theophrastus Bombast von Hohenheim), a Swedish physician as well as an alchemist, advocated the relevance of alchemy in medicine and supported the usage of chemical elements in preparing drugs (medicines). He connected chemistry with human existence. In his opinion, anything that existed including human beings are formed of three elements- sulphur, mercury and salt (not in the sense of its current usage); and any imbalance in these three elements would cause diseases. To him many chemical processes took place within human body (especially digestive process), and these were controlled by what he called an 'alchemist' or 'archeus' whose success and failure determined health, diseases and death. The failure would result into accumulation of poison which according to him could be cured only with the same poison. The use of alchemy in preparation of medicines would therefore aid the 'archeus' in fighting diseases. Later he also put forward the importance of dosage in using chemical elements for treatment. The practice of medicine that followed came to be known as Iatrochemistry (Paracelsus, 1941).

This relation between chemistry and biology was also demonstrated by Johannes Baptista Van Helmont, a Flemish chemist and a practitioner of iatrochemistry. While he separately contributed to the field of chemistry and Biology through the discovery of the concept of 'Gas' and his 'Willow Tree' experiment respectively; it was on the basis of this very experiment that he claimed water as the central element of every matter that existed. Also, he introduced the concept of quantifying values in experiments even when concerned with processes pertaining to living organisms. He supported Paracelsus's idea of 'archeus' and use of chemicals in preparation of medicine. Furthermore, he dealt with the digestive process of human and illustrated a six-step process that involved various parts of human body and also the role of acids, salts, alkalis and ferments (Helmont, 1662).

Physiologist of the seventeenth century was of the opinion that digestion was a kind of fermentation where saliva and pancreatic juice played an important role. However, another group believed digestion takes place in stomach but was the result of trituration of food.

Although the nature of chemistry then practiced; explanations of human physiological activities as well as perception of medicine were much different from how it exists today, and also lacked current day scientific explanations, but works of Paracelsus, Helmont and followers of Iatrochemistry initiated a relation of chemistry with medicine and physiology and can be considered as forerunner of both 'Physiological' 'Agricultural' and 'Medical' Chemistry.

Loose Assemblage (1752 - 1832): In the late 18th century, the relationship between biology and chemistry began to develop from a scientific perspective. The adoption of scientific techniques not only promoted this connection but also facilitated the understanding of many biological processes from a chemical standpoint. One of the concepts that received considerable importance was digestion. There came up some researchers who considered digestion as a chemical process. They took up a number of tests and made observations to prove their notion. One of the earliest proponents was René-Antoine Ferchault de Réaumur, a French naturalist. In 1752 Réaumur (as cited in Baron, 1979) carried out a test to make observation of digestive process of birds and concluded that digestion was at least partially a chemical process. A similar attempt was made by Lazaro Spallanzani, an Italian physiologist, in 1783. He made several observations of the process of digestions in various animals as well as birds and concluded digestion to be a chemical process aided by what he called 'gastric juice'. To him the more the amount of gastric juice, faster is the process of digestion. He also carried out 'artificial digestion experiments' and claimed the process of digestion could be performed outside body of living beings with the help of gastric juice (Spallanzani, 1784/1789).

Meanwhile the discovery of oxygen by Karl Wilhelm Scheele, a Swedish chemist in 1773 and by Joseph Priestly, an English chemist in 1774 gave a new dimension to the understanding of the role of chemistry in biology. Significant advancements came with Scheele's discovery of many organic acid viz: tartaric acid (1769); uric acid from urinary calculi (1776); lactic acid from sour whey (1780); citric acid from lime (1784); malic acid from apple (1785); mucic acid by oxidisation of lactic with nitric acid (1780); glycerol (1783) etc. (as cited in Browne, 1944).

The analogy that Antonie Lavoisier, a French chemist, drew through his experiment, between the chemical oxidisation taking place both in respiration and combustion, illustrated the understanding of a physiological process in terms of a non-living activity. He in collaboration with De Laplace made a number of experiments from 1777-1783 and observed "respiration is therefore a combustion, a very slow one to be sure, but moreover perfectly similar to that of carbon. It takes place inside the lungs without giving off any perceptible light, because the matter of fire, once liberated, is forthwith absorbed by the moisture of these organs" (Lavoisier & Laplace, 1994, p. 199). Spallanzani in his 'Memories of respiration' discussed respiration of various living creatures and made observations that atmospheric temperature affects the process of respiration. To him respiration is a process that is carried out both in the whole body as well as in tissues of the organism (Spallanzani, 1803)

Lavoisier (1789/1790) in his book 'Traité Élémentaire de Chimie' discussed his experiment on sugar to understand the fermentation (chemical decomposition) process through which sugars are transformed into alcohol and carbon dioxide. He stated fermentation is "accomplished by a little yeast bear and when the fermentation is once excited, it continues of itself until completed" (p. 132). "The effect of the vinous fermentation upon sugar is thus reduced to the mere separation of its elements into two portions; one part is oxygenated at the expense of the other, so as to form carbonic acid, while the other part being disoxygenated in favour of the former, is converted into combustible substance called alcohol; therefore if it were possible to reunite alcohol and carbonic acid together we ought to form sugar" (p. 139) (Lavoisier, 1790). Thus, this idea of fermentation was a chemical process reflecting the concept of theory of mass conservation.

The root of understanding the concept of photosynthesis as a chemical process can be traced to this period. Priestley (1790) in one of his experiments with mercuric oxide extracted air, which he termed as 'dephlogisticated air', and concluded that this air is capable of burning candle and sustain life better that the common air. This production of good sir, he also attributed to plants through another of his experiment. This idea of his was furthered by Jan Ingenhousz, a British physician. He through his experiments put forward that plant uses sunlight to produce bubbles (oxygen) that creates good air and that in night in the absence of sunlight no bubble is present, and this creates bad sir. But the proportion of good air created by plants are much more in comparison to bad air (Ingenhousz, 1779). Jean Senebier carried out several experiments and published various books from 1782-1800 that dealt with the concept of photosynthesis. According to Senebier (as cited in Browne, 1944) "presence of fixed air, intensity of light, length of exposure, temperature, and state of leaf are the chief conditions that govern the photochemical production of oxygen by plants".

It was at this juncture in 1806 a book titled 'Animal Chemistry' was published by Swedish chemist Berzelius. This is often considered as the earliest published book dealing with what we know today as Biochemistry.

It was becoming evident that chemistry and different aspects of biology were clearly intertwined. On one hand the study of respiration, digestion as a chemical process marked the inception of 'physiological chemistry', on the other hand the discovery of organic acids and compound from plants also initiated the first step towards 'Agricultural chemistry'.

However, it was an unplanned synthesis of Urea (an organic compound) by Friedrick Wohler, a German chemist, from ammonium cyanate (an inorganic compound) in the laboratory in 1828 (as cited in Rosenfeld, 1999) that brought in a new era in the development of biochemistry. The fact that organic compounds can now be synthesized in the laboratories, beyond living being, opened a completely new avenue for chemistry.

Until this time, it can be seen that most of the studies made were either Biology in relation to chemistry or Chemistry in relation to Biology. Thus, a mode of Loose Assemblage was identified.

Thus, by 1830s chemists turned their interest in applying the techniques and theories of chemistry in medicine, agriculture, physiological and biological processes.

Lamination (1833 – 1904): In 1833 Ansclme Peyen, and Jean-Francios Persoz, both French chemists, isolated an enzyme called diastase which was obtained from the mixture of water and germinated barley, responsible for converting starch to sugar. In 1836 Theodor Schwann discovered an enzyme while studying the digestion system in animals and named it 'Pepsin'. He extracted it from animal tissues (as cited in Mikulas, 1992).

Swedish chemist Berzelius in 1836 (as cited in Mikulas, 1992) came up with the concept of catalyst and stated "in the living plants and animals thousands of catalytic process go on between the tissues and the fluids, and produce the amount of dissimilar chemical synthesis for whose formation from common raw materials, the plant sap or the blood, we could never see acceptable cause, which perhaps in the future we shall discover in the catalytic force of the organic tissue of which the organs of the living body consists."

In 1838 Dutch chemist Gerardus Johannes Mulder studied and analysed fibrin from blood, the albumen from both serum of blood, protein of wheat, casein from cow milk and many more. His analysis revealed the existence of a large molecule which he, on suggestion of Berzelius (Chemists) named 'protein'. He concluded that the elements of proteins (carbon, hydrogen, nitrogen, oxygen) are same for each of them along with varying amount of phosphorus and sulpher. He represented the composition as $10(C^{4}H^{31}N^{5}O^{12})$ (Mulder, trans. 1849). Although Mulder's analysis of the elemental composition was found to be controversial, but it led to phase of further extensive elemental analysis of proteins by other chemists.

The emergence of cell theory marked a significant development in biological sciences. In 1838 Mathias Schleiden, a German botanist and in 1839 Theodor Schwann, a German physiologist, put forward the concept that cells are the basic unit of life of both plants and animals respectively ("Cell," 1999)

Around 1840 observations made by James Prescott Joule, Julius Robert von Mayer and Hermann Ludwig Ferdinand von Helmontz made significant contribution towards the formulation of 'laws of conservation of force'. This later formed the basis of 'laws of thermodynamics' leading to many biophysical studies. (Emergence of Fission). Mayer in 1842 (as cited in Truesdell, 1980) and Joule through a series of experiments from 1843 made similar conclusion that the amount of heat produced is equivalent to the amount of force exerted. Joule (1849) stated 'the quantity of heat produced by the friction of bodies, weather solid or liquid, is always proportional to the quality of force expended' (as cited in Young, 2015). Helmontz (1847), a German physicist and physician to whom the basic theory of 'law of conservation of force' is that when a work is lost an equal amount of heat or chemical force is obtained. If heat is lost, then equivalent quantity of mechanical or chemical force is obtained; and if chemical force is lost then an equal amount of heat or mechanical force reappears. In words of Helmontz "it is thus neither increased nor diminished, but always remains in the same quantity" (Helmontz, 2022, p.26). Helmontz carried out a number of experiments to prove his assertion which also included the working of energy in human arm muscles without which the arms would not be able to perform any function.

The study of fermentation got a new dimension because of two personalities: Justus von Liebig and Louis Pasteur. While Liebig was in favour of chemical theory of fermentation; Pasteur on the other hand believed fermentation to be a result of microbes. This idea later led to the led to the development of new field of microbiology (Emergence of fission). Liebig in 1839 explained his theory of fermentation in which he opined that ferments are nitrogen constituted materials if and when comes in contact with water or air acquires the capability to cause fermentation. To him it is not the material but the chemical reaction that is responsible for the process of fermentation and after the onset of the process the removal of the ferment will not affect the process. (Liebig, 1840). Louis Pasture however advocated a completely opposite point of view. He highlighted the role of yeast as a living organism in specifically in converting sugar to alcohol and fermentation in general (Pasteur, 1879).

Liebig's another contribution was his idea of analysing chemical presence in plants and gave importance to the concept of photosynthesis. One of his famous books is titled 'Organic chemistry in its application to physiology and pathology (1842). His contribution initiated the field of Agricultural chemistry.

The study of digestion as a chemical process continued. Willam Beaumont, a surgeon, further made a number of observations on human digestions since 1822 and in his book 'Experiments and observations on the gastric juice, and the physiology of digestion' made a 51-point inferences of his observations in which he stated that gastric juice (stomach acid) and not the physical process of 'mashing, pounding and squeezing of the stomach' helps in digestion of food (Beaumont, 1833). Meanwhile it was William Prout, an English chemist, who put forward that the gastric juice or stomach acid that was being referred is actually muriatic acid also known as hydrochloric acid (Prout, 1823). Claude Bernard, a French physiologist, made significant observation on the role of pancreatic juice in digestion; the isolated glycogen from liver tissue in 1857 and highlighted its relations with blood sugar (as cited in Young 1957; Chittenden, 1930).

In 1869 a substance was isolated from the nuclei of pus cells by Friedrich Miescher which he named as 'nuclein', a chemical rich in phosphorus. He published about his work in 1871 in his book 'Ueber Die Chemische Zusammensetzung der Eiterzellen alled' (as cited in Hall and Sankaran, 2021).

In 1877, a journal Zeitschrift für Physiologische Chemie (Journal of Physiological Chemistry) was started. In it Felix Hoppe-Seyler used the term 'Biochemie' in German. He used it to mean physiological chemistry. In 1880 the first degree of Doctor of Philosophy in Physiological Chemistry was awarded in Yale University (Chittenden, 1930).

German physiologist Wilhelm Kuhne used the term enzyme for the first time in 1877 (Heckman, 2020). In the year 1897, Eduard and Hans Buchner, finally settled the still ongoing debate on fermentation and proved that not just living yeast but yeast cell extracts can also carry out the process of fermentation (White, Handler & Smith, 1968). In 1902 Emil Fischer and Franz Hofmeister showed in two different ways how amino acids forms proteins. This bond came to be known as peptide bond (Hirshmann, 1999).

Carl Neuberg, a German chemist is often credited with coining the term Biochemistry in 1903 (White, Handler & Smith, 1968).

This period witnessed the study of various biological processes, and the chemistry involved in it. A typology of Lamination can be identified that included a number of isolates compounding to main subjects like Physiology, Biology, Medicine, Chemistry, Food Technology etc. These included instances like 'role of gastric acid or pancreatic juice in digestion'; 'microbial role in fermentation'; 'chemical process of photosynthesis'; 'energy release from human muscle activities'; 'role of bio-substances in physiological and biological processes' etc.

Fusion (1905 onwards): A journal titled 'Journal of Biological Chemistry' (JBC) started to be published from 1905. In 1906 an American Society of Biological Chemists was formed, which was renamed as American Society for Biochemistry and Molecular Biology in 1987. In 1925 the society acquired the Journal of Biological Chemistry. In 1913 American Chemical Society created a 'Division of Biological Chemistry'.

Meanwhile in 1902, an invitation to assume a chair in Biochemistry was given to Frederick Hopkins at the University of Liverpool, and by 1914, he had been appointed as a Professor at the University of Cambridge. In 1911 a Biochemical Club was established that was subsequently renamed as the Biochemical Society (https://www.biochemistry.org/) in 1913. The Bio-chemical Journal (https://portlandpress.com/biochemj) that was first published in 1906 was acquired by the society in 1912. In 1922 another journal the 'Journal of Biochemistry' was started and in 1925 the Japanese Biochemical society was established. In 1949 the first international congress of Biochemistry was conducted.

The development of new technology such as X-ray diffraction, chromatography, Radio-isotopic labelling, electron microscopy and molecular dynamics paved the way for many other discoveries in Biochemistry. The understanding of proteins, enzymes, chemical cell activities, importance of RNA and DNA; DNA's double helix structure; complete protein structure (insulin) took forward the interdisciplinary field of Biochemistry and its application in various other fields of study.

5.5 Bioinformatics

Bioinformatics can be defined as "the collection, storage, and analysis of DNA and protein sequence data using computerised systems. The data generated by genome projects and protein studies are held in various databanks and made available to researchers throughout the world via internet" ("Bioinformatics, 2017, p.815). The National Centre for Biotechnology Information (2001) defines bioinformatics as " the field of science in which biology, computer science, and information technology merge into a single discipline" (as cited in Ray, 2022).

Bioinformatics is comparatively a new interdisciplinary subject. It is evident from the above definitions that Bioinformatics emerged out of convergence between Biology and its allied subjects on one hand and on the other hand computer science and information technology. Initially started as a multidisciplinary subject, bioinformatics witnessed the fusion of the interacting subjects in a way that now it has its own theories and subdisciplines that are unique to it. The application of Bioinformatics is found in areas like biology, genetics, medicine etc.

Below are the stages of development of Bioinformatics along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1961): Deoxyribo Nuclic Acid or DNA was of the little significance before 1952. In 1952 when Harshey and Chase put forward the role of DNA as a carrier of genetic information a new era begin. The subject of Molecular Biology which was in a developing stage; got its firm footing as a new science subject (Hershey & Chase, 1952). While its role was now clear but little knowledge was available about the arrangement of this molecule. The next breakthrough came in 1953 with the deciphering of double helix structure of DNA molecule by Watson, Crick & Franklin (Watson, & Crick, 1953; as cited in Cobb, & Comfort, 2023).

In the 1950's another advancement came in the form of understanding protein structure. The first sequence that got published was of protein 'insulin'. Different methods were employed to carry out protein sequencing which included Crystallography, Edman degradation etc. But all these methods were suitable for smaller protein. For large protein, fragmentation became mandatory & re-arranging the sequence from numerous smaller fragments to form the whole sequence was indeed challenged. The condition was demanding a method that would be suitable for smaller and larger molecules.

Loose Assemblage (1962-1984): At this backdrop witnessed the development of advanced computers and software. Thus, there arose an increasing interest in developing computer software to tackle the problem.

Margaret Oakley Dayhoff and Robert S. Ledley of National Biomedical Research Foundation Silver of Maryland during 1962 used a computational method to determine primary protein structure. They used 'COMPROTEIN' (IBM 7090 Computer program) to analyze many small peptide fragments. They were highly hopeful about the possibility to use such computational methods to decipher molecular order in these substances (Dayhoff, & Ledley, 1962). Dayhoff along with Eck, Chang and Schard in 1965 published the 'Atlas of Protein Sequences and Structure' which was the 'the first computer-based protein sequences database'. They published 65 protein sequence (Dayhoff, Eck, Chang, & Schard, 1965). In 1969 Dayhoff used computers to understand the evolution of protein. She wanted to analyze the history of living things. She used a single letter to analyze the protein with the help of computers (Dauhoff, 1969). Emile Zuckerkandl, & Linus Pauling in 1965 opined that orthologous protein evolved from a common ancestor giving rise to the concept of paleogenetics (Zuckerkandl, & Pauling, 1965). But Needleman and Wunsch in 1969 developed a computer adaptable method to find similarities in the amino acid sequences of two proteins. For pairwise protein sequence alignments, it was the first dynamic programming algorithm (Needleman, & Wunsch, 1970).

Meanwhile Francis Crick enunciated the Central Dogma sequence in 1958 (Crick, 1970) and 1968 all the genetic codes were deciphered. In 1976 Maxam & Gilbert adopted a DNA sequencing method. (Maxam, & Gilbert, 1977).

In 1977 Fredrick Sanger introduced sequencing method. This led to the Sanger chain termination method. The first genome sequencing (bacteriophage UX174 genome) was done by this (Moorcraft, Gonzalez, & Walker, 2015). Dayhoff, Schwartz, and Orcutt in 1978 computed relationships between sequences. They measured evolutionary distances between proteins (Dayhoff, Schwartz, & Orcutt, 1978).

Although computers were used for sequencing however application of these techniques through dedicated software still awaited further development. A mode of loose assemblage in which studies in biology and its allied fields using computational tools to understand biological data is observed.

Towards Fusion (1979-1984): In 1979 Staden of MRC Laboratory of Molecular Biology of Cambridge came up with the first completely dedicated software for Sanger sequencing analysis. Sanger described it as “computer programs that can be used to order both sequence gel readings and clones” (p. 2601) A coding method in gel reading was described (Staden, 1979).

Meanwhile Paulien Hogeweg used the term ‘Bioinformatics’ in 1978. From the late 1980s onward, the term ‘bioinformatics’ mostly has been used to refer to computational methods for comparative analysis of genome data.

The first practical Multiple Sequence Alignment (MSA) emerged in the 1980’s. Joseph Felsenstein of Department of Genetics, University of Washington first used Maximum Likelihood (ML) method to sequence data using computers. His method also allowed to test hypothesis “about the constancy of evolutionary rates by likelihood ratio tests and gives rough indication of the error of the estimate of the tree” (Felsenstein, 1981, p. 368).

Fusion (1985 onwards): A journal relating to 'Bioinformatics' came up in 1985 – 'Computer Applications in Biosciences (CABIOS). The journal was later renamed as "Bioinformatics" (https://academic.oup.com/bioinformatics) in 1998 and became the main journal of 'International Society of Computational Biology' till 2004.

Da-Fei Feng and Russell F. Doolitle of Department of Chemistry, University of California-San Diego in 1987 used a progressive alignment method which utilized Needleman and Wunsch's pairwise alignment algorithm to achieve Multiple Sequence alignments (MSA). They called it 'Progressive Sequence Alignment'. They followed a rule called "once a gap, always a gap" (Feng, & Doolittle, 1987).

William Ramsay Taylor in 1987 and Barton & Sternberg in 1987 used multiple alignment to produce very effective and fast result of protein sequence with the help of computer (Taylor, 1987; Barton, & Sternberg, 1987).

Desmond G. Higgins and Paul M. Sharp of Department of Genetics, Trinity College developed CLUSTAL (MSA software) in 1988 used microcomputer to perform "multiple alignments of large numbers of ammo acid or nucleotide sequences…using a fast pairwise alignment algorithm" (Higgins, & Sharp, p. 239). It was a reconstruction of an evolutionary tree like Feng and Doolittle of 1987. Speed, simplicity and flexibility were the main features of mainframe computers.

The National Human Genome Research Institute was established in 1989. In the meantime, in 1994 EMBL's European Bioinformatics Institute was established. The first global society for bioinformatics and computational biology was established in 1997, known as the International Society for Computational Biology (ISCB).

Various countries showed their interest in providing 'Bioinformatics' degree. Jaap Heringa graduated in Bioinformatics in 1984. He completed his Ph.D in Bioinformatics in 1993 from University of Utrecht, The Netherlands. Another development that had highly impacted the development of Bioinformatics was the coming up of 'The Human Genome Project' that was started in 1990 by the U.S. National Institutes of Health. This resulted in generation of huge data beyond the human capability to handle it. Thus, Special Bioinformatics software to handle such huge data came up viz: PHRAP, Celera Assembler, TIGR Assembler, MIRA, EULER and many others.

In the 1990s, when "the data on sequencing and mapping the genomes of different species began" 'Bioinformatics' originated as a discipline (Fando, & Klavdieva, p. 34). In 1999 the School of Biological Sciences at Georgia Tech proposed & established Master of Science in Bioinformatics degree programme which was the first in U.S. (Computational Biology and BioInformatics, n.d.). In India 'Bioinformatics' advance diploma courses started in JNU, CU, University of Pune in 1987; P.hD and M.Sc programme started in University of Pune in 1997 and 2002 respectively (Kulkarni-Kale, Sawant & Chavan, 2010).

"Apart from analysis of genome sequence data, bioinformatics is now being used for a vast array of other important tasks, including analysis of gene variation and expression, analysis and prediction of gene and protein structure and function…" (Bayet, 2002, p. 1021). Bioinformatics Club for Experimenting Scientists (BIOCLUES) (https://bioclues.org/) a non-profit organisation was established in 2005 in India to promote 'Bioinformatics' in India. The developments of high perform computers and the advent of the internet changed the whole research and analysis process related to bioinformatics. Companies like Amazon (https://aws.amazon.com/health/genomics/) and Microsoft (https://enterprise.microsoft.com/en-us/industries/health/genomics/) now and then offering services to 'bioinformatics'.

All these developments (from 1985 onwards) led to the emergence of Bioinformatics as a distinct field. They are no more in a state where only computer science and software are used as a tool. Rather Bioinformatics as a subject now itself offers theories and bases to further understand the genetics of living beings far better.

