International Journal of Pure and Applied Mathematics
Volume 116 No. 22 2017, 301-313
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

A Comparative Study of Kerala and European Schools of Mathematics

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Abstract

Kerala School of Mathematics is famous for its contributions to early developments in the field of mathematics. Notable contributions have been made by prominent figures in the field of astronomy and calculus. It has been argued that the knowledge explosion in the field of classical mathematics that took place in Europe during the period from 1500AD – 1800 AD was greatly influenced by the contributions of Kerala School. There existed many connections between the two cultures either directly or via Arabs. In this article we make an analysis of these connections and conduct a study based on social network and analyze the during the period 1300 AD -1499 AD.

Key Words: Kerala school of mathematics, european school of mathematics, institutions of higher learning.

1. Introduction

From the beginning itself, Kerala have been producing a number of scholars, who have made significant contributions in Mathematics and Astronomy. The social structure of Kerala played important role for the uninterrupted developments of Mathematics and Astronomy, which led to the formation of a very large number of treatises in these disciplines. These works were inscribed on the palm leaf manuscripts, a bulk of which had been lost due to the inclement climate and some other reasons, and as a result only a fraction of these works have come down to us. Of these works, some texts are available in the printed form, while some others are still in the manuscript form [1].

Social network analysis is a powerful toll in the study of the nature and dynamics of social groups and its dynamics. Such studies can reveal many hidden facts about the past and present of societies. This information is very useful in shaping social relations in future. In this study we construct networks representing scientific collaborations or mathematical dependencies among mathematicians of two famous schools (Kerala School and European school during 1300 AD to 1500 AD). These networks are used to compare the intensity or strength of mathematical activities of the schools. All the information which form the basis of the relations among the mathematicians are discussed in the subsequent sections. Second section ends with the network constructed representing Kerala School. In the third section we concentrate on European school and construct the related network. Fourth section concludes findings of the comparison and discuses further extensions of this work.

2. Developments in Kerala School of Mathematics

In the classical period (AD 450-1150), Mathematics and Astronomy begins with Aryabhatta [2], who occupied a central place in a group of major Indian scholars of the time and made great contributions to the Mathematical and Astronomical developments [6]. A number of commentaries on Aryabhattiya had been made by Kerala Mathematicians and most of their Astronomical works were based on Aryabhattiya [1]. Famous Mathematicians and Astronomers, Bhaskara I, Varahamihira, Brahmagupta, Mahaviracharya, Sridhara, Govindasvamin, Mahavira, Jayadeva, Aryabhatta II, Sripati, Bhaskara II etc. were the followers of Aryabhatta. Works of Aryabhatta and Bhaskara were the major inspirations to successors of Kerala School of Mathematicians [2].

Narayana Pandit, a Mathematician, who lived in the early medieval period, was highly influenced by the works of Bhaskaracharya. Hitopadesh, Ganita Kaumudi and Bijaganitaavatmsa were some of his major works. He had concentrated more to calculate approximate values of square roots, solutions of indeterminate higher order equations, Mathematical operations with zero and some contributions in differential calculus [3].

Madhava of Sangamagrama (popularly known as "one who knows the sphere" [4], one of the major Mathematical figures of medieval period, flourished during AD 1340 to 1425, had contributed a significant part for the development of Mathematics and Astronomy during the period. Significant offerings of Madhava were infinite series for circular and trigonometric functions and approximation of value of π to 3.14159265359 [5]. Moreover, the rare theorems and computational methods developed by Madhava in Mahajyanayanaprakara and Madhyamanayana - prakara were referred by his descendants [1]. Astronomical works Venvaroha and Sputacandrapti of Madhava contains a revision of the Chandravakyas of Vararuci [2].