5.6 Biomechanics

Biomechanics is the "study of biological systems, particularly their structure and function, using methods derived from mechanics, which is concerned with the effects that forces have on the motion of bodies". (Biomechanics, n.d.). It involves "the application of the principles of mechanics to living systems particularly those living systems that have co-ordinated movements" (Biomechanics, 2017).

Mechanics have long been a sub-field of physics whose theories and principles were applied to understand movements in living organisms. For a long time, biomechanics received no separate attention as a field of study. It was considered as a branch of

Biophysics. The history of Biomechanics therefore overlaps with the history of biophysics up till a point. But the scope of Biophysics is much broader in comparison to Biomechanics. With time understanding movements in living organisms from a mechanical perspective became so advanced that biomechanics began to come out as a separate field of study with its own journal and institutions. Although mechanics and biology as distinct disciplines development much later however the history of relation between mechanics and biology can be traced long back.

Below are the stages of development of Biophysics along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1678): Movements in living being has always been a topic of attention for philosophers and researchers. Although the initial studies had very little scientific accuracy, but they clearly focused on understanding the mechanics behind locomotion in living organisms.

Aristotle's 'De Motu Animalium' (Movement of animals) can be considered as one the most ancient traceable book on the concept of Biomechanics. In this book he dealt with locomotion of living beings; the mechanics involved in the different ways of movement in both human and non-human living organisms especially those of joints of limbs. He considered that movement in animals involves a 'moved', an 'unmoved mover' and a 'resisting surface'. (Aristotle, trans. 1978). Another of his book involving animal locomotion is 'De Partibus Animalium' (On the Parts of Animals) where he dealt with the functioning of the internal organs of the body of the living being (as cited in Doblare, 2015). For instance, he discussed about the mechanism of muscle contraction and relaxation behind the flow of urine from kidney to bladder. (Aristotle, trans. 1882).

Galen of Pergamon, a physician, in his book 'De Usu Partium Corporis Humani' (On the Usefulness of Parts of the Body) dealt with human body and its movement. He studied the anatomy of monkey to understand human anatomy and also stated the importance of a vital fluid in muscle action. He also "showed how different parts are paralyzed by the destruction of different nerves" (Galen, trans. 1968, p.63).

Another significant contribution came from Leonardo da Vinci's study of human anatomy mostly represented through his drawings. His observations revolved around study of bones and muscles and provided insight into the mechanics of human body and its activities. This included the study of human foot, legs, skull etc. His works have been an important source of information towards understanding mechanics in the motions of living creatures. (Claton and Philo, 2013). He also studied the anatomy of birds especially the mechanism behind birds flight along with the importance of air (O'Grody, 2008).

Andreas Vesalius, a Flemish Physician in 1543 wrote 'De Humani Corporis Fabrica' (On the Structure of the Human Body) in which he contrasted with the point of view given by Galen and attempted to provide different description of anatomy especially human anatomy. He carried out dissections and laid the foundation of the future subject of anatomy (Vesalius, trans., 2007).

While studies on living beings and mechanics involved in them was carried out, the entire scientific world witnessed the beginning of a new era with the publication of Copernicus's (1543) work 'On the revolution of the heavenly spheres'. This book had profound impact on physics and so had on mechanics.

Studies on pulmonary circulation also found importance. Michael Servetus a Spanish polymath and physician was one of the first whose description of pulmonary flow in his work "Chritianismi Restitutio" published in 1553 is considered accurate (as cited in Bainton, 1951)

William Harvey, a British physician, focused on the describing pulmonary flow or movement of blood in human in 1615. In 1628 he published his treatise "Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus" where he put forward his idea that blood "flows through the lungs and heart and is pumped to the whole body" (as cited in Ribatti, 2009).

In his work 'Discourse on the Method of Rightly Conducting the Reason and Seeking Truth in the Sciences' Descartes dealt with human anatomy. He said, "such persons will look upon this body as a machine made by the hands of God, which incomparably better arranged, and adequate to movements more admirable than is any machine of human invention" (Decartes, 1637/1903, p.60).

A major change came with the studies of Galileo Galilei. He made details study about bone structure and strength and its difference in land and marine animals. While studying bone structure he stated "if the bones are heavier, it is necessary that the muscles or other constituents after body should be lighter in order that their buoyancy may counterbalance the weight of the bones. In aquatic animals therefore circumstances are just reversed from what they are with land animals in as much as, in the latter, the bones sustain not only their own weight but also that of the flesh, while in the former it is the flesh which supports not only its own weight but also that of the bones" (Galilei, 1638/1914, p.133).

Although the above studies were mostly depended on observations and neither had scientific basis nor the subjects interacting were clearly defined but the influence and role of mechanics on activities and movements of living organisms (biology) started to become evident.

Loose Assemblage (1679-1881): This period saw efforts from many physicists to understand the mechanics of movement in a more scientific way.

Giovanni Alfanso Borelli, a physicist in 1679 wrote 'De Motu Animalinum' which probably for the first time attempted to provide to certain extent a scientific understanding of 'movements' in living organisms. It can therefore be considered as the first book written on Biomechanics. The book has 2 parts: first part dealt with locomotion that are outside the body that is walking, jumping, running, etc. while the second part dealt with motions that are in internal viz: breathing, heartbeat, liver function, blood circulation, etc. He used mathematical knowledge to express his views on locomotion. He stated, "I tackle the difficult physiology of movements in animals…Nobody has succeeded so far in confirming or solving these problems by using demonstrations based on mechanics" (Borelli, 1679/1989, p.6).

Leonard Euler, a Swiss physicist, in 1775 wrote an essay titled 'Principia pro motu sanguinis per arteries determinando' in which he through his observation of the mechanics behind flows in elastic tubes, attempted to study how blood flows through arteries and thereby developed a 'hemodynamic equations' (as cited in Bistafa, 2021).

Thomas Young, a British polymath had his interest both in physics and physiology. He was also a physician. His interest made him study mechanics involved in the functioning of heart and arteries, motion of blood as well as mechanism of human eyes in visualising objects. He in one of his lectures stated, "the mechanical motion, which take place in animal body, are regulated by the same general laws as the motions of inanimate bodies" (Young, 1809, p.1).

Around 1839-40 came another important study in which Jean Leonard Marie Poiseuille put forward an equation that is commonly referred to as Poiseuille's law. The law deals with rate of flow and is considered to be significant in understanding flow of blood or hemodynamic (Sutera & Skalak, 1993).

Wilhelm and Eduard Weber in their book "Mechanik der menschlichen Gehwerkzeuge" published in 1836 carried out studies of human walking and running, backed by mathematical experiments and observations made by naked eyes and telescope, to understand the mechanics involved in it. Their study involved the basic assumption that "walking and running are such mechanical movements able to be predicted by calculations that at a voluntary act of will is not needed to move the active instruments successively in the necessary order" (p.2). They also discussed the importance of 'centre of gravity' in walking stating, "the distance of the centre of gravity of the trunk from the point where the trunk rests on the leg and the distance of the centre of gravity of the entire body from its support from the ground are of the greatest significance" (p.55) (Weber & Weber, 1836/1992).

Around 1878 came another important study from Eadweard Muybridge, who observed animal and human motions using photography and motion-picture project. He is credited with being able to take pictures of "movement in space" in which he captured a galloping horse, who's at point all four legs were lifted above the ground. He also studied various human motions like walking, turning around, running etc (Clegg, 2007). His works includes 'Animal Locomotion' (1887); 'Animals in Motion' (1899); The Human Figure in Motion (1901) etc.

Guillaume Wertheim studied tissue of human bones, muscles, arteries, nerves, tendons etc. with the focus on its mechanical properties considering age, type and gender (Bell, 1989)

Up till this point the progress in understanding human movement and the mechanics involved were scientific but mostly observational. Mostly the aim was to analyse how different movement, both internal and external, takes place in human body. Thus, a typology of Loose Assemblage is identified. Movement in living beings (Biology) were studied in relation to mechanics, or the laws of mechanics were studied in relation to various movements of living organisms.

Lamination (1882-1966): French scientist Étienne-Jules Marey is credited with studying motion in both human and other animals. Although he initially started with recording motions that are internal to animal body like heartbeat, pulse, circulation of bloods etc; eventually he shifted to external animal movement like jumping, running, walking etc. However, his studies were aimed at not only mere observation but rather a scientific 'measurement of time' involved in each movement as well as the 'efforts involved'. It was by 1882 he developed a photographic rifle which he used to capture motions in such a way that gave an idea of the time lapsed. This allowed him to study locomotion in human, birds and various other forms of animals in its truest form (Marey, 1895; as cited in Braun, 1992)

Adolf Fick, a German physiologist studied mechanics involved in skeletal muscle movement and contraction. He made a significant contribution in 1862 by inventing pendulum myograph for measuring muscle twitches; the plethysmograph that records the speed of blood in the human artery in 1868. He also formulated the Fick's principle that is applicable in understanding the mechanics of heart (Shapiro, 1972).

Christian Wilhelm Braune, a German anatomist and Otto Fischer, a physiologist, studied human walking or human gait analysis which Fischer in collaboration with Braune published in the book 'Der Gang Des Menschen' (1895). They also studied about the centre of gravitational force in human body as a whole as well as in its different parts, the movement of leg etc. There observations and analysis on walking and limb movements were much accurate however contradicted Weber brothers. (Braun & Fischer, 1895-1904/1987).

Julies Wolff, a German anatomist and surgeon formulated the Wolff's Law that dealt with the adaptable quality of a healthy bone under a given condition. In his work "The Law of Bone Remodelling" published in 1892 reflected on the remodelling of bone shape or structure caused by internal or external mechanical stimuli (Wolff, 1986).

Throughout the first half of twentieth century many significant works and research followed since then in the development of Biomechanics. Rudolf Fick, an anatomist in his work 'Handbuch der Anatomie und Mechanik der Gelenke' (1904) published in three volumes also dealt with the mechanics of muscle joint of human body (Manolova, 2018; Bindel, 2018).

Jules Amar made significant contribution in advancing the field of biomechanics. His book 'Le Moteur Humain et les bases scientifiques du travail professionnel (The Human Motor, or the Scientific Foundation of Labour and Industry) published in 1914 dealt with human body linking to mechanics. His study included the understanding of prostheses for amputee patients. He is credited with the invention of 'dynamographic sidewalk' for aiding the understanding of prostheses (Amar, 1920; as cited in Manolova, 2018).

Following the first world war the field of Biomechanics came up in a more organised way. The aftermath witnessed of the war witnessed a number of war amputees that escalated the demand for more and more prosthetics. Designing a prosthetic necessitated a collaboration between physicians and experts of mechanics.

Nikolai Bernstein, a Russian physiologist, studied human movement. His study focused on movement involved in human labour which he carried out in 1922 along with fellow researchers under Central Institute of Labour. Later on in 1926 he also observed and examined the movements involved in walking of human being across ages. He also focused on the role of central nervous system in controlling postures and movements. He is credited with coining the term Biomechanics-the study of movement through application of mechanical principals (Bernstein, 2020).

Around this time, in 1926 R. Plato Schwartz, a surgeon established the Myodynamic Laboratory under the department of Surgery in the University of Rochester. With the aim to make mechanisms using which human movement can be recorded.

In 1939 Herbert Lissner (professor) and E. Stephen Gurdjian, a neurosurgeon investigated fracture and injury to head and spine from a mechanical point of view. This led to increased study of spine biomechanics (Grinn & King, 2020).

Carl Hirsch, a Swedish surgeon, in 1940s and 1950s studied biomechanics of human body focusing on knees, hip as well as spine (Denaro & Martino, 2011). Significant work was also conducted by Elftman (1966) on muscle mechanics and gait. He published a paper 'Measurement of external force in Walking' in 1966. Many books and papers began to get published focusing on various areas of biomechanics.

The period from 1882 to 1996 saw a rapid progress in comprehending the mechanics of movement. The studies were no more just observational. Rather they focused on analysing more specific types of movement. A mode of 'Lamination' can be identified where different parts of living organisms are compounded onto the concepts of mechanics going with the main subject Physiology, Medicine, Biophysics or Mechanical engineering. This included the concept of force involved during human locomotion muscle contraction and movement; human walking and human gait;

movement of muscle joint in human; spine injury or fracture; energy involved in locomotion of animals; as well as treatment of amputee patients using prosthesis etc.

Fusion (1967 onwards): By this time Biomechanics emerged as a distinct area for study. In 1967 Richard Nelson set up a Biomechanics laboratory for carrying out research at Pennsylvania State University. Also, for the first time Biomechanics was recognised as a graduate specialisation area. In the same year another Biomechanics laboratory was established in at the University of Indiana under the supervision of John Cooper. Doris Miller and Charles Dillman were two fellows to receive doctoral degree in Biomechanics from Pennsylvania University Laboratory.

Meanwhile in 1967 the First International Seminar on Biomechanics, was held in Switzerland. The Journal of Biomechanics began to get published from 1968. The International Society of Biomechanics was established in 1973 which regularly conducts seminars on Biomechanics and allied areas.

Charles Dillman later on set up a biomechanics programme in University of Illinois. Similarly, another Biomechanics fellow Barry Bates also set up a laboratory and programme in the University of Oregon of which he served as a director since 1974.

In 1976 came the European Society of Biomechanics and in 1977 The American Society of Biomechanics (ASB) was founded.

Around this time a debate on the likeness and difference between biomechanics and a similar area 'Kinesiology' was gaining attention. Later on, this was dissolved by declaring Kinesiology as the science of movement and biomechanics defined as a discipline that focus on the effect of the force that causes movement in body.

International Society of Biomechanics in Sport was established in1982 in California.

In 1993 Y.C. Fung, considered as the father of modern Biomechanic, published the book 'Biomechanics: Material properties of living tissues'.

At present moment Biomechanics studies and research have witnessed immense growth. Biomechanics and its applied areas like Sports Biomechanics are taught in various universities. Its application is vast especially in the field of medicine, physiology and anatomy. Also, there are high demand of professionals who can utilise the advantages of biomechanics in different areas like Sports, Prosthesis etc. The technological advancement has also provided great impetus to the advancement of Biomechanics.

5.7 Biophysics

Biophysics is "the study of physical aspects of biology, including the application of physical laws and the techniques of physics to study biological phenomenon" ("Biophysics", 2017). It involves the understanding of various activities and functioning of living organisms (Biology) in the light of Physics- heat, electricity, mechanics, optics etc. Over the years as the specialised subject field of Biology and Physics developed and new inventions came, the two subjects got more and more intertwined from different aspects giving rise to the interdisciplinary subject of 'Biophysics'.

Below are the stages of development of Biophysics along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1785): Efforts to understand living organisms have been a central focus of study from the ancient times. The earliest evidence suggesting a possible interaction between biology and physics can be traced to the ancient philosopher's observations that some living organisms are capable of emitting light. Aristotle wrote about observing light in flesh, horns, scales, and eyes of fish; and in fungi (Aristotle, trans, 1855). Pliny the Elder considered damp woods as having the capacity to produce light (Pliny, trans, n.d.). This scientific study later came to be known as Bioluminescence. The book Ars Magna Lucis et Umbrae written by German Jesuit priest Athanasius Kircher in 1646 studied animal luminescence and also was probably one of the initial attempts to consider it as a source of light (as cited in Harvey, 1957). Attempts for understanding the process of life through application of physics also considered mechanical models. This included "mechanistic theories of processes of life and insights into their dynamics, for example Heraclitus in 5th century BC" (as cited in Glaser, 2012). Leonardo Da Vinci in his 'Codex on the Flight of Birds', published in 1505, studied the mechanical principles involved in bird flight (as cited in O'Grody, 2008). Also, the study of medicine using physics can be traced to a period when it was known as Iatrophysics. The basic idea behind it was understanding of physiological phenomenon it terms of biophysics.

In the book "De motu animalium", Giovanni Alfonso Borelli in 1680 gave a biomechanical analysis of movements during swimming, mobility of limbs, etc (Borelli, 1680/1989). Robert Boyle, a naturalist, in 1667 carried out a number of experiments to show the importance of air for observing bioluminescence (Boyle, 1668). Abbé J.A. Nollet's in 1748 experiment led to the discovery of osmotic pressure i.e. the force responsible for the passive flow of matter in living organisms (Nollet, 1752/1995) was another significant contribution that furthered the possibility of interaction.

In late 18th century P. S. de Laplace, a French physicist studied the production of heat caused due to changes of temperature in mammals. He along with Lavoisier, from 1777-1783 made observations on respiration as a process involving combustion and stated about respiration that "the heat developed in this combustion is imparted to the blood that flows through the lungs, whence it spreads throughout the animal's body" (Lavoisier & Laplace, 1794, pp. 199-200). This was one of the first direct explanation of a phenomenon of living organism involving heat.

Although these studies reflected interdisciplinary interactions but those who were involved had very little interest is establishing any scientific basis for this interaction. Many of these interactions even did not involve any specialists from either of the fields.

Loose Assemblage (1786-1888): In 1786 physician Luigi Galvani's discovery of effects of static electricity on frog's muscles, which was documented in 'De Viribus Electricitatis in Motu Musculari Commentatius' in 1791, led to a series of experiments that made significant contribution towards understanding the concept of 'Animal heat'. (Galvani, 1791/1953). This was a significant step towards scientifically understanding the possibility of relation between physics and biology. It marked the beginning of loose assemblage. However, his experiment was not directed towards any biophysical investigation. It was rather accidental, and the results were not accepted easily leading to many controversies. Thus, the study of electrical potential in animals saw a reduction in focus. When galvanometers came and production of current from muscles as well as the differences in nerve membranes were successfully measured Galvani's claim that tissues can produce currents was finally accepted.

Another area of interaction is the optics of living organisms. Thomas Young an English physicist made observations through experiments carried out in areas like human visions (Young & Brocklesby, 1793). His observations on eye published in two of his works 'Observation on Vision' and 'Mechanism of the Eye (1801) encouraged further growth in research in optics in human beings.

French scientist René Dutrochet wrote in 1828, "it appears from these new studies that the endosmotic and exosmotic phenomena, which I discovered, belong to a new class of physical phenomena, whose powerful intervention in the vital phenomenon is no longer doubtful." (Biophysics, n.d).

Significant developments came when the relation between force and heat was studied by Mayer in 1842 (as cited in Truesdell, 1980). Mayer made studied human metabolism and also made observations on mechanical equivalent of heat. Joule in 1843 also concluded that when force is exerted, and an equivalent amount of heat is produced. (Joule 1849). Helmontz (1847), a German physicist carried out a number of experiments and put forward his laws of conservation of energy. By observing the functioning of human muscles can concluded that it is the energy in human arm muscles without which the arms would not be able to perform any function. All these observations led the foundation of laws of thermodynamics which became the basis for numerous biophysical investigations.

Botanist W.F.P.Pfeffer (1877) in his monograph 'Osmotic Investigation' discussed about osmotic pressure. He designed an apparatus using which he was for the first time, able to measure osmotic pressure successfully (as cited in Findlay, 1913).

In 1855 German physiologist Adolf Eugen Fick, formulated the laws of diffusion. He formulated the law on liquid diffusion. Fick stated, "this law for the diffusion of a salt in its solvent must be identical with that, according to which the diffusion of heat in a conducting body takes place" (Fick, 1855, p.30). In 1856 he published possibly the first biophysics text, Die medizinische Physik ("Medical Physics")' ("Biophysics", n.d).

At this time a group of physiologists in Berlin formed The Berlin school of physiologists of which, Emil DuBois-Reymond, Ernst von Brücke, Carl Ludwig and Hermann von Helmholtz were members. Emil DuBois-Reymond, a German physiologist, contributed towards electrophysiology. He conducted his studies on frog current and electromotive fishes; and advocated the idea of current being generated in human muscles and nerves and studied the reasons behind muscle contraction. His observations were published in 1848 and 1884 in two volumes (Finkelstein, 2013).

Until this point the study of what later on became Biophysics concentrated on studying various phenomenon of living beings in terms of Physics or the laws and theories of physics were being studied in relation to living beings. Thus a stage of 'Loose Assemblage' can be identified during this period.

Lamination (1889-1956): One of the important application of physics in biology was explored by French physicist Arsonval. In his 1889 paper "Action physiologique de courants alternatives," he put forward the advantageous effects of the controlled application of electrical currents and endorsed the therapeutic use of electromagnetic fields (Reif-Acherman, 2017) In 1907 German physicist Karl Franz Nagelschmidt coined the term diathermy to refer to the application of electrical heat for medicinal purpose (Diathermy, n.d.).

The discovery of X-ray in 1895 by German physicist Wilhelm Konrad Rontgen brought about a major breakthrough in the development of Biophysics. He stated, "regular reflection does not exist, but that bodies behave to the X rays as turbid media to the light" (Rontgen, 1896, p. 275). This came as huge leap in the application of radiography in medical treatment.

The concept that genetic information in covalent bonds is stored in a molecule present in living being first appeared in the book "What is life"? in 1944. The book is a compilation of lectures by Austrian physicist Erwin Schrödinger delivered at Dublin (Schrödinger, 1967). Thereafter researchers like James Watson and Francis Crick in their endeavour to find and define the genetic material used Rosalind Franklin's x-ray crystallography work and successfully deciphered the double helix structure of DNA in 1953 (Watson & Crick, 1953). While these investigations on one hand led to the study of structure of microorganisms as well as of haemoglobin and viruses it also necessitated the advancement of instruments such as electron microscope and ultracentrifuge that in turn facilitates the study of biological phenomenon on the other.

Meanwhile Karl Pearson coined the termed Biophysics in 1892.

All these experiments accounted to the development of biology as a co-related subject with physics and a mode of 'Lamination' is identified at this stage. Subjects like 'Application of radiation in treatment' or 'application of electrical heat in treatment' are compound subjects going with the basic subject 'Medicine'.

The breaking of two world wars accelerated the process of fusion of biology and physics. During the second world war extensive and effective use of radiation was found in the treatment of soldiers. More and more instruments and techniques of physics were being incorporated for understanding biological phenomenon.

Fusion (1957 onwards): In 1957 after much communication and collaboration among Biophysicists across the world, there came into existence the Biophysical Society (1957). It was made responsible for conducting research for the development of the subject. The Society had members like Ernest C. Pollard, Samuel A. Talbot, Otto Schmitt, Kenneth S. Cole.

A massive revolution has come after the formation of the society. The "First National Biophysics Conference" was held in Columbus, Ohio on March 4–6, 1957. Since 1960 Biophysical society has been publishing peer-reviewed Journal called "Biophysical Journal" whose major aim is to reflect the new developments taking place in this field. In recent years number of other Biophysics journals are being published- Annual Review of Biophysics (https://www.annualreviews.org/content/journals/biophys), European Biophysics Journal (https://link.springer.com/journal/249), Quarterly Review of Biophysics (https://www.cambridge.org/core/journals/quarterly-reviews-of-biophysics) to a name a few.

The significance of Biophysics can also be felt in the field of Space programme.

Impact of radiation on living things dominated the area of studies in Biophysics in early 20th century. Its' applications can be seen in varied areas like preparation of Vaccines, advancement of imaging techniques (MRI & CAT scans), in treatments like dialysis, radiation therapy, and pacemakers. Also living microorganisms are taken into consideration to produce Biofuel by the Biophysicists.

Now-a day many universities of the world have separate departments for Biophysics offering courses of it as an independent subject.

Thus, at this stage a separate field that was developing independently of Physics or Biology can be clearly identified. This field was then reaching a stage where Biophysics itself as a fused subject emerged and also started to collaborate with other basic subjects, for example: Nanotechnology, Mathematics etc.

5.8 Geochemistry

Geochemistry is the "scientific study of the chemical composition of the earth. It includes the study of the abundance of the earth's elements and their isotopes and the distribution of the elements in the environments of the earth (lithosphere, atmosphere, biosphere and hydrosphere)" (Geochemistry, 2017, p. 1594). Thus, it encompasses the understanding of the chemical elements of which the earth is composed of; how these elements are present in earth's different layers (core, mantle, crust); chemical elements present in the form of minerals, ores, rocks, soils, crystals found in earth; the distribution of these chemical elements beyond earth as well as the subsequent extraction of those chemicals from its sources. In other words, geochemistry uses theories and methods of chemistry to understand geology. Therefore, the base of the subject belongs to both geology and chemistry and the history of Geochemistry is greatly influenced by the development of Chemistry and Geology as separate fields.

Below are the stages of development of Geochemistry along with the typology of relations as identified.

Pre-Loose Assemblage (Till 1762): The development of the subject 'Geochemistry' can be traced both in the history of chemistry and geology. Accounts of the presence of chemical elements found since ancient periods show the use of both metallic and nonmetallic chemical elements. The identification of archeological periods of human civilization using metals and its alloys testifies to their presence. Metals like 'Copper' and 'Iron' and the alloy 'Bronze' mark the three most important eras of human civilization- Copper Age (5000-3300 BC), Bronze Age (3300 to 1200 BC) and Iron Age (1200BC to 550BC). Also were in use metals like tin, lead, gold, silver for various purposes including making ornaments, decorative items, weapons etc. Evidence shows the knowledge of mining as well as smelting of metals were prevalent during these periods. On the other hand, the earliest known non-metallic elements included Carbon (in the form of charcoal, graphite), Sulfur and Mercury.

The identification of elements forming all terrestrial matters can be found in works of ancient Greek philosophers. Empedocles around 400BC put forward earth, fire, air and water as the four elements forming all matters (Empedocles, trans. 1981). Around 300 BC these same elements were also recognized by Aristotle in his book 'Meteorologica' as forming everything in the terrestrial region. In the same book he also discussed about the reasons behind the formation of metals and minerals in the earth (Aristotle, trans. 1951).

Traces of geological studies can be found in works of Greek philosopher Theophrastus who around 300BC wrote the treaties 'On Stone' having discussions on rocks, stones and minerals found on earth, their composition as well as their formation (Theophrastus, trans. 19556). Also, Roman writer Pliny the Elder in his work 'Natural history' written in 77AD discussed the various metals and minerals available and how they were used at that time (Pliny, n.d.)). From the geological perspective it is the study, mining and extraction of minerals and metallurgy that became the common ground with chemistry.

During the Middle age when scientific progress took a backfoot the progress towards modern day chemistry came through Alchemy. The focus was on finding new elements or systematically recognizing elements that were already known to exist in some form.

By the 16th and 17th century the development of science began to revive. George Agricola (1556) wrote "De re Metallica", having details on mining, extraction, excavation, mining sites and metallurgy. It therefore can be referred to as one of the first books that contributed to the field of geochemistry.

In geology a significant impetus came from when Danish scientist Nicholas Steno (1669) published his 'Dissertation Prodromus' where he dealt with the formation of rock, mountains and made observations on earth's strata, fossils and different types of ores viz copper, silver etc.

From the prehistoric period until the 18th century, interaction between chemistry and geology was neither conscious nor scientific. Identifying minerals and metals; and their extraction from the ores were what made them related.

Loose Assemblage (1763-1903): With gradual development of chemistry as a science; its scientific relation with geology unfolded. The eighteenth and nineteenth centuries saw the emergence of some important scientists who were at the same time interested in both chemistry and geology. On one hand Chemists showed interests in the chemical compositions of geological materials like rocks, minerals with the aim to discover new chemical elements. On the other hand, the discovery of new elements gave rise to questions among geologists about the various geological components of the earth, the state in which they exist, and the chemical processes involved.

One of the first person to have entered the field of chemistry with interest in geology was Antonie Lavoisier. While known for his contribution to chemistry, he had a history of involvement in voyages including geological expeditions. Around 1763-1767 Antoine Lavoisier accompanied geologist Jean Etinner Guettard in his explorations several times; he also undertook a number of field trips individually with the aim of gathering geological data for drawing a map/atlas of France, an idea that was taken up by Guettard. Lavoisier indeed drew a few maps of regions of France. His accounts of voyages included details about soil, earth's strata, terrains, riverbeds etc. (Rappaport, 1967). His geological experiences had their bearing on his chemical works. His studies included chemical analysis of rocks and minerals. He chemically studied Gypsum which he wrote in his memoir around 1764-1766. By 1768 he was included in the Academic of Science, where he nurtured his interest in chemistry and carried out numerous chemical experiments. His major contribution to chemistry came in the form of his concept of 'elements'. He also discovered several chemical elements and discussed 33 such elements in his famous publication "Traité Élémentaire de Chimie" published in 1789. Meanwhile in 1785 he briefly restarted his activities related to geology and eventually published his gathered data in his 'Memoire sur la hauteur des montagnes des environs de Paris' in 1792.

Similar contributions can also be found in the works of English chemist Humphry Davy. His interest in studying the chemistry of earth laid down a strong nexus between geology and chemistry. He gave several lectures from 1805 onwards on geological topics including chemical nature of minerals, stones, rocks; extraction of metals as well as on coal mines at the Royal Institution (Davy, n.d.) and played a major role in the establishment of the Geological Society of London. The book "Consolidations in Travel" published after his death consists many of his geological works.

Jorns Jacob Berzelius, a chemist, is credited with the discovery of a number of elements as well as determining atomic weight. So far, his geological ideas are concerned he was a plutonist or vulcanist and opposed the neptunists idea of rock formation. He was of the opinion that earth's interior exterior is cool, but its interior is still hot. His geological ideas were well supported by his voyages and expeditions studies and measurements. He also focused on mineralogy and was much interested in the chemical composition of minerals which later on formed the basis of his mineral classification. He published a book titled "An Attempt to Establish a Pure Scientific System of

Mineralogy by the Application of the Electrochemical Theory and Chemical Proportion” in 1814. His geological observations and viewpoints were to a great extent dependent on chemical explanation (Berzelius, 1814).

Thus, a subject area was developing where geological phenomenon were being understood from the perspective chemistry or by using tools or concepts chemistry. It was regarded as “Chemical Geology”.

The appearance of the term ‘geochemistry’ came with German chemist C.F Schonbein in 1838 when he first time used it in his work. He wrote “a comparative geochemistry ought to be launched, before geognosy / geochemistry can become geology, and before the mystery of the genesis of our planets and their inorganic matter may be revealed” (as cited in Reinhardt, 2001, p.161).

French geologist Elei de Beaumont (1847) in his paper titled “Notes Sur Les Emanations Volcaniques et Metallifereres” studied geological entities and the presence of minerals or chemicals in it. His studies focused on mineral water, types of metal deposits and other products of volcanism. His studies have been a major contribution towards chemical geology. He also gave his theory of mountain formation in the paper ‘Notice Sur le systeme des montagnes published in 1852 (De la Beche, 1853).

Swedish chemist, Karl Gustav Bischof a German chemist is one of the significant figures in development of chemical geology. His work titled “Lehrbuch der Chemischen und Physikalischen Geologie” which began to be published from 1847 is considered as an important contribution towards Geochemistry. His main focus was on the chemical composition and chemical processes around geological features like rocks, minerals, natural waters, coal. He therefore greatly influenced the use of chemical analysis in geology (Bischof, trans. 1859). Bishchof’s work was further progressed through the works done by Roth’s Allgemeine und chemische Geologie published between 1859-1893 further extended the work of Bischof.

The establishment of major laboratories at the U.S Geological Survey in 1884 came as a major impetus to the development of geochemistry.

At this stage a typology of ‘Loose Assemblage’ is identified between Geology and Chemistry. Most of the studies involved understanding the geological entities in terms of their chemical compositions.

Lamination (1904-1949): The emergence of geochemistry as a separate discipline was initiated when the rocks and their mineral compositions began to be systematically studied in the laboratories of various institutions like Carnegie Institution of Washington D.C. in 1904 and in several European countries and the Soviet Union between roughly 1910 – 1925. Many scientists employed a range of techniques to ascertain the primary chemical composition of the earth throughout the first half of the 20th century.

Geologist Bertram Boltwood, in 1907 introduced dating of radioactive elements or radioisotope dating as methods to determine age of rocks and other aspects of geology.

One of the most remarkable contributions made towards the evolution of the subject Geochemistry was done by chemist Frank Wigglesworth Clarke. He is often regarded as the Father of Geochemistry. His work 'The Data of Geochemistry' in 1908 dealt with Earth's composition and their components. He wrote in his work that "Each rock might be regarded as a chemical system in which, by various agencies, chemical changes can be brought about" (Clarke, 1924).

The study of metamorphic rocks using the Phase rule of Gibbs by European petrologists B. Roozeboom and P. Eskola laid the chemical foundation for the concepts related to metamorphic focus.

In 1912 Max Von Laue discovered the potential of crystalline substances to cause diffraction. This contributed to the determining of structure of various substances including halite (Mason & Moore, 1982).

Victor Moritz Goldschmidt, a Norwegian minerologist, made major contribution in making Geochemistry a mature science and is regarded as the father of "Modern Geochemistry". He laid down the theoretical and conceptual basis for the subject. His work "Geochemische Verteilungsgesetze der Elemente" published between 1923-1938 provided with the laws that became fundamental for Geochemistry. Also noteworthy was his contribution in Crystal chemistry using the then newly invented techniques like X-Ray diffraction etc. He also focused on availability of rare elements in solid earth's crust as well as in hydrosphere and atmosphere; and later extended his study to abundance of all elements in the whole of the earth. Further he dealt with deduction of cosmic abundance of chemical elements from meteorites. His textbook titled "Geochemistry" was published posthumously in 1954.

Another important contribution was made by geologist Vladimir Ivanovich Vernadsky, who is also regarded as one of the founders of Geochemistry. He studied the presence of chemical elements and isotopes in earth's crust. He explained how chemical elements exist in each of the layers and the formation of chemical compounds due to geologic processes. In 1924 he published a book "La Geochimie" in French and opined that "Geochemistry is concerned with the chemical elements, that is the atoms of Earth's crust and, if possible, of the whole Earth" (Vernadsky, 1924). He also identified "radioactive decay" as a source of terrestrial energy.

At Geophysical Laboratories of the Carnegie Institute of Washington, Norman L. Bowen and his colleagues in 1928 studied igneous rock by applying the phase rule.

The emergence of mass spectrometers in the 1930s further aided geochemical studies. One of them was built in 1947 by Alfred O. C. Nier's that were widely used for making geochemical observations.

Until 1950 geochemical prospecting programs had been conducted only by large mining companies.

This period involved the application of the rules and principles of physical chemistry to geological processes. Concepts like radioactive elements compounded with the study of rocks forming compound subjects like 'radioisotope dating of age of rocks'; 'chemical basis of metamorphic rock' etc. going with the basic Geology or Chemistry.

Fusion (1950 onwards): The period beyond 1950 witnesses Geochemistry arrives as a distinct subject. The advancement in instruments, analytical techniques and computers as well as new organizations and associations all contributed to the emergence of the subject. The journal 'Geochimica et Cosmochimica Acta' started to be published in 1950. The Geochemical Society was established in 1955 and 'Geochimica et Cosmochimica Acta' became their official journal in 1957. Also came up the International Association of Geochemistry and Cosmochemistry 1967. It began publishing the journal 'Applied Geochemistry' in 1986. The European Association of Geochemistry was established in 1985, and 'Chemical Geology' became its affiliated journal.

Regular conferences were organized and held by the various associations and organizations. Since 1991 the Goldschmidt conference has been held. Numerous books were published; awards were conferred to achievements that advanced the field of Geochemistry ex: Clarke award, Goldschmidt awards etc.

The subject has also immensely benefited from technological developments as a result of which Geochemistry has also advanced as an applied science along with its theoretical studies.

5.9 Geophysics

Geophysics is the science in which "the principles of mathematics and physics are applied to the study of the earth's crust and interior" ("Geophysics", 2017). The scope of geophysics includes the study of earth's geological features including earth's gravity, thermal properties, geo-electricity, geomagnetism, shape and size, as well as earthquake, tectonic structures, continents, oceans etc. Thus, as a subject it employs the theories and laws of physics to explain the different features and geological phenomena of earth- both interior and exterior. The two science subjects interacting here are geology and physics. Geophysics also involves the discovery and locating of earth's resources forming the field of Applied Geophysics. The scope of Geophysics is thus vast and diverse and tracing its history therefore requires covering of all the areas falling within the purview of the subject.

However direct observation in many of the above branches might not be possible. The development of Geophysics as a discipline is a nineteenth century phenomena. As theories and instruments in Physics developed, its use in understanding earth became more intermingled. The interaction at one point became so intertwined that there came a group of people having expertise in both the subjects providing the subject with its own proponents. Further studies gradually led to the development of the subject of Geophysics as a distinct area of study.

Below are some of the landmark developments in Geophysics along with the stages of development and typology of relation as identified.

Pre-Loose Assemblage (Till 1686): Understanding the earth- its shape, size, motion and phenomenon like earthquake has been a focus of study from the ancient times. Assumption of Earth's shape can be traced to the Chaldeans and Egyptians who thought it to be a flat disc shaped. The Greek philosophers like Pythagoras, Ptolemy and Aristotle advocated a spherical shape of the earth (Holden, 1909).

One of the documented written sources in favour of earth's spherical shape can be found in Greek Philosopher Aristotle's work 'On the Heavens' where he opined the Earth is spherical and gave reasons to substantiate his claims (Aristotle, trans. 1989).

Aristotle's idea got support in the learned society however it was only in the 16th century that the notion of spherical shape of earth was practically proved. It was explorer Ferdinand Magella accompanied by Juan Sebastian Elean carried out a voyage from Spain from 1519 across Atlantic and Pacific and returned to Spain in 1522. This voyage was first of a kind to circumvent the globe settling the debate to a great extent (Holden, 1904).

Similarly Greek polymath Eratosthenes of Cyrene around 240 BC is credited with measuring the circumference of the earth's sphere by observing the angle of the shadow casted by sun and the value calculated by him is to a large extent close to the value calculated at present time (Helden, 1985).

James Usher an Irish archbishop determined the age of earth and put forward 23 October 4004 BC as to be the date when earth was created. His interpretation was largely based on religious belief and Bible (Ussher, 1650).

So far as understanding earthquake is concerned it had been time and again related to supernatural power. Gradually with time it was explained as a natural phenomenon. Aristotle in his 'Meteorologica' while discussing earthquake attributed its cause to wind (Aristotle, trans. 1951). Accounts on earthquake can also be found in Strabo's 'Geographia' as well as Pliny the elders' 'Naturalis Historia'. Most of the data on earthquake were observational and measured in nearby earthquake hit areas.

Understanding about magnetism of earth can be traced to Greek Philosopher Thales of Miletus who showed the magnetic feature of loadstone. Also, can be found the account of use of magnetic compass for directional purposes. One initial assumption of earth's magnetic poles was by Peregrinus. The fact the earth's magnetic field is tilted got its initial support from an English Scientist Robert Normen in 1576 (as cited in Lowrie, 2007).

Till the 16th century understanding of the Earth's physical properties were mostly observational and had little scientific and theoretical backup. The scientific revolution of 17th century brought some major developments and findings both in Geology and Physics that contributed towards geophysical interaction.

One of the landmark accounts of earth's magnetic property came from English Physician William Gilbert, who probably was the first to substantially explain earth's magnetism where he recognized the poles & equator by carrying out observations using loadstone sphere and magnetic needles. His observations were published in 1600 in 'De Magnete' (Gilbert, 1600/1958).

Athanasius Kircher, a German polymath, advocated the concept of 'Hollow Earth' about which he wrote in 'Mundus Subterraneus' in 1664. He observed mountainous eruptions and studied volcanoes and finally opined that it is the fire whose movement below earth causes earthquake (as cited in Glassie, 2012).

Triangulation method was used by Jean Picard, an astronomer, to calculate the size of the earth in 1671 in which he measured the length of a degree of arc meridian. His results showed earth radius to be 6375km.

Loose Assemblage (1687-1838): A new phase of understanding of earth started when Isaac Newton with his background of Physics discussed about the shape of earth in his 'Philosophiæ Naturalis Principia Mathematica' published in 1687. He while determining the proportion of axis to the diameter perpendicular to axis, through his evaluation, showed that Earth's shape is not a complete sphere. Rather it is somewhat flattened near the two poles of earth in comparison to the equator. He also took into consideration the centrifugal force to come to his conclusion. (as cited in Heine, 2013; Newton, 1687/1884).

Another geophysical study was carried out around 1698-1700 by Edmund Halley, the English astronomer as well as physicist, who explored Atlantic Ocean to observe variation in compass. Based on his observation he put forward the concept of differently magnetised poles of earth. He also compiled the first magnetic chart of the Atlantic that consisted of lines that came to be known as Halleyan Lines (as cited in Cook, 1998).

Newton's idea of Earth's shape was challenged by French scientist who considered its shape as 'prolate ellipsoid, elongated at the poles and narrowed at the equator'. This debate was settled after two expeditions were carried out between 1735-1743 by two separate groups at two different places and their observations independently proved that the idea of Newton about earth's shape to be true. (as cited in Lowrie, 2007)

Many other significant geophysical phenomena were studied by a number of scientists to understand their causes and impact. In 1741 Celsius of Upasala of Sweden observed magnetic storm (Chapman & Bartels, 1940).

The advent of the eighteenth century witnessed a difference from only observational geophysics to experimental geophysics.

From 1735 to 1745 during French expedition to Peru, Pierre Bouguer attempted to measure the gravity of earth and also calculated earth's mean density. He measured the gravity of earth with the help of a pendulum (Smallwood, 2010).

Measurements of electrostatic and magnetic properties by physicist Charles Augustin de Coulomb using a torsion balance came as an important advancement in measurement of different geological phenomena. He documented his idea of torsion balance in his work 'Reserches theoriques et experimentales sur la force de torsion et sur l'elasticite des fils de metal & c' in 1785 (Robens, Jayaweera & Kiefer, 2014.)

An important expedition around this time was carried out by Jean Baptiste Joseph Delambre and Pierre Méchain, under the command of 'The French Academy of Sciences' from 1792 to 1799. The data collected from the expedition was valuable as it allowed to derive the North Pole- Equador distance (as cited in Lowrie, 2007).

The value of G measured by physicist Lord Charles Cavendish in 1798 was a significant advancement. He calculated the value of G to be 6.754 x 10-11 m3 kg-1 s-2 (Morison, 2013).

In 1797 the magnetic property of rocks was studied, and naturalist Alexander von Humboldt attributed this rock magnetisation to lighting strikes (McElhinny &. McFadden, 1999).

Until this point most of the studies of geological phenomenon included tools and theories of physics and thus a mode of loose assemblage is identified where geology was studied in relation to physics or physics in relation geology.

Lamination (1839-1919): Although earth's magnetism by this time was well studied area, however it was still not possible to represent the magnetic forces using unit. Physicist as well as mathematician Carl Freidrick Gauss made significant contribution towards this. He collaborated with physicist Wilhelm Weber and worked towards determining the intensity of earth's magnetic field. By 1839 they came up with their observations. Among many observations they stated that the magnetic field of the earth is a dipole (as cited in Lowrie, 2007).

Physicist Julius Fröbel in 1834 (in German) probably used for the first time the term 'Geophysics'. Forbes is also credited with producing the first modern scientific seismometers (Forbes, 1844).

Rock's magnetics's property was first observed systematically by Delesse (1849) and Melloni (1853). They claimed that during cooling time 'volcanic rocks acquired a remanent magnetization'. Delesse observed the magnetic nature lava flow in respect to earth's magnetic field. This laid the foundation of Palaeomagnetism. Melloni studied the magnetic properties of volcanic rocks (as cited in Lowrie, 2007).

Around 1857 came the first seismic map. It had a detailed account of 6831 earthquakes along with their possible locations marked (as cited in Lowrie, 2007).

William Thomson in 1862 investigated cooling history of earth Scottish mathematical physicist James Clerk Maxwell dealt with electrical and magnetic phenomena that led to the establishment of wave nature of geological entities. His ideas led to the theory of electromagnetic fields (as cited in Lowrie, 2007).

In 1879 Heinrich Lorentz, a Dutch physicist carrier out experiments with vacuum tubes which resulted into the deriving of unit of magnetism.

In 1883 Italian scientist M. S. de Rossi and the Swiss scientist. F. Forel independently devised for the first time a scale to measure earthquake intensity or the seismic density during earthquake. The scale commonly is known as the Rosi-Forel Scale (Rosel-Forel scale, 2013).

In 1894 and 1895 G. Folgerhaiter studied magnetism in lava and published a series of paper thereby showed his conformity with the result of lava magnetism of Mellani. He studied a number of rock samples in the laboratory and artificially induced magnetism to show the magnetic nature of rocks (as cited in Courtillot & Le Mouel, 2007)

Seismographs were installed by the 1880s. The first seismogram of a distant earthquake was obtained on Potsdam, Germany in 1889 (Von Rebeur-Paschwitz, 1889).

A further well devised seismograph was built by John Milne, Prof. of Geology in 1892 (Tobriner, 2015). The device was much more powerful and accurate and also could record data of distant earthquake.

Henry Becquerel came up with the idea radioactive dating determination of geologic entities and calculating earth's age. He himself carried out an experiment using Uranium ore on an undeveloped photographic plate (Henry Becquerel discovers radioactivity, n.d.).

In 1897, German physicist Emil Wiechert concluded that Earth's interior consists of a mantle of silicates, surrounding a core of iron (McDonough, 2003).

During this period the subject reflected a lamination stage. Several isolates formed a compound subject going with physics or geology. This includes subjects like Radioactive dating of Rocks, Seismic Density of Earthquake, elctro-magmetic nature of earth.

Towards Fusion: The first chair of geophysics in Göttingen since 1898 was Emil Wiechert. He developed mechanical seismographs which since 1900 were used worldwide (History - Earthquake measurement in Hamburg since 1898, n.d.).

In 1902 an Italian seismologist, G. Mercalli, proposed a more extensive, expanded intensity scale which reclassified earthquake severity in twelve stages. In 1903, the German geophysicist Emil Wiechert substantially increased the accuracy of the seismograph by improving the amplification method and by damping the instrument. In 1906, the electromagnetic seismometer put forward by Russian physicist Prince Boris Galitzin which allowed galvanometric recording on photographic paper. This electrical method had the great advantage that the recorder could now be separated from the seismometer (as cited in Lowrie, 2007).

Geologist R. D. Oldham studied San Francisco earthquake in 1906 and demonstrate telesesmic waves (Oldham, 1906).

Mohorovicic studied the interior of earth in 1909 by recordings of the Kupa Valley earthquake. He first recorded the existence of crust-mantle boundary later known as Mohorovičić discontinuity or Moho (as cited in Herak & Herak, 2007). The first sufficiently accurate depth of the earth's core was determined by Gutenberg (as cited in Lowrie, 2007).