Through his treatise and commentaries, Vatasseri Paramesvara (a student of Madhava and a prominent scholar) had made significant role in the development of Astronomy and Astrology, using the knowledge acquired from Madhava. Drgganita consists of Parahita system of computation, Siddhantadipika, which contains details of eclipses, Goladipika (works on sphere), Grahanastaka, Grahanamandana and Grahananyayadipika (works on improved computations and rationale on eclipses), Candraccayaganita, a text on the computation of the moon shade and Vakyakarana, a justification on the computation on mnemonic tables were his major works [1]. Nilakantha Somayaji and Jyesthadeva were two notable students of an influential teacher, Damodara, son of Paramesvara. Nilakantha acquired the basic principles in Mathematical computations and the science of Astronomy from Damodara, who had been his regular teacher. In addition, Nilakantha received occasional instruction during his stay at his teacher Paramesvara's house [1].

It had been Madhava, who had played an important role in developing a school of Mathematics and Astronomy during the medieval period [5]. The information about the works of Kerala School of Mathematics and Astronomy were known through the works of Aryabhatiyabhasya, Tantrasamgraha of Nilakantha Somayaji, Yuktibhasa of Jyesthadeva, Kriyakramakari of Sankara Variyar and Narayana, Karanapadhati of Putumana Somayaji and Sadratnamala of Sankara Varman. The works of Madhava had been survived through the works of Nilakantha Somayaji and Jyesthadeva.

In Siddhantadarpana, Nilakatha referred Damodara and Paramesvara as sources for his knowledge about Astronomy and Mathematics [6]. Infinite series expansions, problems of algebra and spherical geometry contained in Aryabhatiyabhasya and Tantrasamgraha reveal that Nilakantha was not only an Astronomer but a scholar in Mathematics also [6]. Nilakantha's important Mathematical and Astronomical works were a commentary on Aryabhatiya, Golasara, Chandrachayaganita, a commentary on Chandrachayaganita and Grahananirnaya. The master piece work of Nilakantha, "Tantrasamgraha" contains several Mathematical and Astronomical ideas, where the Mathematical section consists of contributions that are ascribed to Madhava [4]. In its eight chapters of Tantrasamgraha contains 432 rhymes dealing with various

Astronomical calculations and follows Paramesvara's Drgganita system [2].

A formula for the sum of an infinite convergent geometrical progression had been introduced in India for the first time by Nilakantha Somayaji [1]. More over Nilakantha gave geometrical proofs for the sum of an arithmetic progression, the sum of triangular numbers and sum of squares and cubes of natural numbers. He also wrote commentaries on his own works such as chandravakyaganita and siddhantadarpana [6]. Citrabhanu one of the disciples of Nilkantha, wrote Karanamrta, a manual of astronomical calculations made within the frame work of Paramesvara's Drgganita system [6]. Sankara Variyar, a student of Nilakantha, Citrabhanu and Damodara became a member of the astronomical and mathematical lineage originated by Madhava. Sankara Variyar wrote commentaries Laghuvivrti, Yuktidipika and Kriyakalapa on Nilakantha's Tantrasamgraha [6].

Mahisamangalam Narayana, a student of Citrabhanu was an admirer of Nilakantha Somayaji and he made a strong association with Nilakantha. The astronomical text Karanasara (composed in 1550) and its Malayalam commentary Karanasarakriyakrama were also attributed to Sankara Variyar [6].

These are the notable collaborations or use of mathematical ideas contributed by a mathematician in the work of another mathematician in Kerala school of mathematicians from 1300 AD to 1500 AD. References from which idea about the relation between two mathematicians are obtained are cited along with description. Visualization of the above mentioned relations is done using the software "Pajek". The six mathematicians of Kerala School are represented by vertices and they are identified by the numbers 1, 2, 3, 4, 5, 6. Arc and edges represent their connections, in which an arc represents a one way relation and an edge represents a two way connection. Six important mathematicians are listed below.

i. Narayana Pandit (1340-1400)
ii. Sangamagrama Madhava (1340-1425)
iii. Vatasseri Paramesvara (1360-1460)
iv. Damodara (1410-1510)
v. Nilakantha Somayaji (1443-1560)
vi. Citrabhanu (1475-1550)

Table 1: List of Arcs

Total Vertices 6	
Arcs	Edges
2 3 1	2 4 1
3 4 1	2 5 1
3 5 1	2 6 1
5 6 1	4 5 1

Corresponding network diagram drawn using Pajek is given below. From the diagram it is clear that collaborative and continuous research activities in Kerala School are very rare.