Fusion (1919 Onwards): The International Union of Geodesy and Geophysics was established in 1919 at Brussels, Belgium "to promote activities of already-existing international scientific societies dealing with geodesy, terrestrial magnetism and electricity, meteorology, physical oceanography, seismology, and volcanology"

(Celebrating the 100th Anniversary of IUGG, n.d.). Geophysical journal 'Journal of Geophysics' was published from 1924. Bilingual publication of the journal started from 1953 and from 1974 stated publishing in English language. Harrold Jeffreys in 1926 investigated earth's central core and claimed that 'metallic core is truly fluid' (Jeffrey, 1926).

In 1930 The Society of Exploration Geophysicists (SEG) was established keeping in view the objective to connect and inspire scientists and people of geophysics. In 1931 SEG name changed to 1931 SPG (Society of Petroleum Geophysicists). In 1936 the first issue of the journal Geophysics was published. In 1937 the name changed to Society of Exploration Geophysicists (SEG - History, n.d.).

Thus, there was emerging a field of applied geophysics. Danish seismologist Inge Lehmann in 1936 suggested "from the analysis of P-wave data that the Earth must have an inner core — an important breakthrough in the understanding of the nature of the Earth's interior" (as cited in Kölbl-Ebert, 2001).

The International Geophysical Year or IGY was decided to be in 1950s to study of the Earth its atmosphere, its poles etc. The first study happened in 1957-1958. Since 1960s developments of computer technologies and satellites boosted up the studies related to geophysics.

Thus, a separate field of geophysics that deals with the physical properties and phenomenon of geological entities can clearly be seen to emerge.

5.10 Microbiology

Microbiology is defined as the "scientific study of microorganisms e.g. bacteria, viruses, and fungi" ("Microbiology", 2017, p. 2104). The term 'Micro' is a Greek word meaning 'small'. Organisms that are living but too small and invisible to naked eyes are known as 'Microbe' or 'Microorganisms'. They include Bacteria, Virus, Funguses, Protozoa etc. The field of microbiology "is concerned with the structure, function, and classification of such organisms and with ways of both exploiting and controlling their activities" (as cited in Pelczar & Pelczar, n.d.) and their impact on other living organisms and environment. Microbiology is an interdisciplinary subject having its own well-developed theories, principals, proponents, and areas of application.

As defined above it is the concept of ‘Microbes’ that forms the core of Microbiology. Microbes is an isolate belonging to the main subject “Biology”. However, tracing the history of Microbiology clearly shows that the isolate ‘Microbes’ have been time and again studied in subjects viz Biology, Medicine, Chemistry, Agriculture etc. that led to the increase in its literary warrant and contributed to the development of new theories, postulates and principles, discoveries, and application in diverse areas like medicine, engineering, genetics, physiology as well as environmental science. All these resulted in certain autonomy of the concept, which finally culminated in the coming up of ‘Microbiology’ as a distinct specialisation by itself.

The stages of development of microbiology developed through the study of the concept ‘Microbes’ in different subjects. The advancement of the subject largely depended on two-fold study: first the disapproval of spontaneous generation theory and secondly germ theory of diseases. Both these theories formed the basis of all the other developments that took place over the years.

Below are the stages of development of Microbiology along with the typology of relations as identified.

Pre-Lamination (Till 1856): Assumptions about birth and generation of micro-organisms were present since ancient period. One of the earliest mentions about the existence of microorganisms were made by Greek philosopher Aristotle who opined that ‘it is the non-living materials from which living organisms are born’ (Aristotle, trans. 1943). This idea was popularly accepted for a long time; until came the debate on ‘spontaneous generation’.

Another idea that gained significant attention was the influence of micro-organisms as a contributing factor to the onset of diseases. Roman philosopher Lucretius (1473/2001) in his book “On the Nature of Things” spoke about invisible living creatures capable of causing different diseases.

In 1530 Girolamo Fracastoro of Verona used the term Syphilis to describe a disease that got spread in entire Europe after French soldiers returned from war (Fracastaro, 1530/1686). In his book ‘De Contagione et Contagiosis Morbis’, Fracastoro (as cited in Nutton, 1983) put forward the concept of ‘seeds of disease’ which he named as ‘seminaria morbi’ to denote microbes that causes contagious diseases. He identified three forms of contagions viz.: by direct contact; by formites, and at distance by air or water.

So even though microbes were not visible to human eyes there was an inherent belief that microorganisms exist and also cause diseases. However, a clear scientific understanding of microorganisms was awaiting the invention that would allow scientists to see, observe and study them accurately. This breakthrough came with the invention of microscope.

Robert Hooke (1665) in 'Micrographia' wrote one of the earliest account having details of microorganisms. Hooke, and English polymath, used microscope to observe microorganisms which he described in this book accompanied by drawings based on his observations. The microorganisms he observed included moulds and also the smallest unit of tissues which he termed as 'cells' (Micrographia, 1665).

Similar to Hooke, Athanasius Kircher, a polymath, used the term worms to describe the microbes he observed in decaying meat, milk as well as bodies thereby laying the first stone of food microbiology (as cited in Jay, 1996).

Another significant observation was made by Antony van Leeuwenhoek (now regarded as the earliest microbiologist) in 1676. With his interest in microscopes, he carried out extensive studies, of what he called 'animalcules' meaning little animals and gave detailing account of the observed microbes. He sent numerous letters to the Royal Society of London until his death in 1723 explaining his discoveries which included the description of his observations made on microorganisms that are later on came to be known as by its various forms like bacteria, fungi or protozoa (as cited in Dobell, 1949).

However, these were mere observations and did not involve any application. Simple observation was no more enough for the advancement of the study of microbes. It became necessary to have highly capable microscopes and develop mechanisms that would allow isolating and growing pure forms of microorganisms 'in vitro and in vivo'. As a result, the development of the subject got stagnant.

For a long time, Aristotle's idea of spontaneous generation remained unchallenged. Gradually came a group of scientists who started to contend the theory of spontaneous generation. This debate once again brought the study of microbes into forefront.

A series of experiments was carried out by Francesco Redi an Italian physician in 1668. He came with his medical background and challenged the spontaneous generation theory by revealing that the birth of worms or maggots in decaying meat is not a spontaneous phenomenon and can be avoided if kept covered (Redi, 1668/1909).

What followed is a series of experiments one after another with some proponents supporting the spontaneous generation and some against it. One of the important experiments included that of John Needham, a naturalist and a supporter of the theory, who in 1745 showed the growth of microbes on mutton gravy through his experiments even after following the procedures that Francesco Redi has recommended (Needham, 1749).

Italian naturalist, Lazzaro Spallanzani was in consensus with Redi's claim. To disapprove Needham, he in 1769 carried out a two-step experiment. In the first step he after boiling beef broth removed the air from the container and again sealed it. His experiment revealed no growth. In the second step he allowed air to enter the flask through a crack which he purposefully made. This time growth of microbes was observed thus proving that exposure to air if controlled then growth of microbes is not possible after boiling. He thus demonstrated that the theory of spontaneous generation was a myth. While the debate continued the role of microbes in food spoilage to quite evident by this time (as cited in Vasanthakumari, 2016).

One of the first step towards food preservation from microbes can be traced to an interesting experiment carried out by Nicolas Appert, a French confectionarist and wine maker around 1789. He used thick champagne bottles to store soups and liquids after heating them extensively. No growth of any kind of microbes were observed (Appert, 1812)

From 1836 onwards a series of experiments were carried out by different investigators to understand the possibility of spontaneous generation. One such experiment was taken up by T. Schwann, a German naturalist, who made observation of the impact of heated air on meat broth and liquid containing sugar separately when passed through a glass tube. While in the first instance no microbes were found to be born, in the second sample living microorganisms often were found to be born. A somewhat similar experiment was carried out by F. Schulze in the same year. The only difference was that Schulze made sure that the air passed on to the vessel are germ free using sulphuric acid. The results had similar disparities. In 1853 H. Schroder and T. Dusch further enhanced the purification of the air by filtering through sterilised cotton. Boiled meat broths and wort of beer did not witness any changes however meat without water did show growth of microbes. Thus, most of these experiments disfavoured the notion of spontaneous generation. (Oparin, trans. 1957)

All these experiments that were being carried out unfortunately lacked a proper scientific method or explanation and gave very little attention towards practical applications. However, the experiments did contribute largely to the study of microbes in relation to preservation of food or spoilage of food making the study of microbes a significant area of study.

On the other hand, a relation between microbes and medicine can be traced back to 1796 when English Physician Edward Jenner dealt with smallpox prevention. He found that those who already suffered from cow pox were immune to smallpox. He also carried out a test to prove his claims and thus is credited to develop the first ever known vaccine against smallpox. However, Jenner did not make any attempt to identify the causal agent of smallpox and thus did not involve a direct study of any microorganism (Jenner, 1798).

Studies attempting to associated tiny living organisms or microorganisms and animal diseases can be traced to the contributions of Agostino Bassi in 1836, who identified a specific fungus as the cause of diseases affecting silkworms. In 1845, M. J. Berkeley claimed that microorganisms similar to fungi were responsible for the infamous Irish potato famine/blight. Furthermore, C. J. Davine, during the years 1863 to 1868, asserted that he discovered microbes in the blood of deceased animals, a finding he could not find in the blood samples of living animals. (Stanier, Ingram, Wheelis & Painter, 1986)

Again, these studies were mostly observational and although this time it involved microorganisms as causal agent, but neither any attempt was made to find the exact type of microorganism nor the reasons behind the cause of the disease.

The observations however gave a stage for further investigations that clearly established the importance of study of microbes. The period that followed witnessed attempts to identify these microorganisms and also culture them in laboratories for further examinations.

Lamination (1857-1881): One of the significant contributions came from Louis Pasteur, who came into the field of understanding microbes with his expertise as chemist. His works on fermentation and subsequently his findings on spontaneous generation of microorganisms brought breakthrough to the study of microbes.

He in 1857 was the first to claim that fermentation was caused by a living organism which he demonstrated through the fermentation process of lactic acid (Pasteur 1857/1999). In 1860 in his study of alcoholic fermentation he quantified the changes of yeast undergoes further establishing his claims of yeast as a living organism (Pasteur, 1860/1999).

His experiments and findings brought an end to the debate on spontaneous generation of microorganisms. A series of experiments demonstrated that organisms grew in broth when exposed to air in a flask with a straight neck, but not in a flask with a swanneck. By using a flask with an S-shaped neck, he was able to trap dust particles and prevent them from contaminating the broth. Thus, in 1858 the debate of spontaneous generation of microorganisms from inanimate objects got a closure. It was clear that microbes only originated from other living microorganisms i.e. the concept of biogenesis (Dubos, 1950).

In 1861 Pasteur experimented to understand the presence of 'animal infusoria' and its role in fermentation. He attributed the production of Butyric acid to the presence of such infusorian. He also put forward that this infusoriums have the capability to survive without oxygen; can be cultured in the same way that of yeast. This came as an important discovery and led to the study of different types of microbes and their role in fermentation and pathology (Pasteur, 1861/1999).

He made significant observations on the relation between the chemical process of fermentation in foods and microbes. To him while the fermentation in food is caused by microbes; it is the same microbes that are also responsible for its spoilage.

Around 1864 while carrying out experiments to destroy microbes in wine, Pasteur opined that heating the wine at 50^0C – 60^0C for few minutes was enough to kill the germs. This to him also had no negative effect on the quality or taste of the wine (Vallery-Radot, 1902). This concept is now commonly known as 'Pasteurization' and is used for preservation of food.

John Tyndall, an English physicist, developed in 1877 a process of sterilization by heating of the infusion to prevent spoilage. He favoured discontinued or fractional sterilization. To him repeated heating would kill the germs at every step leading to its complete elimination. (Tyndall, 1877/1999). This process is referred as Tyndallisation.

Thus, a clear typology of relation of Lamination can be identified where the concept of microbes compounded onto the concept of food preservation or food spoilage forming a compound subject under Food technology. This can include areas like ‘Bacterial spoilage of food’; ‘fermentation of food by yeast’. This also set the stage for the development of sub-areas like Food Microbiology.

Another very important theory that led to the advancement in the study of microbes is the germ theory of disease. The basic assumption was that microbes can act as pathogens and cause diseases.

Joseph Lister, a British surgeon advocated the introduction of the concept of ‘antiseptic surgery’ in 1867. He aimed at using carbolic or phenic acid as antiseptic in injuries that have fractures and wounds having the possibility of resulting into sepsis. The idea was to control the growth of microbes. The approach brought about remarkable transformation in the field of surgery (Lister, 1867/1999).

Works of both Pasture and Koch are considered as important contributions in understanding the relation between microbes (as pathogens) and medicine (diseases). Robert Koch, a German physician also made significant contributions. He identified two disease causing bacteria viz: Bacillus anthracis, the cause of anthrax in 1876 and tubercle bacillus causing tuberculises in 1882 (as cited in Brock, 1961). He put forward four criteria to identify relation between microbes and diseases. This came to be known as Koch’s postulates in 1884 (Koch, 1884/1999).

Pasteur also extended his concepts of germ theory to the understanding of diseases. In one of his initial attempts to understand the disease of ‘fowl cholera’ he experimented and cultured the disease-causing agent and after several observation concluded that the intensity of a virus weakens over the time and that the animals that have survived the fresh disease have already been previously infected. Thus, he used this idea of ‘attenuation’ to develop further concepts of Vaccine. He carried out experiments on chickens and developed a vaccine for fowl cholera. (Pasteur, 1881/1999). Subsequently he also developed vaccines against Anthrax in 1881 and Rabies in 1885.

This once again created a scope for formation of compound subject like Bacterial causes of Diseases going with Medicine as main class. This also created another sub-area of Microbiology that is Medical Microbiology.

Meanwhile a significant contribution came from Ferdinand Cohn, a German botanist, in 1875, when he came up with a bacterial taxonomic classification. He organised the then known bacteria into groups having more than one genre. His classification although had restrictions formed the basis of future bacterial classification (Cohn, 1875/1999).

Towards Distillation (1882-1944): While such study of individual microbes and their role in different processes continued a significant advancement that led Microbiology to establish itself as a distinct subject is culturing of Microbes for experimental purposes. The process of culturing microbes flourished in 1881 when Koch suggested the use of gelatine as the solidifying medium to culture bacteria. This came as a major advancement in the process isolating pure culture (Hitchens & Leikind, 1938). But soon certain drawbacks were encountered. The solution came from one of his assistants Walter Hesse in 1882 who on suggestion of his wife Fannie Hesse gave the idea to use 'agar' instead of gelatine as the solidifying agent for the isolation of pure culture (Hesse, 1992). In 1882 Paul Ehrlich based on the acid-fast characteristics of 'tubercle bacillus' developed a staining procedure for the bacteria. He also studied the properties of the particular bacteria that got revealed through the process of staining (Ehrilch, 1882/1999).

In 1884, Christian Gram, a Danish scientist, also contributed towards understanding bacteria. He developed a staining process in which he differentiated between types of bacteria either were highly decolourised or were resistant to decolourisation after conducting the staining process. Those that got stained are referred to as 'Gram Positive' and those did not were referred as 'Gram Negative'. This process commonly known as 'Gram Stain' became an important method in classifying and identifying bacteria (Gram, 1884/1999).

In 1887, Richard Petri, brought a modification to the plate technique that Koch used for solid culturing. He gave a description of the container which he considered better to culture microorganisms. This came to be known as 'Petri Dish' (Petri, 1887/1999).

Meanwhile culturing of microorganisms in laboratories became a practice. A number of researchers were able to identify a number of microorganisms causing various diseases. The leprosy bacillus was described by Hansen in 1874; followed by Neisser's discovery of the gonococcus in 1879; Eberth made significant observations of the typhoid bacillus in 1880. In 1881, Alexander Ogston detailed the staphylococci found in abscesses and suppurative lesions. Loeffler's observations in 1884 led to the characterization of the diphtheria bacillus, while Nicolaier identified the tetanus bacillus in soil the same year. Rosenbach described the tetanus bacillus in 1886. Frankel demonstrated the pneumococcus in 1886. Furthermore, Weichselbaum isolated the meningococcus from fluid of spine of a patient affected with meningitis in 1887, and Bruce identified the causative agent of Malta fever in 1887 (Vasanthakumari, 2016).

In 1887, the 'Institut Pasteur' was established.

Jules Bordet, in 1895, showed the presence of a substance named 'complement' in an animal that is not immunised. The substance has a property to react in combination with some antibodies against particular bacteria. This reaction of the combination of complement and antibody had a great significance in advancing the study of immunology (Bordet, 1895/1999). All these developments contributed to the progress in all areas of microbiology.

Adolf E. Meyer, a Dutch agricultural chemist, in 1887 pointed out a plant disease, specifically a disease observed in tobacco plants, called mosaic disease. He, through his experiments, showed the disease to be contagious and can get transmitted to other plants. However, studies showed that the cause of the disease was not any known bacteria. Martinus Beijerinck in 1898, carried out further experiments to show that the causal agent is a fluid or water-soluble substance and can also pass through agar. He named it 'Virus' (Beijerinck, 1899/1999).

In 1890 Emil von Behring, a German physiologist and Kitasati Shibasaburo, a Japanese physician wrote a paper highlighting their development of antitoxin to diphtheria and tetanus respectively. The antitoxin developed was aimed at curing those affected or preventing the nonimmunized from getting affected. This is considered as the beginning of serum treatment. (Behring & Kitasato, 1890/1999). Around 1892 Elias Metschnikoff put forward the cellular theory of immunity also referred as phagocytosis where he made observations that certain cells (Phagocytes) can act against bacteria and provide an initial round of immunity (as cited in Brock, 1961).

The study of bacteria became to advanced that by 1899 ‘Society of American Bacteriologists’ was formed. The constant culturing of Bacteria and understanding its role in different process led to the emergence of a separate field of ‘Bacteriology’ *(Emergence of Fission).*

The concept of ‘bacterial viruses or bacteriophages was put forward by Federick William Twort in 1915 and further studied by Felix d’Herelle in 1917 who stated that the presence of an invisible microbe, which he isolated, that had an antagonistic property against dysentery bacteria (as cited in Brock, 1961). This led to the development of Phage theory.

In 1928, Alexander Fleming, a Scottish physician, observed that penicillin as a substance can be derived from certain Mold species. He studied the substance extensively and advocated its use for treating diseases caused by bacteria in human (Fleming, 1929/1999).

Meanwhile in 1934 the electron microscope was developed that further aided the study of bacteria and viruses. Gradually it was more and more perfected. Soon followed the determining of a number of antibiotics that came to be used against bacterial infection. In 1944 the streptomycin antibiotic was recognised by Selman Waksman from Streptomyces, a bacteria found in soil. It was used for the treatment of tuberculosis (Comroe, 1978).

Also, viruses were cultured also the culturing of viruses developed significantly by this time by the end of World War II antibiotics became much developed and were able to treat a number of diseases. This was also the first step towards further study of different Viruses later leading to the field of Virology *(Emergence of Fission).*

Distillation (1945 onwards): In 1945 the ‘Society for General Microbiology’ was established. Since 1947 it started to publish a journal named Journal of General Microbiology and also began to hold regular symposium from 1949. From 1951 the ‘*International Journal of Systematic and Evolutionary Microbiology’ began to get published by the* Microbiology Society.

In 1960, the name ‘Society of American Bacteriologists’ was changed to "American Society for Microbiology”.

The 'Journal of General Microbiology' was renamed as 'Microbiology' in 1994. Also, in 1997 the 'Society for Agricultural Bacteriologists' changed its name to 'Society for Applied microbiology'. Since 2022 it is known as 'Applied Microbiology International'.

In 2015 the 'Society for General Microbiology' came to be known as 'Microbiology Society'.

Thus, by mid of 1900 the study of 'microbes' came to a point where it developed itself as a distinct subject with its own areas of study and applications to the other already established subjects. The study of microbes became so distinct with its own tools, theories and findings that gradually the separate subject of 'Microbiology' was formed. Also became evident the role of bacteria in genetic transfer (Lederberg & Tatum, 1946) as well as in synthesis of protein (Jacob & Manod, 1961). At present microbiology has significant application in various fields including medical, pharmaceutical, food production and preservation and other industrial use.

5.12 Molecular Biology

Molecular Biology is the study of "the structure and function of large molecules associated with living organisms, in particular proteins and the nucleic acids, DNA and RNA" ("Molecular Biology", 2017, p. 2137). The subject field focuses on macromolecules and its role in various biological functions as well as the molecular processes that takes place in living beings. It is an interdisciplinary science subject as its scope includes areas from multiple science subjects viz: chemistry, biology, biochemistry, genetics and employs methods and techniques from physics to understand the molecular functions better.

As evident from the above, it is the concept of the 'Molecule' that forms the core of the subject. A molecule is "one of the fundamental units forming a chemical compound…molecules consist of groups of atoms held together by covalent or coordinate bonds" ("Molecule", 2017, p. 2142). A molecule as a concept belongs to the subject chemistry. However, tracing the history of molecular biology makes it evident that certain large molecules present in living beings can replicate and are responsible for transmission of genetic information. They are in general referred to as macromolecules. It is the process of replication and transmission of genetic materials that forms the interest of molecular biologists. The study of the concept of macromolecules in the context of living beings led to a completely new understanding of the concept of evolution and inheritance giving rise to this new field. Over the time, a gradual growth it its literary warrant and development its own theories, techniques, having its own proponents and applications in other fields have resulted into a clear autonomy of the concept giving rise to a distinct subject field of 'Molecular Biology'. The emergence of it as a distinct area of study is, however, a 20th century phenomenon.

Below are the stages of development of Molecular Biology along with the typology of relations as identified.

Pre-Lamination (Till 1921): Scientific developments and experiments that have directly contributed to the emergence of Molecular Biology are backed by multiple observations that can be traced to antiquity. This includes observations on heredity and inheritance as well as what constitutes the basic unit of life.

Greek philosopher Hippocrates proposed his theory of heredity in which he identified particles which he termed as 'seed' as the carrier of heredity from the parents to the offsprings (as cited in Poczai and Santiago-Blay, 2022). Greek philosopher Aristotle (trans. 1943) described his idea of heredity in his 'Generation of Animals' wherein he opined that both the parents are responsible for the transfer of genetic materials to offsprings. His observations were in conformity to what is now largely known about heredity and inheritance. However, the unavailability of modern technology resulted in a lack of proper observations and experimentation. As a result, his ideas were not backed by scientific gene-based analysis of heredity. Studies of what constitute the any matter can also be traced to Greek philosophers like Leucippus and Democritus who gave the idea of 'atom' and 'void' forming the universe. Other Greek philosophers like Empedocles followed by Aristotle identified four earth, air, fire, and water as the basic elements constituting any matter (Empedocles, trans. 1981; Aristotle, trans. 1951)

Changes in the perception of heredity and what constitutes living organisms came with the invention of compound microscope that paved the way for advanced observations. As the concept of 'cell' developed the entire understanding of existence of living creatures changed. In 1665 Robert Hooke in his 'Micrographia' while putting forward his observations on microorganisms used the term 'cell' to refer to the smallest unit of the tissue (Hooke, 1665). Also, Antonie Van Leeuwenhoek in 1674 analyzed living cells during his observations of algae (as cited in Dobell, 1949). On the other hand, a significant concept resembling present day ‘molecule’ was given by Robert Boyle in 1661 in his ‘The Sceptical Chymist’ wherein he identified particles which he named ‘corpuscles’ capable of bonding together to form a larger concrete (Boyle, 1661). Such studies on structures that were later found to be similar to molecule can be found throughout eighteenth century.

Much later the discovery cell nuclei by Robert Brown, Scottish botanist in 1831 came as a breakthrough. (Brown, 1831); This was followed by the observations of plant cells by Matthias Schleiden in 1838 and of animal cells by Theodor Schwann in 1839 (“Cell”, 1999) and the discovery that cell grow from pre-existing cells by Virchow in 1855 (Virchow, 1860) leading to the coming up of cell theory which established cells as the basic unit of life.

In 1869 Swiss chemist Friedrich Miescher discovered a substance inside the nuclei of human blood cells that according to him was not protein. He named this substance ‘nuclein’ and developed methods for its extraction (as cited in Dahm, 2007). However, the significance of this discovery was not well understood at that point in the study of genetics and heredity. Around 1881 another important concept that came up was the result of the experiment and observation made by Eduard Zacharia, a botanist. He observed a nuclein like substance through staining which was later named by W. Flemming as ‘Chromatin’ in 1882. (as cited in Lamm, Harman, Veigl, 2020). In 1889 German pathologist and histologist, Richard Altmann put forward that nuclein should always “refer to the mixture of nucleic acid and protein, and the term nucleic acid should denote the substance cleaned of all proteins” (as cited in Lamm, Harman, Veigl, 2020). Thus, Altmann’s Nucleic Acid was same as Miescher’s ‘nuclein’ (as cited in Dahm, 2007).

Meanwhile Gregor Mendel came up with his pea plant experiment between 1856-1863 and published his findings in the paper ‘Experiment in Plant Hybridization’ in 1865. His findings came to be known as ‘Mendel’s Principles of Heredity’ which dealt with inheritance of trait. His work was of utmost importance in the understanding of inheritance and heredity, however remained ignored until re-discovered later (Mendel, 1925). The re-finding of what Mendel proved through his experiment came around 1900. Hugo DeVries, a Dutch Botanist, Carl Correns, also a botanist, and Erich von Tschermak, an Austrian botanist independently carried out experiments on different models and made observations on inheritance of traits. Findings of all three of them were in conformity with Mendel's observation after his pea-plant experiment. This led to the re-established of Mendel's law and this time with a much wider acceptance in the scientific community (Rosenberg & Rosenberg, 2012).

The chromosome theory given by Theodor Boveri and Walter Sutton separately in 1902 and 1903 respectively brought the study of genes and the study of chromosomes at the same platform. Both through their experiment and observation concluded that it is chromosome that is responsible for inheritance when it is passed from one generation to the other (Sutton, 1902; Sutton, 1903). In 1909 Wilhelm Johannsen coined the term 'Gene' to represent the basic unit of heredity as per Mendel's law.

One of the significant studies came from biologist Thomas Hunt Morgan in 1910; in which he studied 'Drosophila Melanogaster' or fruit fly, to make observation on heredity and concluded the presence of genes in chromosomes and the possibility of inheritance due to the observed link between some genes (Morgan, 1926).

All these discoveries and propositions resulted into an increasing need to carryout experiments to understand the phenomenon of heredity and inheritance clearly. Such explorations, this time was supported by the use of new scientific methods developed in chemistry and physics. Extensive study under microscope revealed that the observed structure that forms living organisms consists of well-defined structure. Thus, gradually came the concept of macromolecules. The revelation of the structure and role of selected macromolecules that are related to the study of heredity or genes contributed to the formation of the field of molecular biology.

Lamination (1922-1943): Hermann Staudinger, a German chemist in 1922 came up with the concept of macromolecular to describe high mass molecule (Staudinger, trans. 1970).

In 1926, an important study on 'Gene' was carried out by Hermann Joseph Muller who employed X-rays to understand gene mutation. Through his experiments on 'Drosophila' or fruit flies he made significant observation that x-rays can cause gene mutation that is x-rays can induce alteration in genes. (Muller, 1973).

In 1928 Frederick Griffith, a physician and bacteriologist, studied pneumococcus bacteria and put forward the concept of 'transformation'. According to his observation, from the experiments that he carried out on mouse, genetic transfer of information can take place through bacteria, and it is this process which is termed as 'transformation' (Griffith, 1928).

In 1929 deoxyribose was discovered by Phoebus A T Levene (Hargittai, 2009).

Harriet Creighton and Barbara McClintock in 1931 published 'A correlation of Cytological and Genetical Cross-over in Zea May" wherein they showed the "pairing chromosomes… exchange parts at the same time they exchange genes" (p.497) (Creighton and McClintock, 1931).

Meanwhile in 1940s came the "The Phage Group" mainly under the leadership of Max Delbrueck, a physicist who came into the field of biology and in collaboration with many other carried out experiments to study Bacteriophage. Their studies contributed largely to the understanding of genetic transfer and advancement of the subject field that developed into molecular biology (Mullins, 1972).

Linus Pauling, a physical chemist, used X-ray mechanism to understand molecular structure. His ideas were published in his book in 1939 "The nature of Chemical Bond and the Structure of Molecules and Crystals." His interest in understanding molecules led to bis exploring of the protein haemoglobin. He also gave the concept of alpha helix structure in relation to protein (Hargittai, 2009). Although his idea of structure of DNA was replaced by Watson and Crick's structure however his observations and findings contributed towards structural chemistry that in turn expanded the understanding of molecular biology.

Svedberg (1933) carried out an experiment to study respiratory proteins using ultracentrifugal technique. He concluded that haemoglobin has higher molecular weight and have uniformity in size, thus providing further support to the concept of macromolecule in living creatures instead of the colloid hypothesis. His observations were published in his work 'Sedimentation constants, molecular weight and isoelectric points of the Respiratory Proteins.

Torbjörn Caspersson, a Swedish geneticist, studied nucleic acid towards the second half of the 1930s and indicated towards the possibility of it being a macromolecule. He also put forward that RNA might play a significant role in synthesis of protein (Ruddle, 1989). His research was published much later in the 1950 in his work titled 'Cell Growth and Cell Function'

One of the major supports to carry out further research came from the Rockefeller Foundation under the leadership of Warren Weaver. The term molecular biology was first introduced by Warren Weaver in 1938 in connection to the works conducted by Rockefeller Foundation. Soon, it was adopted by the scientific community to refer to similar kinds of work of experimental biology- that is understanding biology in the light of techniques and explanations of Physics and Chemistry.

George Beadle and Edward Tatum in 1941 in their work 'Genetic control of biochemical reactions in 'Neurospora', a fungus, established the 'one gene–one enzyme hypothesis'. They choose Neurospora Crassa as their model organism for their experiment. The result of the study proved that each gene has relation with a single specific enzyme and x-ray induced mutant are incapable of carrying out or producing the biochemical reactions (Beadle & Tatum, 1941).

At this point a stage of 'Lamination' can be identified in the development of the subject. The concept of gene appeared in compound subjects such as 'x-ray induced gene mutation' going with the subject Medicine; 'bacterial transfer of genetic information' going with either of the basic subjects like Biochemistry, Biology, Microbiology, Medicine. Also the concept of macromolecule appeared in compound subject such as 'RNA in protein Synthesis' going with the basic subject Biochemistry.

Although the understanding was increasing however there was still a lot to decipher. This included the genetic codes, chemical composition of genes, gene replication and information transfer. The next few years saw scientists from different fields to collaborate for finding answers to these questions.

Towards Distillation: (1944-1960): The publication of the book 'What Is Life? : The Physical Aspect of the Living Cell' by physicist Erwin Schrödinger in 1944 came as an impetus for further studying the concept of inheritance in relation to chemical and physical processes involved in gene. He highlighted about gene mutation and connected molecules as to be probable heredity materials (Schrödinger, 1967).

A breakthrough came from the experiments of Oswald T. Avery, Colin M. MacLeod, and Maclyn McCarty in 1944. Published in the work 'Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types: Induction of Transformation by A Desoxyribonucleic Acid Fraction Isolated from Pneumococcus Type III. They showed through their experiment that unlike to the then common assumption, it is not protein or lipid, but a "highly polymerized, viscous form of desoxyribonucleic acid" (p. 156) that is responsible for bringing transformation. Thus, their findings confirmed the presence of DNA in genes (Avery, MacLeod, McCarty, 1944).

In 1952, the genetic character of DNA was further proved by Alfred Hershey and Martha Chase in the popularly known Hershey–Chase experiment. In their work 'Independent Function of Viral Protein and Nucleic Acid in Growth of Bacteriophage', they inferred that protein had no function in growth of Bacteriophage, rather they found DNA forming its genetic material to have some role to play. (Hershey & Chase, 1952).

As the DNA structure was clear the focus now shifted to how gene replication takes place and the process by which the DNA aides it as well as the role of gene in heredity in a scientific way.

In 1953, came a major discovery that changed the field of Molecular Biology. James Watson and Francis Crick deciphered the double helical structure of the DNA molecule. In their paper 'Molecular Structure of Nucleic Acid: a structure for Deoxyribose Nucleic Acid' Watson & Crick (1953) put forward that DNA structure has "two helical chains each coiled round the same axis" (p.737). They also came up with a semiconservative model of gene replication.

In 1958 Matthew Meselson and Franklin Stahl, carried out their experiment known as Meselson-Stahl experiment. In it they through their experiment once again proved the semiconservative gene replication hypothesis as given by Watson and Crick (Meselson & Stahl, 1958).

François Jacob and Jacques Monod in 1961 in their article 'Genetic Regulatory Mechanisms in the Synthesis of Proteins' put forward an idea of how protein production and genes are interrelated and identified an RNA fraction as the intermediary substance or messenger referring it to as messenger RNA or mRNA (Jacob & Manod, 1961).

Distillation (1961 onwards): As genetic code and DNA structure and compositions were deciphered 'Molecular Biology' as a subject started to distil out of the related subjects under which the previous studies were being carried out.

Meanwhile Journal of Molecular Biology (https://www.sciencedirect.com/journal/journal-of-molecular-biology) was established in 1959.

By 1964 the 'European Molecular Biology Organisation'(EMBO) was established. In 1972 an EMBO workshop was held at Basel that was attained by a number of molecular biologists.

The Society for Molecular Biology and Evolution was also founded in 1982. In the same year a symposium was held at the State University of New York on 'Evolution of Genes and Proteins'. In 1983, a new journal 'Molecular Biology and Evolution' began to get published.

Meanwhile a number of universities began to give courses on Molecular Biology. The American Society for Biochemistry and Molecular Biology came into existence in 1987.

Thus, a subject of 'Molecular Biology' came into existence as the concept of 'Macromolecules and its role in genetics' developed and distilled out as a subject gaining considerable literary warrant. The subject now itself contributes largely to the development of other subjects like Genetics, Bioinformatics as well as Medicine.

5.13 Environmental Science

Environmental Science is an "interdisciplinary academic field that draws on ecology, geology, meteorology, biology, chemistry, engineering, and physics to study environmental problems and human impacts on the environment. Environmental science is a quantitative discipline with both applied and theoretical aspects and has been influential in informing the policies of governments around the world" (Britannica, n.d.).

Understanding of 'environment' depends somewhat upon the perspective from which it is being studied. The perception of environment to a layman, or to a farmer, or to a biologist or ecologist are bound to differ. As a result, environmental sciences as a subject requires an interdisciplinary approach. Environmental Science encompasses the study of components of environment – land, air, water as well as sustenance of life. There is various academic subjects which deal with either environment as a whole or any of its components. These include Biology, Ecology, Geology, Soil Science, meteorology, biology Chemistry, physics, engineering minerology etc. Environmental Science as a subject differs from environmental studies from the point that environmental studies deal with human interaction to environment.

Background: The development of environmental science as a subject is a recent one. However, observation and preservation of the environment have been part of ancient civilization. People were largely dependent on it for their survival. They worshipped nature as God. The adverse impact of the environment can also be found in various historical accounts. According to an article published in *New Science* "Archaeologists working in Palestine found signs that deforestation caused the collapse of communities in the southern Levant (the area of present-day Israel, Jordan, and southern Syria) around 6000 BC" (as cited in Bowler, Charles, Kenward, Joyce & Dickinson, 1990).

Aristotle, an ancient Greek philosopher, in his book 'Meteorologica' dealt with environment and environmental calamities like earthquake and gave accounts on weather. (Aristotle, trans. 1951). Another Greek philosopher Pliny the Elder also dealt with environmental concerns in ancient civilization in his work 'Natural history' (Pliny, n.d.).

Thus, the environment has played an important role in either survival or extinction of human civilization.

Pre-Clustering (Till 1926): Rather than perceiving nature on the basis of assumption, scientific revolution brought about changes in ways to study environment. Contributions by Keplar, Galileo, Newton, Descartes gave a new dimension to the concept of the nature and environment. However, none of these understanding of environment aimed at establishing it as an academic subject.

With time the world witnessed increased hazards that created the necessity to protect the environment. This led to the coming up of studying environment from a much more scientific and an organized manner.

Industrial revolution took place in the late half of 18^{th} century and in the beginning of 19^{th} century. While it brought advancement in human civilization, it also caused the issue of pollution. "Although IR had unlimited successes, it had some negative effects, such as increase of unskilled workers, rise of women and child labour in unhygienic and risky situation, rise of slave trade, and rapid increase of environment pollution" (Mohajan, 2019, p. 19).

In 1798 Thomas Malthus wrote a book 'Doctrine of population growth and resource scarcity' where he showed the danger of population growth on the environment (Malthus, 1798). In America, natural scientists John James Audubon, John Muir, William Bartram and Meriwether Lewis & William Clark showed their interest in nature which can be traced from their expeditions from 1804 to 1806 (Schlager & Lauer, 2000).

Scientists were engaged in studying properties of gases at this time. French mathematician and natural philosopher Jean-Baptiste Joseph Fourier in 1820's studied earth's temperature distribution. He observed that Sun is the source of the temperature. His theories are regarded as important work in studying the greenhouse effect (Fourier, 1827/2004).

In 1859 Charles Darwin published his work 'On the origin of species: By means of natural selection' where he spoke about adapting to the environment for survival (Darwin, 1960).

Swedish scientist Svante Arrhenius in 1896 identified influence of carbonic acid in air upon the temperature of the ground. (Arrhenius, 1896). He is regarded as the first to connect rising CO2 with global warming.

Environment, its chemical compositions, agricultural utilization, environmental threats all were studied in a scattered manner by experts of different subjects.

Towards Clustering (1927 – 1970): 'Environmental Science' as a topic started to grow in 20^{th} century. Scientists were engaged studying the subject with the help of tools and techniques from biology, chemistry, meteorology, physics etc.

Application of physics in studying environmental science can be clearly traced from 1920s. Rudolf Geiger is a well-known name in this regard. His book 'The Climate Near the Ground' dealt with the physical basis of microclimatological observations and its interactions with the biosphere which was first published in 1927. The effect of climate on humans, plants, animals etc. are traced from his study (Geiger, 1950).

Ecology has a long history which is regarded as part of environmental science. The involvement of ecology in studying aspects of environmental science can remarkably be traced to the work of Raymond L. Lindeman about 'The Trophic-Dynamic Aspect of Ecology' (Lindeman, 1942). Eugene Odum in 1953 published a book named 'Fundamentals of Ecology' to educate people about ecological science (Odum, 1971).

Stanley Auerbach dealt with soil ecosystem and also radioactive waste disposal in his work in 1958. Odum in 1956 reviewed the paper and also summarized its ecological implications.The advent of atomic power in industry creates this radioactive problem. According to him, it can create biological imbalance (Auerbach, 1958).

Ecology and Biology especially marine biology has great impact on environment. French born biologist and ecologist Rene Dubos in 1964 spoke about the effect of 'total environment' on human in his article 'Environmental Biology' (Dubos, 1964).

Application of chemistry in studying environment or the involvements chemicals with environment can be clearly traced since 1930s. Callender (1938) identified that earth's temperature increases 0.3 degree Celsius and this was due to artificial production of CO_2 by burning of fossil fuels. It influences the temperature. Revelle & Suess (1957) studied CO_2 exchange between Ocean and atmosphere. Total amount of CO_2 in air identified by them. They conclude that the average life of Co_2 is 10 years before it dissolved in the sea. In 1958 atmospheric CO_2 was measured by Charles David Keeling of Scripps Institution of Oceanography (American Chemical Society, 2015). Rachel Carson published 'Silent Spring' in 1962. He asked for banned of harmful DDT in United States (Carson, 1962). Through this study 'Environmental science' gained popularity as a subject. American geochemist Claire Patterson studied "occurrence of lead in the earth and the oceans" (p. 344). He warned the people of America about the danger of lead (Patterson, 1965).

In 1945, the atomic bomb on Hiroshima and Nagasaki caused not only tremendous environmental pollution but also affected human life. Many people were killed, temperature of ground increased to too high, radioactive rain happened. Survivors faced various serious health issues (Hiroshima and Nagasaki bombings, n.d.).

In 1948 first major U.S. law that address water pollution was 'The Federal Water Pollution Control Act'. From 1972, it was known as the Clean Water Act (CWA) (History of the Clean Water Act, n.d.).

Various acts were implemented to protect the environment, research institutes & international organizations were established to study environments. In most of the cases all these institutions were formed after the consequences of second world war.

"The American conversation about protecting the environment began in the 1960s" (The Origins of EPA, n.d.). Congress enacted in United States 'National Environmental Policy Act' in 1969 and after the sign of the President Nixon it started its' journey from 1st January 1970. In the US it was the first major law on the environment. NEPA established 'The Council on Environmental Quality' (CEQ) "to ensure that Federal agencies meet their obligations under NEPA" (Welcome, n.d.).

During 1969 two important incidents happened in the world. Due to water pollution, Ohio's Cuyahoga River caught fire in 22nd June, 1969 (Boissoneault, 2019) and also Santa Barbara oil spill's 3 million crude oil endangered thousands of animals of ocean (Mai-Duc, 2015). These two incidents impacted on environmental scientists two think about protection of environment which leads to established of Environmental Protection Agency (EPA).

'Environmental Science & Technology' journal started its publication in 1967. In 1969 Department of Geography and the Department of Geology of University of Virginia merged and formed Department of Environmental Sciences, the first environmental science department of United States. It offered degrees ranging from B.A. - Ph.D. levels (History, n.d.).

In United States EPA was established on 2nd December 1970, keeping in view of the objective to protect environment and to protect human health (EPA History, n.d.).

Thus 'environment' as a topic became a center point of discussion in almost all subjects: Physics, Chemistry, Geology, Economics, Policy Making and Administration, Public Health, Geography, Ecology and so on. At this juncture the growing awareness and research on the environment witnesses a growth. Thus, gradually 'environment' as a core entity brought specialists from different subjects to collaborate and work together giving rise to a distinct area of study.

Clustering (1971 onwards): Developments of Journals & departments in 1960's and research on environment from the biologist / chemist / physicist point of view in 1950's and 1960's impacted scientist as well as humans. So, for that reason various Programmes, acts, protocols etc. came into forefront.

The Institution of Environmental Sciences (IES) was founded in 1971, keeping in view the objective to promote and raise awareness among the public about the environment.

The Great Lakes Water Quality Agreement started in 1972. The Agreement was first signed by U.S. and Canada. "It was amended in 1983 and 1987. In 2012, it was updated to enhance water quality programs that ensure the "chemical, physical, and biological integrity" of the Great Lakes" (What is GLWQA?, n.d.).

First conference which introduced environment as a major issue to the whole world was held in Stockholm in 1972 as ‘United Nations Conference on the Human Environment’ which leads to the establishment of the United Nations Environment Programme (UNEP) (Stockholm 1972, n.d.). In 1970s Paul Crutzen, Mario Molina and Sherwood Rowland showed concern about chlorofluorocarbons (CFCs) on the Antarctic ozone. Later, in 1985 they discovered a hole in the ozone layer which resulted in 1987 ‘Montreal Protocol’ (The ozone hole, n.d.). Vienna Convention in 1985 was the reason behind it. It was done for the protection of the ozone layer (Weiss, 2009). In 1992, the United Nations Conference on Environment and Development (UNCED) which also known as the 'Earth Summit', was held in Rio de Janeiro, Brazil (Rio 1992, n.d.).

Research Center for Eco-Environmental Sciences (formerly Institute of Environmental Chemistry of Chinese Academy of Sciences) founded in 1975 in China for research on eco-environmental science and technology (About RCEES, n.d.).

Monteith & Unsworth (2013) published a book named ‘Principles of Environmental Physics’ in 1973. The book is regarded as important book related to ‘Environmental Physics’. It covers properties of gases and liquids; radiation environment; microclimatology of radiation etc.

‘The School of Environmental Sciences’ was established in 1974 and started first ‘Environmetal Science’ course in India by offering the M.Phil./Ph.D. Program from 1975 and also M.sc. Degree since 1987 (School of Environmental Sciences, n.d.).

Apart from that, social movements and some important disasters also happened in 1970s, 1980s. Love Canal tragedy of 1978 of America is one of the important environmental tragedies among them (Beck, 1979). The Three Mile Island accident in a nuclear power plant in USA in 1979 also affects health and environment It shows concern about radioactive waste released to air, radioactive materials released to water. All these caused health issues and environmental issues (Three Mile Island Accident, 2022).

Environmental justice movement in 1982 in North Carolina was about illegal dumping of toxic waste by African American community (Environmental Justice History, n.d.) is an important incident in the history of environmental science. In India in 1984 Bhopal gas power plant disaster happened. Methyl isocyanate gas contaminated the air.

Thousands of people were affected (Diamond, 1985). This is regarded as one of the most important disasters in the history of the environment.

The Chernobyl nuclear power plant accident happened in 1986. The environment was polluted by radioactive materials (Chernobyl Accident 1986, n.d.). Environmental damage was caused during Gulf War by burning Kuwaiti oil wells in 1991 (Toukn, 1991).

The Chartered Institution of Water and Environmental Management (CIWEM) (https://www.ciwem.org/) was established in 1987.

In 1990s Environmental practices gain its popularity. The Institution of Water Officers (now the Institute of Water (https://instituteofwater.org.uk/)), Forum for Environmental Professionals (FEP) were created.

Studies were going on phytoplankton and zooplankton of seas in 1990's; institutions were involved in studying ocean life. The details can be traced through the history of 'Oceanography' (see clustering of chapter 5).

Chartered Umbrella Body for the Environment (CUBE) was formed in 2000. It was renamed the Society for the Environment (SocEnv) in 2002. In 2008 the UK passed the Climate Change Act by targeting to reduce greenhouse gas.

"The Paris Agreement was adopted on 12 December 2015 and came into force less than a year later, on 4 November 2016. Although the 1997 Kyoto Protocol also technically remains in force, the Paris Agreement has, in effect, superseded the Kyoto Protocol as the principal regulatory instrument governing the global response to climate change" (Bodansky, 2021).

which from 2014 renamed as 'Environmental Science & Technology'. On the other hand, 'Journal of Environmental Sciences' & 'Environmental Sciences Europe' started its journey from 1989.

Environmental science emerged and growth as an interdisciplinary subject after the major establishments of organizations, institutions etc. Since the 1970s its growth has reached its peak. Various degree courses are now available all over the world on 'Environmental Sciences'. Environmental scientists focused their research mainly on climate change after coming up with the burning topic of global warming in forefront of the world. After the advent of the internet, modern technologies like Geographic information systems (GIS), Artificial Intelligence, Satellite, block chain technologies etc. Research on environmental science upgraded and benefits can be seen in their research on plants, animals and on ozone layers.