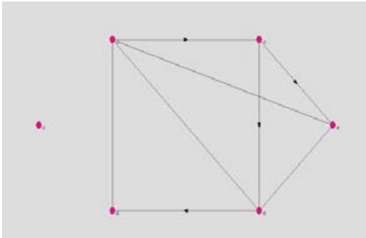

Figure 1: Network Diagram of Kerala Mathematicians in the Period 1300 - 1499 European School of Mathematics

Renaissance in mathematics in Europe was considered to be closely related with the discovery of solutions of the third and fourth degree algebraic equations, formulated by Italian algebraists [7]. Some of the information's collected regarding the education, achievements, contributions, collaborations, contacts or correspondence, disputes or arguments among some important European mathematicians, who were flourished during 1300 to 1499 are detailed below.

In Europe, the renaissance begins with Levi ben Gershom (Gersonides) who was a French native, whose life span had been from 1288 to 1344. He composed a book on numbers containing arithmetical operations, methods for extracting square roots, permutations and combinations. Moreover, Gersonides's mathematical works include arithmetic operations, algebraic identities, binomial coefficients and simple combinatorial identities. In addition to this he worked on trigonometry also. Richard of Wallingford (1292-1336) was an English mathematician who flourished during the above mentioned period. He had been an expert for constructing calculating devices. Most of his mathematical works were on trigonometry. A contemporary mathematician, Thomas Bradwardine (1295-1349), composed several works on mathematics, logic and philosophy during 1300 while he was at Oxford. He used mathematical results for proving certain physical phenomena [8].

Another scholar, Simon Bredon (1300-1372), who showed an interest in the field of medicine, was also an astronomer and mathematician. He wrote many works related to trigonometry, arithmetic and astronomy [9]. Immanuel Ben Bonfils (1300-1377) was a French mathematician and astronomer who was famous for the invention of the system of decimal fractions. He Studied the works of Levi Ben Gershom and taught mathematics and astronomy at an academy in Orange, founded by Levi Ben Gershom [10]. A theologian, Nicole Oresme (1323-1382), was the first mathematician, who developed the proof of the divergence of the harmonic series. He remained as a philosopher, economist, mathematician, physicist, astrologer and an astronomer. Moreover, he had been engaged in translation works also [11].

William Batecumbe, a teacher at the University of Oxford, was a mathematician as well as an astronomer [7]. Antonio de' Mazzinghi (1353-1383) learnt arithmetic, geometry, astrology, architecture and algebra. He was considered to be a best algebraist of the 14th and 15th centuries, since he wrote several algebraic works and worked for the improvement of algebra [12]. A German genius who had a great interest in geometry and logic was Nicolas of Cusa (1401-1464). He studied Euclid's Elements and the works of Thomas Bradwardine and made many contributions in the field of mathematics and astronomy [13]. His contributions were widely circulated among Jacques d'Etaples and Charles de Bovelles [14]. Paolodal Pozzo Toscanelli (1397-1482), an Italian mathematician, made constant contact with a circle of scholars including mathematicians, philosophers, architects, writers etc. at Padua, Toscanelli studied mathematics and medicine. Nicolas of Cusa and Toscanelli, became close friends while they were in Padua and Nicolas dedicated two of his short mathematical works to Toscanelli. The friendship between them remained throughout their life and has strongly influenced each other [15].

Piero Della Francesca (1420 – 1492), is a well known painter as well as a great mathematician, who proved that one can analyze mathematics artistically. Through his entire works, he revealed that mathematics and painting are not two different entities but they should be considered together. To understand Piero's mathematics deeply, one must have refers to Luca Pacioli's De Divina Proportione which also includes the drawings of Leonardo da Vince [15].