5.14 Oceanography

Oceanography is "the study of oceans. It includes the origin, structure and form of the oceans, nature of the sea floor and its sediments, the characteristics of the ocean waters (eg. Tides, salinity and currents), and the types of flora and fauna living within the oceans. The effect of human intervention also forms an important aspect of oceanography" ("Oceanography", 2017, p.2259).

It is evident from the above definition that oceanography is an interdisciplinary science. 'Ocean' as the core entity of the subject, oceanography as a subject studies it from the perspective of physics, biology, ecology as well as geology. It employs tools and theories of each of these subjects to understand the ocean from a particular perspective- physical, chemical, ecological, biological or geological. Oceanography as a science emerged in the 20th century. However, the study of oceans almost dated back to antiquity.

Background: The history of the ocean is mostly the history of voyages and explorations. In 4000 B.C. Egyptians developed the art of building ship and attempted for the development of ocean piloting schemes. Big vessels were constructed by the Polynesians for voyages to colonize islands in the Pacific including Hawaii in between 4000 -2000 B.C. Phoenicians explored the Mediterranean Sea around 1000 to 600 BC. They navigated through stars. Navigation was probably one of the earliest uses of ocean in a systematic way. The Greek Pytheas explored Atlantic Ocean by the help North star in 325 B.C. In 'Meteorologica' around 340 B.C. Aristotle described the physical structure and the geography of the Greek world which known as first treatise on marine biology. Eratosthenes (276–192 B.C.) determined the circumference of the Earth.

Another significant outcome of the explorations was compilation of maps with navigational routes. Ptolemy in 150 A.D compiled a map with latitudes and longitudes of Rome. The English monk Bede (673–735 A.D.) published 'De Temporum Ratione' which holds information about tide. Contribution of Leonardo da Vinci (1452-1519) about current and waves; rediscovery of America in 1492 by Christopher Columbus also has significant in ocean study. Vasco da Gama's arrival in India in 1498 opened a gate to world to take interest in sea. In the meantime, several voyages were taking place around the world. Geradus Mercator of Netherlands in 1569 constructed a map of the world for navigational accuracy. These developments lead the study of oceans to the next level where studies or experiments were done more frequently from the latter half of 17th century and beginning of 18th century.

Pre-Clustering (Till 1846): Robert Boyel in 1674 in his work 'Observations and Experiments about the Saltness of the Sea' attempted understand the cause of sea's salinity (Boyel, 1674). He studied sea water to find the solution for natural water in the sea (Boyle, 1693).

Edmond Halley an English astronomer, physicist and mathematician in 1685 published his work 'An historical account of the trade winds, and monsoons, observable in the seas between and near the Tropicks, with an attempt to assign the physical cause of the said winds' where he said that there was an exact relation between constant and periodical winds (Halley, 1685). In 1735 George Hadley in his work in 'Concerning the Cause of the General Trade-Winds' discussed the general cause of trade winds. He said that the actual cause behind it is the Sun (Hadley, 1735).

Temperature of deep ocean layers was measured by Captain of British ship Henry Ellis in 1751 in Atlantic Ocean using rudimentary equipment (as cited in Voituriez, 2003).

The first ocean chart of Gulf Stream was prepared Benjamin Franklin with the help of Timothy Folger by 1769 –1770 which British Captains consulted during voyages for speeding up their passage to New York as it was the first good chart of Gulf Stream. (as cited in Richardson, 1980).

The French chemist Antoine Lavoisier in 1772 analyzed sea water. Swedish chemist Torbern Olaf Bergman in 1784 also examined seas water and identified list of substances in water. Bergman's "work in mineral waters stimulated and accelerated much of the future work on fresh waters and solution chemistry that was applicable to sea water" (as cited in Wallace, 1980, p. 337).

Late 18th century witnessed exploration of James Cook. From 1776 -1779 Captain Cook made three great voyages of explorations to chart the Pacific Ocean. His chart for the first time connected Geology & Biology. “A voyage to the Pacific Ocean. Undertaken, by the command of His Majesty, to make discoveries in the Northern hemisphere, to determine the position and extent of the west side of North America; its distance from Asia; and the practicability of a northern passage to Europe. Performed under the direction of Captain Cook, Clerke, and Gore, in His Majesty's ships the Resolution and Discovery, in the years 1776, 1777, 1778, 1779, and 1780” published in three volumes is considered one of the important book that placed oceanography in the path to become a subject. (Cook, 1774; King, 1784). Throughout their voyages, they gathered data on geography, geology, tides, currents, temperature of waters etc.

Cook’s expedition helped to discover of “the east coasts of New Zealand and Australia through which geography and oceanography was gained popularity…J.Cook’s three voyages initiated marine research expeditions ” (as cited in Inyaeva, 2007).

During 1775 - 1777 first modern American submarine was invented by David Bushnell called ‘Turtle’ which was engaged into active combat (Thomson, 1942).

Chemical ingredients of sea water were studied in 1820 by the London Physician Alexander Marcet in 1819 (as cited in Coley, 1968). A scientific book named ‘An Investigation of the Currents of the Atlantic Ocean: And of Those which Prevail Between the Indian Ocean and the Atlantic’ was published during this time on oceanography by Rennell (Rennell, 1832).

Around 1839 –1843, Sir James Ross “led a scientific expedition to Antarctica, recovering samples of deep- sea bottom life down to a maximum depth of 7 kilometers” (as cited in Pinet, 2003).

‘A History of British Starfishes: And Other Animals of the Class Echinodermata’ was published by Sir Edward Forbes (British naturalist) in 1841 which is about life of starfishes in Irish sea. The characters of this inhabitant were explored in this book (Forbes, 1841). Contribution in Marine Ecology started from this study. In another work ‘Distribution of Marine Life’ which was published in 1854, he argued that sea life cannot exist below about 600 meters (as cited in Pinet, 2003).

All these voyages resulted in increasing interest in understanding Ocean and the physical and biological samples collected during the voyages were remarkable source of information about ocean and marine life to the chemists, physicists, geologists as well as the biologists.

Towards Clustering (1847-1974): Subjects like Chemistry, Biology, Physics, Geography, Marine Science etc. have great involvements in studying oceans which can be traced clearly from 19th century onwards. Technology has great impact on this especially in 20th century. Some of the major developments that involved various subject fields and led to the formation of cluster subject 'Oceanography' are highlighted below:

J. Francon Williams wrote a treatise named 'The Geography of the Oceans: Physical, Historical, and Descriptive' in 1881. The book was about general geography and physical geography of ocean. Geography of Atlantic, Pacific and Indian oceans were studied along with their composition of sea water, density of sea water, temperature of ocean and distribution of marine life. Some lists of maps and charts were also provided in that book (Williams, 1881).

One of the most significant steps that led to the emergence of 'Oceanography' as a science was the famous 'Challenger Expedition' of 1872-1876. Led by Charles Wyville Thomson and John Murray along with other scientists, this was one of the first scientific explorations of the Ocean. This expedition collected information and samples of both physical condition and biological new species. The findings of the expedition have been published in the form of a multivolume report titled "Report of the Scientific Results of the Exploration Voyage of HMS Challenger" published 1885. The samples collected provided data for chemists, biologists as well as geologists that laying the scientific beginning of biological oceanography, chemical oceanography as well as geological oceanography.

Stations were established in 1872 in Germany by Anton Dohrn, a German zoologist. The station boosted marine biology research in a new way by providing access to scientists from various parts of the world (Statzione Zoologica Anton Dorhon Napoli, n.d.). In 1873 first, Marine Biological Laboratory was established in America under United States Department of Commerce's Bureau of Fisheries.

Marine Biological Association UK was established in 1884 that provided scope to various countries to study marine biology. 'Journal of the Marine Biological

Association of the United Kingdom' was published since 1887 that covers marine biology.

The Scripps Institution of Oceanography was developed in 1903 in California as a marine biology station. The International Council for the Exploration of the Sea (ICES) was established in 1902.

Martin Knudsen, a north Funen physicist had great interest in oceanography. "Ingolf" expedition was one of the finest achievements of him (Helge, 1950).

It was Lieutenant Matthew F. Maury of America who first produced wind and current charts based on the North Atlantic Ocean through his publication 'Wind and Current Chart of the North Atlantic' in 1847 (Lewis, 1927). The book of Maury (1855) "The Physical Geography of the Sea" is one of the important books of Physical oceanography. It covers topics like the depth of sea, analysis of air in sea, depth of ocean, influence of gulf stream upon climate etc.

Woods Hole Oceanographic Institute was created in 1930. In 1958 atmospheric CO2 was measured by Charles David Keeling of Scripps Institution of Oceanography (American Chemical Society, 2015).

In 1885 during several months from a moored ship, John Elliott Pillsbury, U.S navy officer measured current from a ship at anchor. This was first direct measurement. The 'currentmeters' is still in use in marine environment for measuring wind speed and direction (Voituriez, 2003).

Kirk Bryan and Michael Cox in 1967 wrote a paper named 'A numerical investigation of the oceanic general circulation'. They develop numerical models of the oceanic circulation. In their study "Solutions are obtained by the direct numerical integration of a corresponding initial value problem using an electronic computer. Dimensional analysis indicates that the system depends on 5 basic parameters. The geophysically significant range of these parameters is investigated in 8 numerical experiments" (Bryan & Cox, 1967).

'Conductivity, Temperature, and Depth' which also known as CTD in modern time was developed by Bruce Hamon and of Australia. Bruce Hamon were engaged in 1958 in designing an instrument for use to depths of 1,000 meters known as CTD. In 1961 they were also engaged in developing Salinity-Temperature-Depth (STD) (as cited in Brown, 1991).

The formation of the survey Geochemical Ocean Sections Study (GEOSECS) from July 1972 to May 1973 in Atlantic; from August 1973 to June 1974 in Pacific and also from December 1977 to March 1978 provided a clear indication of involvement of Chemistry in Oceanography as it surveyed chemical, isotopic, and radiochemical tracers in the ocean (GEOSECS, n.d.).

Also, various societies were established, and journals were published that covered all aspects of oceanography. Meanwhile 'The Oceanographic Society' of Japan was established in 1941. The Journal of Oceanography began to get published from 1942 as their official journal.

Thus 'ocean' by this time was definitely one of the important entities around which scientists and researchers from different subjects were collaborating to explore the physical, chemical as well as biological characteristics.

Clustering (1975 onwards): The Canadian Meteorological Society (CMS) was formed in 1967 and in the beginning of 1975 when oceanographers were included, CMS became Canadian Meteorological and Oceanographic Society (CMOS). In U.S., the Oceanography Society (TOS) was established in 1988 "to advance oceanographic research, technology, and education, and to disseminate knowledge of oceanography and its application through research and education". 'Oceanography' is the official magazine of The Oceanography Society which was first published in July 1988 (The Oceanography Society, n.d.).

NASA's SEASAT program (26th June to October 1978) was one of the earliest satellites that observed earth "to test various oceanographic sensors and gain a better understanding of Earth's seas…measuring sea-surface winds and temperatures, wave heights, atmospheric liquid water content, sea ice features and ocean topography" (SEASAT, n.d.).

In 1985 the International Oceanographic Community prepared a 5-year experiment plan to provide "provide the first comprehensive global survey of physical properties of the oceans". Finally, the World Ocean Circulation Experiment (WOCE) was carried out 1990 - 1998. A book named "Ocean Circulation and Climate: Observing and Modelling the Global Ocean: was released on 2001 which was structural guide of World Ocean Circulation Experiment (WOCE) (Siedler, Church & Gould, 2001).

On March 12, 1985, U.S. Navy GEOdetic SATellite (GEOSAT) was launched. "It carried an altimeter that was capable of measuring the distance from satellite to sea surface. The studies made using GEOSAT data are numerous and the GEOSAT data set is regarded as a milestone in both satellite oceanography and satellite geodesy" (GEOdetic SATellite (GEOSAT), n.d.).

The Australian Meteorological and Oceanographic Society (AMOS) was established in 1987.

JASON, a two-body ROV system equipped with sonar, video images etc. was used to study marine in 1988 (ROV Jason/Medea, n.d.). The Bio-Optical Multi-frequency Acoustical and Physical Environmental Recorder called BIOMAPER-II was used to study phytoplankton and zooplankton of seas by scientists using a five-frequency sonar system. (BIOMAPER-II, n.d.). Modern technologies like TowCam camera invented in 2003 are used in capturing photographs of the seafloor. (Towed Camera System, n.d.). "Through these photographic and material samples, TowCam has facilitated the study of underwater geology and volcanology around the globe" (Deep Dive into Oceanography, n.d.).

The development of computer technologies has a great impact on oceanographers. It helped as a tool to study ocean life, its' properties time to time. Also, Military technologies had a good impact in studying oceanography. "The use of submarines, starting in the U.S. Civil War, prompted the development of sonar and the magnetometer. Sonar measures distance by timing sound waves as they leave and return to a ship after bouncing off surrounding objects. Sonar enables scientists to measure distances from the ocean surface to the seafloor more accurately and efficiently than the rope depth-soundings of the Challenger era. The magnetometer, originally developed to detect the metal hulls of submarines, is used by oceanographers to measure the magnetic properties of the seafloor. These measurements have enhanced our understanding of Earth's magnetic core" (as cited in Deep Dive into Oceanography, n.d.).

The Ocean Society of India (OSI) established in 2002 with the mission to share knowledge and experience of individuals, research institutions, and industrial organizations working on Ocean Sciences. Various universities across the world now have well established departments of Oceanography. Researchers, scientists, and students from various subject fields collaborate to study Oceanography. Even collaborations between or among disciplines like Physics, Chemistry, Biology, geography etc. are marked from journals related to oceanography.

This collaborative works, the presence or involvements of various subjects, continuous research all resulted in 'Oceanography' to come out as separate subject field now having its own theories, principles and hypothesis.

This chapter has detailed the landmark developments of the selected interdisciplinary subjects and attempted to trace the typology of relations that are identifiable at a particular stage. The typologies identified are specific to the studied subject and varies from one to another depending upon the pace of development. The reflection of these typologies in the classificatory devices have been dealt in Chapter 7 'Analysis and Findings'.

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Chapter 6
Reflections in Classificatory Devices

6.1 Introduction

This chapter shows how selected interdisciplinary science subjects got reflected in various editions of DDC, UDC and CC. For the purpose of the study all the twenty-three editions of DDC and all the seven editions of CC has been selected. For UDC three editions viz International Medium Edition of 1985 and 1993 and the 2005 Standard edition has been selected. A through study has been done of all the editions of all the schemes to find out the class numbers assigned as well as any other relevant class number that were relevant to the objective of this chapter. The interdisciplinary subjects studied have been arranged alphabetically categorised under their final mode of subject formation viz: Fusion, Distillation and Clustering.

Fusion

6.2 Astrobiology

This section shows the reflection of the subject Astrobiology in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 5: Reflection of Astrobiology in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Astrobiology
1st	1876	-	-	521 Plurality of Worlds (Index)
2nd -14th	1885-1942	520 Astronomy	523 Descriptive Astronomy 523.1 Universe	523.13 Plurality of Worlds
15th	1951	-	-	-
16th	1958	520 Astronomy and Allied Sciences	523 Descriptive Astronomy & Astrophysics 523.1 Physical Universe	523.13 Plurality of Worlds
17th	1965	520 Astronomy and Allied Sciences	523 Descriptive Astronomy 523.1 Physical Universe. (Cosmology)	523.13 Astrobiology
18th	1971	570 Life Science	574 Biology 574.9 Geographical Treatment	574.999 Astrobiology
19th - 20th	1979 - 1989	570 Life Science	574 Biology 574.9 Geographical Treatment of Organisms	574.999 Astrobiology
21st -22nd	1996-2003	Life Sciences. Biology 570	576 Genetic and Evolution 576.8	576.839 Extraterrestrial life (Class here Astrobiology)

			Evolution 576.83 Origin of Life	
23rd	2011	Biology 570	576 Genetic and Evolution 576.8 Evolution 576.83 Origin of Life	576.839 Extraterrestrial life (Class here Astrobiology)

From table 5 it is observed that the term 'Astrobiology' first got included in 17th edition of DDC i.e., in 1965 having the class number 523.13 where the base number 523 represented 'Descriptive Astronomy' and 523.1 represented 'Physical Universe. Cosmology'. The main class was 520 'Astronomy and Allied Sciences'.

Prior to this, the subject was represented as 'Plurality of worlds' as an index entry in 1st edition having the class number 521 and as an entry in the main schedule from the 2nd edition having the class number 523.13 under Descriptive Astronomy.

The number remained unchanged till 16th edition except for 15th edition where no representation was found.

From the 18th edition the class number for 'Astrobiology' was shifted to the main class 570 'Life Science'. It was assigned the class number 574.999 where the base number 574 denoted 'Biology', 574.9 represented geographical treatment.

The exact class denoted 'Treatment by Specific Continents, Countries, Localities, Extraterrestrial worlds', Ex: Astrobiology. This class number continued to appear in nineteen (1979) & twentieth (1989) edition of DDC.

From 21st edition the class number, although still under 'Biology' but was once again shifted to class number 576.839 where base number 576 denoted Genetic and Evolution; 576.8 represented 'Evolution' and 576.83 represented 'Origin of Life.

The new class number assigned was representing origin of extraterrestrial life, including 'theory of extraterrestrial origin of life on earth'. In 23rd edition it remained unchanged.

Table 6: Reflection of Astrobiology in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Astrobiology**
International Medium Edition	1985	-	-	-
International Medium Edition	1993	-	-	-
Standard Edition	2005	-	-	-

The class number for Astrobiology was not included in any of the above three editions of UDC. A probable class number as per instruction for class number building could be constructed as 57:52

Table 7: Reflection of Astrobiology in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Astrobiology**
1^{st} -7^{th}	1933-1987	-	-	-

The class number for Astrobiology was not found in any of the editions of Colon Classification. As per the 7^{th} ed. the class number Astrobiology if constructed would be BYG.

6.3 Astrophysics

This section shows the reflection of the subject Astrophysics in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 8: Reflection of Astrophysics in editions of DDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Astrophysics**
1st -6th	1876-1899	520 Astronomy	521 Theoretical Astronomy	521.1 Celestial Dynamics
7th-14th	1911-1942	520 Astronomy	521 Theoretical Astronomy	521.1 Celestial Dynamics 523 Index
15th	1951	520 Astronomy	521 Theoretical Astronomy	521.1 Celestial Dynamics 523 Descriptive Astronomy. Astrophysics
16th	1958	520 Astronomy and Allied Sciences	521 Theoretical Astronomy 523 Descriptive Astronomy and Astrophysics	521.1 Celestial Dynamics 523.01 Astrophysics
17th	1965	520 Astronomy and Allied Sciences	521 Theoretical Astronomy 523 Descriptive Astronomy 523.01 Physical & Chemical Aspects	521.1 Celestial Dynamics 523.013 Astrophysics
18th – 19th	1971-1979	520 Astronomy and Allied Sciences	521 Theoretical Astronomy 523 Descriptive Astronomy	521.1 Celestial Dynamics 523.01 Astrophysics

20th – 23rd	1989 - 2011	520 Astronomy and Allied Sciences	521 Theoretical Astronomy 523 Specific Celestial Bodies and Phenomena	521.1 Celestial Dynamics 523.01 Astrophysics

The above table shows that the term ‘Astrophysics’ was first included in DDC in the 7th edition (1911) as an index entry having the class number 523. In the main schedule 523 represented ‘Descriptive Astronomy’. The term remained as an index entry upto the 14th edition (1942).

Prior to the 7th edition from edition 2nd to 6th there was no direct representation of Astrophysics however there were class number for ‘Celestial Dynamics’ 521.1 under 521 Theoretical Astronomy. From 7th to 15th edition the subject continued to have the same class number. From 16th edition the term ‘Celestial Dynamics’ was replaced by ‘Celestial Mechanics’ the class number remaining the same.

In the 15th edition the term ‘Astrophysics’ got included in the main schedule having the same class number 523 under the main class 520 Astronomy. In the 16th edition ‘Astrophysics’ was assigned a class number 523.01 which got relocated to 523.013 in the 17th edition and once again was shifted back to 523.01 in the 18th edition.

From 20th edition the class number remained unchanged, however 523 now represents ‘Specific Celestial Bodies and Phenomena’ instead of ‘Descriptive Astronomy’.

Table 9: Reflection of Astrophysics in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Astrophysics**
International Medium Edition	1985-1993	5 Mathematics and Natural sciences	-	52
Standard Edition	2005	5 Mathematics and Natural sciences	-	52

In all the editions of UDC the class number for Astrophysics is 52 under the main class Mathematics and Natural sciences.

Table 10: Reflection of Astrophysics in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Astrophysics**
1st – 3rd	1933 -1950	B9 Astronomy	Personality	B96 B9, P, 6
4th - 6th	1952-1969	B9 Astronomy	Energy	B9:6 B9 [E], 6
7th	1987	B Mathematics C Physics	-	BYC

In the 1st edition to 3rd edition the class number for Astrophysics was B96 where B represented mathematics; B9 represented Astronomy and 6 (Problem or P characteristics) represented 'Physical Astronomy. Astrophysics'.

From 4th to 6th editions the class number was B9:6 and here 6 representing Astrophysics was considered Energy E facet. In the 7th ed. (1987) class number assigned for Astrophysics is BYC where B represent Mathematics and C represents Physics.

From 1st to 6th editions class numbers were built using facet formula but in 7th edition the class number was already enumerated in the main schedule.

6.4 Biochemistry

This section shows the reflection of the subject Biochemistry in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 11: Reflection of Biochemistry in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Biochemistry
1st -2nd	1876-1885	-	-	-
3rd-9th and 12th	1888-1915, 1927	540 Chemistry	-	547 Animal Chemistry (Index) Organic Chemistry
10th-11th	1919- 1922	-	-	-
13th – 14th	1932-1942	570 Biology	574 Physiologic and structural biology	574.19 Biochemistry (Index)
15th	1951	570 Biological Sciences	574 Biology 574.1 Physiology	574.19 Biochemistry
16th – 17th	1958 - 1965	570 Anthropological and Biological Sciences	574 Biology 574.1 Biophysiology 574.19 Physics and chemistry of vital processes	574.192 Biochemistry
18th – 20th	1971 - 1989	570 Life Sciences	574 Biology 574.1 Physiology 574.19 Biophysics and Biochemistry	574.192 Biochemistry
21st - 22nd	1996 -2003	570 Life Sciences Biology	-	572 Biochemistry

23rd	2011	570 Biology	-	572 Biochemistry

The above table shows the class number of Biochemistry first was included in the 13th edition (1932) as an index entry having the class number 574.19 under the main class 570 Biology. This remained unchanged in the 14th edition. Prior to this the subject had a partial representation through the term 'Animal Chemistry' included in the index from 3rd to 9th edition and 12th edition having the class number 547. In 15th edition the subject was included in the main schedule having the same class number under the class 574.1 Physiology having main class 570 Biological Sciences. In the 16th and the 17th editions the class number was shifted to 574.192 where 574.1 represented 'Biophysiology' and 574.19 'Physics and Chemistry of Vital Processes'. From 18th-20th edition although the class number remained unchanged but 574.19 now represented 'Biophysics and Biochemistry'.

From 21st edition Biochemistry was assigned a distinct class number 572 in the thousand sections of DDC under the main class 570 Biology. This class number remained same in the 23rd edition.

Table 12: Reflection of Biochemistry in editions of UDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Biochemistry
International Medium Edition	1985	57 Biological Sciences in General	-	577 Biochemistry
International Medium Edition	1993	57 Biological Sciences in General	-	577 Biochemistry
Standard Edition	2005	57 Biological Sciences in General	-	577 Biochemistry

The above table reveals that in all three editions of UDC the class number for Biochemistry i.e., 577 remained unchanged placed under the main class 57 (Biological Sciences in General).

Table 13: Reflection of Biochemistry in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Biochemistry**
1st – 3rd	1933-1950	E Chemistry	Personality	E7 E, P,7
4th	1952	E Chemistry	Energy	E:7 E [E], 7
5th - 6th	1957 -1969	E Chemistry G Biology	Specials	E9G
7th	1987	GX Biology	-	GX

From 1933 – 1950 (1st to 3rd edition) E7 was the class number for Biochemistry in which E represented chemistry and 7 was the Foci in Problems or P facet representing biochemistry. In 4th edition i.e., in 1952 the class number became E:7 where 7 representing Biochemistry was now the Energy or E facet of Chemistry. From 1st to 4th editions class number for Biochemistry was built using facet sequence. The class number for 5th and 6th edition (1957-1969) representing Biochemistry as a 'Special' under chemistry was E9G. In the 7th edition (1987) it was given a class number GX as a primary basic subject. Here Biology is the main class for Biochemistry denoted by G.

6.5 Bioinformatics

This section shows the reflection of the subject Bioinformatics in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 14: Reflection of Bioinformatics in editions of DDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Bioinformatics**
1st -23rd	1876 - 2011	-	-	-

From the above table it is observe that 'Bioinformatics' was neither mentioned in index nor in main schedule.

Table 15: Reflection of Bioinformatics in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Bioinformatics**
International Medium Edition	1985-1993	-	-	-
Standard Edition	2005	57 Biological Science in General	575 General Genetics, General Cytogenetic 575.1 Heredity. Inheritance 575.11 Nuclear Inheritance	575.112

It is found from the above table that only 'Standard Edition' of 2005 included Bioinformatics under the main class 57 (Biological Science in General) and this class number of the latest edition is 575.112

Table 16: Reflection of Bioinformatics in editions of CC

Edition	**Year**	**Main Class**	**Facet**	**Bioinformatics**
1st – 7th	1933-1987	-	-	-

The class number for Bioinformatics was not found in all editions of CC.

6.6 Biomechanics

This section shows the reflection of the subject Biomechanics in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 17: Reflection of Biomechanics in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Biomechanics
1-17th	1876	-	-	-
2nd	1885	-	-	591.7 Animal Locomotion (Index)
3rd – 6th	1888-1899	610 Medicine	612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	591.7 Animal Locomotion (Index) 612.76 Locomotion
7th – 12th	1911-1927	610 Medicine	612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	591.7 Animal Locomotion (Index) 612.76 Locomotion 612.776 Human Locomotion 612.767 Animal Locomotion
13th	1932	610 Medicine	612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	581.18663 Plant Locomotion (index) 591.7 Animal Locomotion (Index) 612.76 Locomotion 612.776 Human Locomotion 612.767

				Animal Locomotion
14th	1942	610 Medicine	612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	591.7 Animal Locomotion (Index) 612.76 Locomotion 612.776 Human Locomotion 612.767 Animal Locomotion
15th	1951	610 Medicine	612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	591.7 Animal Locomotion (Index) 612.76 Locomotion
16th -17th	1958-1965	570 Anthropological Sciences & Biological Sciences 610 Medicine	574.1 Biophysiology 612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	574.18 Response to Stimuli including motion, Locomotion 591.7 Animal Locomotion (Index) 612.76 Locomotion
18th – 20th	1971-1989	570 Life Sciences	574 Biology 574.1 Biophysiology. Movements & Control Mechanism	574.18 Locomotion

		590 Zoological Sciences 610 Medicine	591 Zoology 591.1 Physiology of animals 591.18 Movements. Senses, Control Mechanisms 591.185 Motor System and Integument 612 Physiology 612.7 Function of Motor & Vocal Apparatus & Skin	591.185 2 Motor System Includes Locomotion. Biomechanics 612.76 Locomotion
21st – 23rd	1996-2011	570 Biology 610 Medicine & Health	571 Physiology and Related Subject 571.4 Biophysics 612.7 Function of Motor & Vocal Apparatus & Skin	571.43 Biomechanics 573.79343 Locomotion 612.76 Human Locomotion

The above table shows the reflection of Biomechanics in DDC. The term was first included in the 18th edition of DDC which was published in 1971. The class number was 591.185 2 and the main class was Zoological Sciences. The class number remained unchanged till 20th edition. From 1996 i.e., 21st ed. The class number shifted to to 571.43 and remained same till the latest edition. Also it can be observed that prior to the inclusion of the term Biomechanics; the term 'Locomotion' which partially represent Biomechanics have got reflected from the 2nd edition either as simple motor locomotion or as animal, plant, human locomotion. The class numbers were scattered under the main class Botany, Zoology, Biology and Medicine.

Table 18: Reflection of Biomechanics in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Biomechanics**
International Medium Edition	1985 - 1993	-	-	-
Standard Edition	2005	-	-	-

Class number for Biomechanics was not found in any three editions of UDC.

Table 19: Reflection of Biomechanics in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Biomechanics**
1st – 7th	1933-1987	-	-	-

Class number for Biomechanics was not found in any seven editions of CC. A probable class number according to 7th edition would be GWB

6.7 Biophysics

This section shows the reflection of the subject Biophysics in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 20: Reflection of Biophysics in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Biophysics
1st – 12th	1876-1927	-	-	-
13th – 14th	1932 -1942	-	Index Entry	574.1
15th	1951	570 Biological Sciences	574 Biology 574.1 Physiology 574.19 Biochemistry	574.191
16th	1958	570 Anthropological and Biological Sciences	574 Biology 574.1 Biophysiology 574.19 Physics and chemistry of vital processes	574.191
17th	1965	570 Anthropological and Biological Sciences	574 Biology 574.1 Physiology 574.19 Physics and chemistry of vital processes	574.191
18th – 20th	1971-1989	570 Life Sciences	574 Biology 574.1 Physiology 574.19 Biophysics and Biochemistry	574.191
21st	1996	570 Life Sciences Biology	571 Physiology and Related Subject	571.4

22nd	2003	570 Life Sciences Biology	571 Physiology and Related Subject	571.4
23rd	2011	570 Biology	571 Physiology and Related Subject	571.4

The term 'Biophysics' was mentioned as an index entry from 1932 i.e., 13th ed. having the class number 574.1 and upto 14th ed. it remained unchanged. For the first time in the 15th edition (1951.) it was added in main schedule and the class number assigned was 574.191 which remained same till 20th ed.

From 21st ed. the class number changed to 571.4 and remained unchanged till latest edition with 570 as the main class of DDC for all the editions.

Table 21: Reflection of Biophysics in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Biophysics**
International Medium Edition	1985	570 Biology	577 Material Bases of Life. Biochemistry. Molecular Biology. Biophysics	577.3
International Medium Edition	1993	570 Biology	577 Material Bases of Life. Biochemistry. Molecular Biology. Biophysics	577.3
Standard Edition	2005	570 Biology	577 Material Bases of Life. Biochemistry. Molecular Biology. Biophysics	577.3

In all the above three editions (published from 1985-2005) class number 557.3 was assigned to Biophysics under the main class 570 i.e., Biology.

Table 22: Reflection of Biophysics in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Biophysics**
1st -6th	1933-1969	-	-	-
7th	1987	G Biology C Physics	-	GWC

Class number for Biomechanics was not found in first six editions of CC. But in 7th edition GWC represented it where G represented Biology and C represented Physics.

6.8 Geochemistry

This section shows the reflection of the subject Geochemistry in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 23: Reflection of Geochemistry in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Geochemistry
1st	1876	-	-	-
2nd -9th	1885-1915	550 Geology	551 Physical and Dynamical Geology	551.9 Agents of Geological work
10th	1919	550 Geology	551 Physical and Dynamic Geology including Geophysics and Geochemistry	551.9 Geochemistry (index)
11th-14th	1922-1942	550 Geology	551 Physical and Dynamic Geology including Geophysics and Geochemistry 551.9 Agents of Geological Work	551.94
15th	1951	550 Earth Sciences	551 Physical and Dynamic Geology causes and processes of geological change includes Geophysics, Geochemistry	551 (no separate no.)
16th	1958	550 Earth Sciences	551 Geophysics	551.9
17th	1965	550 Earth Sciences	551 Physical and Dynamic Geology	551.9
18th	1971	550 Sciences of the earth and other worlds	551 Physical and Dynamic Geology	551.9

19th	1979	550 Sciences of the earth and other worlds	551 Geology, Meteorology, General Hydrology	551.9
20th – 23rd	1989 - 2011	550 Earth Sciences	551 Geology, Hydrology, Meteorology	551.9

Geochemistry was included from 10th ed. (1919). Before that from 2nd ed. to 9th ed. the class number now assigned to Geochemistry represented 'Agents of Geological work'. 551.9 was the class number until 11th ed. From 11th – 14th ed. (1922-1942) 551.94 was treated as 'Geochemistry'. Till 14th ed. 550 class i.e., Geology was the main class for Geochemistry. From 15th ed. to 17th ed. and 20th – 23rd editions. 550 was renamed as 'Earth Sciences'. 500 class of 18th and 19th editions was named as 'Sciences of the earth and other worlds'.

No separate class no. was given in 1951 to Geochemistry. It was mentioned under 551. But again from 16th to 23rd editions it was assigned a separate class number that is 551.9.

Table 24: Reflection of Geochemistry in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Geochemistry**
International Medium Edition	1985-1993	55 Earth Sciences. Geology. Meteorology etc.	550 Ancillary Sciences of Geology etc	550.4
Standard Edition	2005	55 Earth Sciences-Geological Sciences	550 Ancillary Sciences of Geology etc	550.4

In UDC all three editions class no. 550.4 stands for Geochemistry under the main class 55 (Earth Sciences. Geology. Meteorology etc.).

Table 25: Reflection of Geochemistry in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Geochemistry**
1st -7th	1933-1987	-	-	-

From the above table, it is observed that Geochemistry was not included in any edition of CC. A probable class number according to 7th edition would be HWT.

6.9 Geophysics

This section shows the reflection of the subject Geophysics in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 26: Reflection of Geophysics in editions of DDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Geophysics**
1st -9th	1876-1915	-	-	-
10th - 14th	1919-1942	550 Geology	551 (Physical and Dynamic Geology)	551 Geophysics
15th	1951	550 Earth Sciences	551 (Physical and Dynamic Geology)	551 Geophysics
16th	1958	550 Earth Sciences	551 (Physical and Dynamic Geology)	551 Geophysics
17th	1965	550 Earth Sciences	551 (Physical and Dynamic Geology)	551 Geophysics
18th	1971	550 Sciences of the earth and other worlds	551 (Physical and Dynamic Geology)	551 Geophysics
19th	1979	550 Sciences of the earth and other worlds	551 (Physical and Dynamic Geology)	551 Geophysics
20th – 23rd	1989 -2011	550 Earth Science Class here Geophysics		550 Geophysics

Though from 1919 (10th ed.) Geophysics was added in DDC but class no for it was assigned separately in any of the editions. It has been classed with the main class 550 Earth Science with an instruction to class Geophysics.

Table 27: Reflection of Geophysics in editions of UDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Geophysics
International Medium Edition	1985	55 Earth Sciences. Geology. Meteorology etc	550 Ancillary Sciences of Geology etc.	550.3
International Medium Edition	1993	55 Earth Sciences. Geology. Meteorology etc 55	550 Ancillary Sciences of Geology etc.	550.3
Standard Edition	2005	55 Earth Sciences. Geological Sciences	550 Ancillary Sciences of Geology etc.	550.3

From the above table it is cleared that 550.3 was the class no. for Geophysics for all above three editions of UDC.

Table 28: Reflection of Geophysics in editions of CC

Edition(s)	Year(s)	Main Class	Facet	Geophysics
1-6th	1933-1969	-	-	-
7th	1987	H Geology	-	HV

Class no. for Geophysics i.e. HV is found only in 7th ed. (1987) of CC where H represents Geology.

Distillation

6.10 Microbiology

This section shows the reflection of the subject Microbiology in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 29: Reflection of Microbiology in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Microbiology
1st	1876	-	-	-
2nd	1885	580 Botany	589 Thallophyta 589.9 Achlorophyllaceae	589.95 Schizomycetes. Bacteria. Mocrobes.
3rd -6th	1888-1899	(Also Includes all the class numbers as sown in 2nd edition)		
		610 Medicine	614 Public Health 614.4 Contagious & Infectious Diseases	614.41 Causes and Origin
7th – 9th	1911-1915	(Also Includes all the class numbers as sown in 2nd, 3rd-6th edition)		
		610 Medicine	612 Physiology 612.336 Pathological Changes of Intestinal Secretion	612.3363 Parasites and Microbes
10th – 12th	1919-1927	(Also Includes all the class numbers as sown in 2nd, 3rd-9th edition)		
		630 Agriculture	631.4 Land and Soil	631.46 Soil Bacteriology: Microbes, ferments, sterilizarion
13th -14th	1932-1942	(Also Includes all the class numbers as sown in 3rd-9th edition)		
		580 Botany	589 Thallophyte 589.9 Achlorophyllaceae	589.95 Schizomycetes Bacteriacles, Fission Fungi, Bacteria, Microbes, Bacteriology
15th	1951	570 Biological Sciences 580 Botany 630 Agriculture	589.9 Bacteriology 631.4 Land Soil	576 Microbiology 631.46 Microbiology of Soil

16th	1958	570 Anthropological and Biological Sciences 610 Medical Sciences	616 Medicine	576 Microbiology 616.01 Medical Microbiology 631.46 Microbes of Soil
17th	1965	(Also Includes all the class numbers as sown in 16th edition)		
		570 Anthropological and Biological Sciences 660 Chemical Technology and Related Industries		576 Microbiology 576.16 Economic Microbiology 660.6 Industrial Microbiology
18th - 20th	1971-1989	(Also Includes all the class numbers as sown in 16th & 17th edition)		
		570 Life Sciences		576 (Microbes class here Microbiology) (Includes Economic Microbiology – 576.16; Food Microbiology-576.163)
21st	1996	570 Life Sciences Biology	-	579 (Microorganisms, fungi, algae Class here Microbiology) 616.01 Medical Microbiology
22nd – 23rd	2003-2011	570 Life Sciences Biology	-	579 (Microorganisms, fungi, algae Class here Microbiology) 616.9041 Medical Microbiology 664.001579 Food Microbiology

From 1951 i.e. 15th ed. of DDC the term Microbiology was assigned the class number 576. Until 1965 (17th ed.) it remained unchanged. From 1971 the name of the class 576 was changed to ‘Microbes’ with the instruction (class here Microbiology). Till

20th editions it remained unchanged. From 21st editions class no. 576 changed to 579 where Microbiology was mentioned under 'Microorganisms, fungi, algae' again with instruction to class Microbiology here and continues to remain the same. However, before microbiology was included as a subject the concept of Microbes can be seen to have class number from the 2nd edition. The class numbers have been scattered under the main classes Botany, Medicine and Biology.

Table 30: Reflection of Microbiology in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Microbiology**
International Medium Edition	1985	57 Biological Sciences in General	-	579
International Medium Edition	1993	57 Biological Sciences in General	-	579
Standard Edition	2005	57 Biological Sciences in General	-	579

The class number 579 under the main class 57 (Biological Sciences in general) represents Microbiology for all the editions of UDC.

Table 6.31: Reflection of Microbiology in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Microbiology**
1st	1933	-	-	-
2nd - 3rd	1939-1950	I Botany	Personality	I21 I, N, 21 Microbes
4th-6th	1952-1957	I Botany	Personality	I21 I, [P], 21 Microbes
7th	1987	G Biology	-	GV Microbiology

In Colon Classification the class number for Microbiology i.e. GV is found only in 7th ed. (1987) where G represents Biology. Prior to it the concept of Microbes got represented as personality facet of Botany in 2-6th edition of CC

6.11 Molecular Biology

This section shows the reflection of the subject Molecular Biology in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 32: Reflection of Molecular Biology in editions of DDC

Edition(s)	Year(s)	Main Class	Hierarchical Sub-divisions	Molecular Biology
1st	1876	-	-	-
2nd -12th	1885-1927	570	575 Evolution	575.1 Heredity
13th - 14th	1932-1942	570 Biology	575 Evolution Molecular	575.1 Heredity 575.1132 Mendel's law 577.23 Molecular Life
15th- 16th	1951-1958	570 Biological Sciences	575 Evolution	575.1 Genetics 575.11 Laws of Heredity (Mendel's law) (Chromosome Theory) 613.9
17th-	1965	570 Anthropological & Biological Sciences	573 Physical Anthropology 575 Evolution	573.2 Organic Evolution and Genetics of Man 573.21 Human Genetics 575.1 Genetics 575.11 Laws of Heredity (Mendel's law) (Chromosome Theory)

18th	1971	570 Life Sciences	574 Biology 574.8 Tissue, cellular, molecular biology	574.8732 Nucleus Including DNA 574.88 Molecular Biology
19th – 20th	1979-1989	570 Life Sciences	574 Biology 574.8 Tissue, cellular, molecular biology	574.873282 DNA 574.873282 RNA 574.88 Molecular Biology
21st	1996	570 Life Sciences Biology	572 Biochemistry	572.8
22nd	2003	570 Life Sciences Biology	572 Biochemistry	572.8 Biochemical genetics Class here Molecular Biology
23rd	2011	570 Biology	572 Biochemistry	572.8

From the above table it is evident that from 1971 (18th ed.) Molecular Biology was added in DDC. From 18th ed. to 20th ed. 574.88 represented the subject Molecular Biology under the class Life Sciences / Biology i.e. 570. The class for Molecular Biology under 574 i.e., Biology changed its position to 572 i.e., Biochemistry from 21st edition and the new class number assigned was 572.8 It remains same in the latest edition also. Prior to its inclusion various terms like ‘Heredity’, ‘Mendel’s Law’ ‘Human Genetics’ that are part of Molecular Biology and allied subjects can be found to have their representation.

Table 33: Reflection of Molecular Biology in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Molecular Biology**
International Medium Edition	1985	57 Biological Sciences in General	577 Materials bases of Life. Biochemistry. Molecular Biology. Biophysics	577.2

International Medium Edition	1993	57 Biological Sciences in General	-	577
Standard Edition	2005	57 Biological Sciences in General	577 Materials bases of Life. Biochemistry. Molecular Biology. Biophysics	577.2

The class no. 577.2 under the main class 57 (Biological Sciences in general) represents Molecular Biology for all the editions of UDC.

Table 34: Reflection of Molecular Biology in editions of CC

Edition	**Year**	**Main Class**	**Facet**	**Molecular Biology**
1st -7th	1933-1987	-	-	-

From the above table, it is cleared that Molecular Biology was not mentioned in CC. A probable class number according to 7th edition would be GWA.

Clustering

6.12 Environmental Science

This section shows the reflection of the subject Environmental Science in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 35: Reflection of Environmental Science in editions of DDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Environmental Science**
1st -23rd	1876-2011	-	-	-

Class number for Environmental Sciences was not found in any of the editions of DDC.

Table 36: Reflection of Environmental Science in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Environmental Science**
International Medium Edition	1985	5 Mathematics and Natural Sciences	-	504
International Medium Edition	1993	5 Mathematics and Natural Sciences	-	504
Standard Edition	2005	5 Mathematics and Natural Sciences	-	502/504

Class number for Environmental Science found in International Medium edition i.e., 502/504 was found in UDC standard edition 2005.

Table 37: Reflection of Environmental Science in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Environmental Science**
1st -7th	1933-1987	-	-	-

Class number for Environmental Science was not found in any editions of CC.

6.13 Oceanography

This section shows the reflection of the subject Environmental Science in various edition of DDC, UDC, CC and traces the changes that its representation has undergone.

Table 38: Reflection of Oceanography in editions of DDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Oceanography**
1 – 13th	1876-1932	-	-	
14th	1942	-	-	551.46 index
15th	1951-2011	550 Earth Sciences	551 Physical and Dynamic Geology 551.4 Physiography	551.46 Oceans and Oceanography
16th	1958	550 Earth Sciences	551 Geophysics 551.4 Geomorphology and physical geography	551.46 Oceanography
17th	1965	550 Earth Sciences	551 Physical and Dynamic Geology 551.4 Geomorphology	551.46-551.47
18th	1971	550 Sciences of the earth and other worlds	551 Physical and Dynamic Geology 551.4 Geomorphology	551.46 Oceans and Seas (Oceanography)
19th	1979	550 Sciences of the earth and other worlds	551 Geology, Meteorology, general Hydrology 551.4 Geomorphology and general Hydrology	551.46 Oceanography

20th	1989	550 Earth Sciences	551 Geology, Hydrology, Meteorology 551.4 Geomorphology and Hydrosphere	551.46 Hydrosphere Oceanography
21st	1996	550 Earth Sciences	551 Geology, Hydrology, Meteorology 551.4 Geomorphology and Hydrosphere	551.46 Hydrosphere Oceanography
22nd	2003	550 Earth Sciences	551 Geology, Hydrology, Meteorology 551.4 Geomorphology and Hydrosphere	551.46 Hydrosphere and Submarine Geology Oceanography
23rd	2011	Earth Sciences 550	551 Geology, Hydrology, Meteorology 551.4 Geomorphology and Hydrosphere	551.46 Oceanography and Submarine Geology

From the table 38 it is clear that 551.46 was mentioned in index as Oceanography in the 14th edition. From 15th ed. this term was added under 551.46 in main schedule and remained same till 2011 (23rd ed.).

Table 39: Reflection of Oceanography in editions of UDC

Edition(s)	**Year(s)**	**Main Class**	**Hierarchical Sub-divisions**	**Oceanography**
International Medium Edition	1985 - 1993	55 Earth Sciences. Geology. Meteorology etc.	550 Ancillary Sciences of Geology etc. 551.4/.4 General Geology 551.4 Geomorphology. Study of Earth's Physical Form	551.46 (Physical Oceanography)

Standard Edition	2005	55 Earh Sciences, Geophysical Sciences	551 General Geology. Meteorology. Climatology. Historical Geology. Stratigraphy. Paleogeography 551.4 Geomorphology. Study of Earth's Physical Form	551.46 (Physical Oceanography. Submarine Topology. Ocean Floor)

From the above table it is evident that the term 'Oceanography' is not clearly mentioned in any of the UDC editions but 551.46 represents Physical Oceanography in all three editions of UDC.

Table 40: Reflection of Oceanography in editions of CC

Edition(s)	**Year(s)**	**Main Class**	**Facet**	**Oceanography**
1st -3rd	1933-1950	U Geography	Personality	U25 U,P,25
4th - 6th	1952-1969	U Geography	Personality	U25 U[P],25
7th	1987	U Geography	Personality	U2,57 U2 (1P1)

From table 40 it is evident that in CC from 1st edition Oceanography was included. From 1933 1st ed. to 1969 6th ed. class no. U25 was used as Oceanography where U represents Geography. In 1987 (7th ed.) U2, 57 is mentioned as Oceanography.

From 1st to 6th editions class numbers were built using the facet sequence of the class Geography but in 7th editions in-built class number for Oceanography was given in the main schedule.

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Chapter 7
Analysis and Interpretations

7.1 Introduction

This chapter deals with the analysis and interpretation of the collected data as reflected in Chapter 5 (Interdisciplinary Subjects in Science: A Study) and Chapter 6 (Reflections in Classificatory Devices). The data collected are analysed and interpreted keeping in mind the objectives of the research as enumerated in chapter 1. The first section represents the stages of development and their corresponding typology of relation; the second section discusses how the stages and typology of relations have been reflected in the classificatory devices; the third section makes a comparative study of the latest edition of classification scheme in terms of the incorporation of the subject; and the fourth section shows the growth of literary warrant of the selected subjects.

7.2 Data analysis and interpretations

7.2.1 Stages of developments and typology of relations

The major stages of developments of an interdisciplinary subjects and typology of relation existed at each stage is shown here.

Table 41 Stages of developments and typology of relations

Subjects	**Stages of developments (Years) and typology of relations (Modes of Formation of Subject)**			
Name	**Pre-Loose Assemblage**	**Loose Assemblage**	**Lamination**	**Fusion**
Astrobiology	Till 1934	1935-1974	1975-1997	1998 Onwards
Astrophysics	Till 1686	1687-1919	1920-1962	1963 Onwards
Biochemistry	Till 1751	1752-1832	1833-1904	1905 Onwards
Bioinformatics	Till 1961	1962-1984	-	1985 Onwards
Biomechanics	Till 1678	1679-1881	1882-1966	1967 Onwards
Biophysics	Till 1785	1786-1888	1889-1956	1957 Onwards
Geochemistry	Till 1762	1763-1903	1904-1949	1950 Onwards
Geophysics	Till 1686	1687-1838	1839-1918	1919 Onwards
Name	**Pre-Lamination**	**Lamination**	**Towards Distillation**	**Distillation**
Microbiology	Till 1856	1857-1881	1882-1944	1945 Onwards
Molecular Biology	Till 1921	1922-1943	1944-1960	1961 Onwards
Name	**Pre Clustering**		**Towards Clustering**	**Clustering**
Environmental Science	Till 1926		1927-1970	1971 Onwards
Oceanography	Till 1846		1847-1974	1975 Onwards

The above table reflects the typology of relation that is the modes of subject formation as identified in each stage of the growth of the selected subjects.

It can be observed that the interdisciplinary subjects that were ultimately formed through ‘Fusion’ reflects two more stages viz: Loose Assemblage and Lamination in the course of their formation. However, for each of the subject the stages are varying. Also, the span for each of the typology of relation is not similar for all subjects. For example, in ‘Biochemistry’ the period for Loose Assemblage lasted from 1752-1832; Lamination from 1833-1904; and became a Fused subject from 1905 onwards. But for Astrobiology although the three modes are same but its span for Loose Assemblage was from 1935-1974: followed by Lamination from 1975-1997 and finally Fusion from 1988 onwards.

For subjects that came out of Distillation, two distinct ‘typology of relations’ can be identified ‘Lamination’ and ‘Distillation’. They also reflect an intermediatory stage (Towards Distillation) where the subject although still in the lamination mode shows enough evidence that Distillation might take place. From the above table it can be observed that Molecular Biology distilled out as a subject from the year 1961 whereas Microbiology distilled out from the year 1945.

In subjects formed out of Clustering the stages of development included a Pre-clustering and Towards clustering stage that ultimately led to the final mode that is ‘Clustering’ of the subject. Incase of a clustered subject as the subjects initially developed under different individual science subjects so identifying a particular typology of relation at a given timeframe is not possible. Any entity after being studied for a prolonged period in different subjects gains certain literary warrant that ultimately leads to the emergence of a new interdisciplinary subject clustered around the entity studied.

So, it is evident that any interdisciplinary interaction has their own course of genesis and development, that they go through, to come out as a distinct interdisciplinary subject.

7.2.2 Reflections of Stages and Typology of relations in Classificatory devices

In this section the above identified (table 7.1) typology of relations is compared with DDC, UDC and CC to show reflections of the identified typology of relation of interdisciplinary subjects in library classification schemes.

Astrobiology:

- The subject Astrobiology initially got reflected by the term ‘Plurality of the world’ in DDC from its 1st to 16th edition that is till 1958. The tracing of the history of the subject reveals that the concept of plurality of world was practiced before the scientific concept of Astrobiology emerged. From 1935-1974 the subject astrobiology was in a state of Loose Assemblage. It was during this period that the term got included in the 17th edition of DDC that is in the year 1965 under the main class Astronomy. However, in the 18th edition (1971) the class number got shifted to 574.99 under the main class Biology. History of the subjects reveals that around this period the focus of Astrobiology was to identify extra-terrestrial life. Thus, the class number representing Geographic treatment of extraterrestrial life is to a greater extent in conformity with the subject development. Between 1975-1997 the subject was in a state of lamination. This included experiments to find conditions that are favourable for microbial survival in extra-terrestrial world. In 1996 the class number again got shifted to 576.839 representing extraterrestrial life under ‘Origin of life’ classed under the main class 576 ‘Genetics and Evolution’. Thus, once again the shift in the class number was in co-ordination with the development of the scope of the subject. The period of fusion began in 1998 and although Astrobiology has now emerged as distinct subject, however the class number continues to be same.

- No reflection was found in UDC and CC.

Astrophysics:

- Before Astrophysics began to emerge as a subject, most of the interaction between Physics and astronomy involved planetary or celestial motion. In DDC from 1st to 6th ed. 521.1 under Theoretical Astronomy’ class number has been provided for ‘Celestial Dynamics’. The period from 1687 – 1919 the subject Astrophysics was in a state of Loose Assemblage and included studies involving Spectroscopic observation, measurement of Stellar parallax as well as Steller classification. All these developments led to the inclusion of 'Astrophysics' in 1911 into DDC as an index entry. It remained so till 1942 14^{th} ed. However, by this time, the subject was already into a state of 'Lamination' and so in 1951 was assigned class number in the main schedule under Descriptive Astronomy'. Until 1962 it remained in a state of lamination and involved application of various aspects of Physics viz. x-ray, radio waves, Gama Rays, Nuclear reactions to understand Astronomical phenomenon. In 1963 Astrophysics entered into a state of Fused subject. In 1965 Astrophysics was assigned the number 523.013 under 523.01 'Physical and Chemical Aspects' of astronomy reflecting the developments in Astrophysics. By 1989 Astrophysics was now representing in DDC 'Specific Celestial Bodies' and phenomena and this resulted out of the constant persuade of Astrophysics to study the physical features of specific celestial bodies. Thus, it can be said that incase of 'Astrophysics' DDC has been to a large extent able to reflect the development of the subject through its representation.

- In UDC Astrophysics was represented in all the three editions with the class number 52 under 5 Mathematics and Natural Science. It had no significant relocations to reflect subject development.

- In CC Astrophysics was first incorporated in the 1^{st} ed, that is in 1933 when the subject was in a Lamination stage. The class number assigned represented a compound subject having the class number B96 This continued until the 6^{th} ed. i.e. 1969. By this time, as Astrophysics was a fused subject so the 7^{th} ed., it was assigned the class number B7C.

Biochemistry:

- Developments of Biochemistry almost proceeds any attempt of classification using a scheme. As a result, its full incorporation is true sense took some time. The subject biochemistry was indexed in DDC in the 13th edition (1932) with the class number 574.19 under the class 574 "Physiologic and Structural Biology". At this time the subject was already at a stage of Fusion. However, it remained under Physiology until 20th century and was not identified as a Primary Basic Subject. The changes that came were in its scope of representation. In the 21st edition it was given the class number 572 directly under 570 'Life Science. 'Biology'. Although the subject was well developed long ago and was already being taught in Universities and Colleges, it took a long time to assign it with a class number as a Primary Basic Subject.

- In UDC in all three editions it was represented by 577 and was included when the subject was already in a state of Fusion.

- In CC for the first three editions, it was represented as a complex subject although by 1933 it was already a well-developed subject. In the 4th edition (1952) it was accorded the status of a compound subject under the main class Chemistry. From 1957-1969 it was represented as a special under Chemistry. So, it was a non-primary basic subject. Finally in the 7th edition it was given the status of a Primary Basic Subject. Although historical development shows Biochemistry had already emerged as a fused subject by 1933, but its recognition took a long time. Only after considerable development in its scope, its growing importance in other subjects like genetics, microbiology, molecular biology the subject was represented as a Primary Basic Subject in CC.

Bioinformatics:

- Bioinformatics as a subject is a much more recent one and its history shows it emerged as a fused subject from 1985. The class number for Bioinformatics is not assigned in either DDC or CC.

- However, in UDC a class number is assigned to Bioinformatics i.e., 575.112 placed under 575.11 Nuclear Inheritance under 575 General Genetics in the 2005 edition (Standard Edition). The period of inclusion is one when it has just begun to come out as a fused subject. Also, its role in Genetics and other related subjects flourished as evident from the traced history.

Biomechanics:

- In DDC Biomechanics was included in the 18th edition that is in the year 1971. By this time the subject has already reached a state of Fusion (1967). However, its incorporation was under 591 Zoology and 591.01 Physiology of animals having the class number 591.1852. Prior to its inclusion Biomechanics as a subject mostly was studied by Physiologists and focused on movement of living beings (locomotion) which the class number assigned to it represented clearly. In the 21st edition i.e., 1996 the subject was assigned the class number 571.43 under 571.4 Biophysics. This was mainly because Biomechanics although gained considerable literary warrant, but it is still considered by many as a subfield of Biophysics.

- The subject however had no representation in UDC & CC.

Biophysics:

- The term 'Biophysics' was incorporated in DDC in 1932 as an index entry that is in the 13th edition & remained unchanged in 14th edition. At this time the subject was at a stage of 'Lamination' mode of subject formation. In the 15th ed. (1951) it was assigned a class number in the main schedule, and it was placed under Biochemistry 574.19 having the class numbers 574.191. In the 16th ed. although its class number remained same but 574.19 now represented 'Physics and Chemistry of Vital Processes'. This was because the traced history shows that Biophysics was mostly concerned about applying physics in biological phenomena. The subject emerged as a 'Fused' subject in 1957 however its class number remained unchanged. It changed only in the 21st edition in 1996 and was placed directly under 571 'Physiology'.

- In UDC the class number assigned was 577.3 in all three editions and was assigned under 577 'Material Bases of Life' under the main class 570 Biology.

- In CC the subject was assigned a class number in the 7th edition i.e. in 1987 much after it has emerged as a fused subject. The status accorded to it was of a 'Primary Basic Subject'.

Geochemistry

- Geochemistry has been incorporated in DDC in the 10th ed. that is 1919 as an index term when the subject was at a 'Lamination' mode of subject formation. The class number represented 'Agents of Geological Work'. In the 11th ed. i.e., in 1922 it was assigned class no. 551.94 under 'Agents of Geological Work'. By this time Geochemistry had already emerged as a 'Fused' subject. The development of Geochemistry involved use of Physics' tools. In the 16th ed. (1958) Geochemistry was assigned the class no. 551.9 under Geophysics 551. This number remained unchanged upto 23rd edition. However, the class number 551 became 'Physical and Dynamic Geology' and by 19th edition 'Geology, Meteorology, General Hydrology.

- In UDC Geochemistry was placed under 550 'Ancillary Sciences of Geology' having the class number 550.4.

- However in CC there is no representation of the subject in any edition.A possible class no for the 7th ed. Would be HWT.

Geophysics:

- Geophysics was included in DDC in the 10th edition having the class number 551 under Geology 550. Till 19th edition (1979) it remained unchanged. Tracing the history shows that just prior to its inclusion it was in a mode of 'lamination' and began to emerge as a fused subject. By 20th edition (1989) it was assigned the class number 550 that represented Earth Science (Class here geophysics). History of geophysics revealed that it deals with almost all aspects of geology but only from a perspective of physics. The scope of the subject is therefore vast and this can also be observed from its reflection in DDC as Geophysics has always been given the class number that is similar to Geology or Earth Science.
- In UDC it is found in all three editions having the class number 550.3
- In CC Geophysics has been included in the 7th edition as an interdisciplinary subject having the class number HV under H geology.

Microbiology

- Microbiology was included in DDC in the 15th ed. that is in 1951 when the subject was already in its 'Distillation' mode. It was placed under 570 'Biological Sciences'. The class number remained same upto 20th ed. and was shifted to 579 in the 21st edition and was renamed as 'Microorganisms, Fungi, Algae'. The traced history shows that by 1996 different types of microbes and their role have become an important object of study in different subjects such as Medicine, Genetics, Food Technology etc. However, prior to the inclusion of Microbiology as a subject the concept of 'Microorganisms' had its representation under different classes/subjects. The first inclusion was under the class 580 Botany under which Microbes were represented by the class number 589.95. Along with it from the 3rd edition the concept was also represented under 614.4 'Contagions & Infectious Diseases' (Cases & origin). Around this time microbiology was at a stage of 'Lamination' in which it formed compound subject with different 'Primary Basic Subject' like Medicine. The history shows that around this time two important concepts 'Spontaneous Generation' and

'Germ Theory' of Microbes were at its peak. The 13th ed. 1932 included the term 'Bacteriology'. The inclusion was predeeded by a period when 'Bacteria' was studied extensively by scientists.

- In UDC 'Microbiology' was included in 1985 (Distilled) having the class number 579 and it continues to be the same.

- In CC Microbiology as a subject included in the 7th edition having the class number GV under the class G Biology. By this time the subject has already reached its distilled state. Prior to this the concept of Microbes have found its representation under Botany as the personality facet having the class no. J21 from 2nd - 6th ed.

Molecular Biology

- The subject 'Molecular Biology' was included in DDC in the 18th ed. (1971) when the subject was already in a stage of Distillation'. The class number since then have remained unchanged. The traced history of the subject shows that one of its important concept 'Heredity' was incorporated in the 2nd ed. that is in 1885 when the subject of Molecular Biology did not even begin to form. In the 13th ed. (1932) Mendell's law was assigned the class number 575.1132. By this time the subject of Molecular Biology' was in a stage of 'Lamination' with its focus on Genetics. In the 18th edition (1971) the concept of Nucleus & DNA was given the class number 574.8732. By this time the subject Molecular Biology has already Distilled out as a subject and thus the concept of DNA, RNA was classed under it. From 21st ed. (1996). The class no. shifted to 572.8 and is now represented as 'Biochemical Genetics' under Biochemistry 572.

- In UDC the class number assigned was 577.2 to Molecular Biology & remains same in 2005 edition. The subject was already distilled when first incorporated in UDC.

- In CC however there is no representation for Molecular Biology.

Environmental Science

- Environmental Science has no representation in DDC as well as in CC.

- In UDC it was included in the International medium 1985 and represented by the class number 504 (1985). The subject 'Environmental Science' was clustered and came out as a subject from 1971 onwards, i.e. few years before the inclusion in UDC.

Oceanography

- The subject 'Oceanography' was included in the index of DDC in the 14th edition (1942). The subject was in a state of 'Towards Clustering' during this period. In 15th edition, 'Oceanography' was included in the main schedule placed under 551.4 'Physiology'. In the 17th edition (1965) the class number was shifted to 551.46-47 and was placed under 'Geomorphology' 551.4. By this time the subject has already become clustered and fissioned out as a subject. The class number however remains unchanged.

- In CC Oceanography was included in the 1st ed. (1933) when it was in a pre-clustering stage having the class number U25. The subject was incorporated as a complex subject. By the 7th edition the class number for Oceanography was U2,57 representing a compound subject.

- Thus, from the above discussion it can be observed that incorporation in classification schemes has its bearing on the growth and development of a subject. Also, the inclusion of subjects is not always simultaneously reflected and can also take much longer to accord a subject its rightful position in the scheme.

7.2.3 Comparison of latest editions of Classification Schemes

The latest editions of the three selected library classifications schemes are compared here (using data of chapter 6) to observe the differences present in the coverage of the subjects selected for the study.

Table 42: Comparison of latest editions of Classification Schemes

Subjects	**Library Classification Scheme**		
Name	**DDC (2011)**	**UDC (2005)**	**CC (1987)**
Astrobiology	✓	x	x
Astrophysics	✓	✓	✓
Biochemistry	✓	✓	✓
Bioinformatics	x	✓	x
Biomechanics	✓	x	x
Biophysics	✓	✓	✓
Environmental Sciences	x	✓	x
Geochemistry	✓	✓	x
Geophysics	✓	✓	✓
Microbiology	✓	✓	✓
Molecular Biology	✓	✓	x
Oceanography	✓	✓	✓

From the above table it is observed that out of 12 subjects both DDC 23rd and UDC Standard Edition includes 10 subjects, whereas CC includes only 6 subjects. Although DDC and UDC covered the same number of subjects however the subjects covered by them vary. The two interdisciplinary science subject that was not covered by DDC are Bioinformatics and Environmental Science. On the other hand, UDC did not cover Astrobiology and Biomechanics. Colon Classification 7th edition included only 6 interdisciplinary science subjects viz: Astrophysics, Biochemistry, Biophysics, Geophysics, Microbiology and Oceanography.

So as far as the latest edition of the classification schemes are concerned it is evident that DDC and UDC had the maximum coverage of Subjects. However, none of them are updated enough to accommodate all the interdisciplinary subjects.

7.2.4 Growth of Literary Warrant

In this section each of the selected interdisciplinary subject is tested in terms of their growth of literary warrant. The idea about the growth of literary warrant of subject would aid in understanding the development of the subject as a distinct interdisciplinary subject. For this purpose, the data has been collected from OCLC WorldCat as per the methodology discussed in chapter 1.

Table 43: Growth of Literary Warrant

Subject	**1st inclusion year (DDC/UDC/CC**	**No. of books 10 years before 1st inclusion**		**Last inclusion year (DDC/UDC/CC)**	**No. of books 10 years before last inclusion**	
Astrobiology	1965 (DDC)	1955-1964	16	2011 (DDC)	2001-2010	1252

Astrophysics	1911 (DDC)	1901-1910	132	2011 (DDC)	2001-2010	17265
Biochemistry	1932 (DDC)	1922-1931	776	2011 (DDC)	2001-2010	34974
Bioinformatics	2005 (UDC latest edition)	1995-2004	4117	2005 UDC (latest edition)	2006-2015 (no. of books 10 years after last inclusion)	20402
Biomechanics	1971 (DDC)	1961-70	503	2011 (DDC)	2001-2010	7633
Biophysics	1932 (DDC)	1922-31	86	2011 (DDC)	2001-2010	8421
Environmental Science	1985 (UDC)	1975-1984	4645	2005 (UDC)	1995-2004	11847
Geochemistry	1919 (DDC)	1909-1918	66	2011 (DDC)	2001-2010	10638

Geophysics	1919 (DDC)	1909-1918	131	2011 (DDC)	2001-2010	12832
Microbiology	1951 (DDC)	1941-1950	1101	2011 (DDC)	2001-2010	30282
Molecular Biology	1971 (DDC)	1961-1970	4395	2011 (DDC)	2001-2010	53805
Oceanography	1942 (DDC)	1932-1941	755	2011 (DDC)	2001-2010	17904

The above table shows that in the span of 10 years prior to its inclusion in DDC the subject ‘Astrobiology’ had only 16 books in the WorldCat whereas in the span of 10 years before the latest edition it had 1252 books. For Astrophysics the number of books prior to its first inclusion was 132 which increased to 17265 for the span of 10 years before the latest edition. For Biochemistry the growth has been from 776 to 34974 books. Similarly, the growth for Biomechanics has been from 503 to 7633; for Biophysics from 86 to 8421; for EVS from 4645 to 11847; for Geochemistry from 66 to 10638; Geophysics 131 to 12832; Microbiology 1101 to 30282; Molecular Biology from 4395 to 53805 and Oceanography from 75 to 17904.

The only exception made here was for the subject Bioinformatics as it has been included only in the latest edition of UDC. So, as declared in the methodology 10 years before and after of the year of publication of the UDC standard edition (that is also its year of inclusion) was considered. However, still a tremendous growth in literary warrant can be observed from 1447 to 20,402 even in such a short span of time.

Therefore, growth in literary warrant can be observed for each of the selected interdisciplinary subjects. Also, some of the subjects viz Microbiology, Molecular Biology, Biomechanics and Geochemistry has reflected unprecedented growth in their literary warrant. It can also be inferred that for any subject to have a representation in classificatory devices a growth in its literary warrant can be considered as an essential indicator.

Chapter 8
Findings and Conclusion

8.1 Findings

The findings drawn from the research are summarised below:

- From the study of the development of the selected interdisciplinary science subjects it is observed that the genesis of the interdisciplinary subjects varies. While the origin of subjects like astrobiology, astrophysics, biochemistry, biophysics, biomechanics, geochemistry, geophysics, microbiology, oceanography, environmental science, can be traced to antiquity; subjects like bioinformatics, molecular biology are comparatively new. As a result, the stages and the span of the development identified for each of the subject differ from one another. However, the final stage of development of the above-mentioned subjects as distinct interdisciplinary science subjects came in the 20th century.

- Interdisciplinary science subjects develops by following a 'modes of formation of subjects' (as mentioned earlier). The study reveals that the typology of relation varies from one subject to another. The initial typology of relation for fused interdisciplinary science subjects has been identified as 'loose assemblage'; the distilled subjects went through 'lamination'. Few subjects also witnessed an overlapping of typology of relations like 'lamination' and 'fission'. Going through the above typology of relation they reached either fusion/distillation/clustering. In each of the relation depending upon the interaction the subjects formed either complex or compound or primary basic subject.

- The landmark developments, the stages of development and the typology of relations have an impact on the inclusion of any interdisciplinary science subject in classificatory devices. The development of the subjects leads to its inclusion and relocation of position due to the progress of the subject in classification schemes. However, it has been observed that there exists a considerable time gap in the development of the subject and its inclusion or representation. Also, the gap in between the publications of new editions results into delay of any relocation of class number in classification schemes when needed.

- None of the selected library classification scheme included all the subjects in their latest edition. Among them DDC covers 10 subjects except bioinformatics and environmental science; UDC covers 10 subjects except astrobiology and biomechanics; CC covers only 6 subjects viz: astrophysics, biochemistry, biophysics, geophysics, microbiology and Oceanography.

- The literary growth for each of the selected subject varies from one another. However considerable growth is found for all the subjects. Subjects like molecular biology biochemistry microbiology showed remarkable growth in their literary warrant.

8.2 Conclusion

The study of the genesis and development of a subject offers an idea of how any subject evolve with time. Incase of interdisciplinary subjects the growth involves interactions with other subjects by crossing the rigid boundaries. These interactions lead to the emergence of new subject fields that may establish themselves as a distinct discipline. The research carried out here shows such interactions among science subjects that have eventually led to the coming up of the selected interdisciplinary subjects. Such insights also play an important role in inclusion and relocation of the subjects in classificatory devices. It is also observed that the inclusion of any subject in classificatory devices requires a significant growth in its scope as well as in its literary warrant. To conclude the research revealed that classificatory devices indeed reflect the development and evolution of interdisciplinary subjects. Although there might be a time lag, but for many subjects they are reflectors of any historical changes that have contributed to the emergence of the interdisciplinary subjects.

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