Georg Peurbach (1423-1461) was an Austrian mathematician and astronomer. He met Johannes Muller (1436-1476), who was a German Mathematician and astronomer, at the University of Vienna. Peuerbach composed manuscripts related to elementary arithmetic, Sine tables, calculating devices, and the construction of astronomical instruments. Both Peuerbach and Muller worked together for completing the table of Sine. Peurbach created several works on practical mathematics. Among them the most popular textbook was Algorismus, which consists of practical calculations with integers and fractions [16]. Regiomontanus (Muller) was the author of De Triangulis Omnimodis (On Triangles of all kinds) which was finished about 1464 but unprinted until 1533. In this work Regiomontanus systematically summed up the earlier works related to Trigonometry and solved all sorts of problems in plane and spherical triangles. Tabulae directionum was his another trigonometric treatise. Regiomontanus introduced two calendars one in Latin and other in German in 1472, which became very popular [17, 13].

A Florence native Antonio Manetti (1423-1497) was an Italian mathematician, architect and was the biographer of the architect Filippo Brundleschi [18]. The French native scholar, Nicolas Chuquet (1445-1500) was initially a doctor turned mathematician. His notable work Triparty (Three parts) was concerned with rational arithmetic operations on numbers, explanation of Hindu-Arabic numerals, roots of numbers, rule of the unknown and so on [8]. Through the manuscript Triparty, Chuquet became famous. While creating his arithmetic text published in 1520, Etienne La Roche (1470-1530), slavishly copied many passages from Triparty [19].

Luca Pacioli (1445-1517) was a French Mathematician commonly known as Fra Luca di Borga and was a contemporary of Regiomontanus [17]. A friendship between Pacioli and Leonardo da Vinci begun while he was a teacher in Milan. Leonardo illustrated regular platonic solids and other geometric figures in Pacioli's 'Divina Proportione' [13].The collaboration between Pacioli and Leonardo da Vinci last for several years and they taught each other. Leonardo da Vinci frequently used Pacioli's work 'De Viribus Quqntitatis' as a reference [8]. Pacioli published 'Summa de Arithmetica Geometria Proportioni et Proportionalita' at Venice in 1494, which was considered as the most influential Mathematical text of that period [17]. 'Compendio de lo abaco' was composed by Francesco Pellos (1450-1500) consists of early form of decimal point and Pacioli borrowed some ideas from this work [8]. Other notable geometric works of Pacioli were De divina proportione and a Latin translation of Euclid's 'Elements'. At the end of his work 'Summa', Pacioli stated that the solution of the cubic equation was impossible as the quadrature of the circle. But in contrast to Pacioli's prediction, del Ferro solved the cubic equation for the special case $x^3 + px = q$; where p and q are positive [17].

Johannes Widmann was the first mathematician to use the symbols + and – in print for addition and subtraction. He used these symbols in his book on arithmetic for giving some examples. Johannes Widmann was born in Czech Republic, lived during 1462 to 1498, educated at university of Leipzig and was a mathematics lecturer also. While writing a work, Adam Ries took some examples from Widmann's lecture script [13].

Scipione Del Ferro (1465-1526), born in Bologna, was known as an Italian mathematician. He was appointed as a lecturer in arithmetic and geometry at the University of Bologna. It was Del Ferro, who had solved the depressed cubic equations. During the days at the University of Bologna, Pacioli and Del Ferro discussed about some mathematical problems [20].

Johann Werner (1468-1522) and Albert Durer (1471-1528) were two contemporary scholars born in the same city, Nuremberg, they used to discuss about mathematical matters. Werner wrote mathematical works related to spherical geometry and conic sections. Peter Apianus (1495-1552) followed the idea of Werner on determining longitude. Estienne de La Roche was a French mathematician lived during 1470 to 1530, who studied mathematics with Nicholas Chuquet and they were in good terms. He taught commercial mathematics and arithmetic. La Roche was influenced by many mathematicians such as Luca Pacioli and Chuquet. La Roche wrote marginal annotations in Chuquet's manuscripts. La Roche adopted Chuquet's 'Algebra', while preparing his work, Larismetique [20]. Although Albert Durer was a skillful painter, he had an interest in studying mathematics. He was aware of the immense relation between mathematics and art. He studied Euclid's Elements and the treatise De architecture of Vitruvius. During 1505 to 1507, Durer spent his time in Italy for studying arts as well as mathematics. He was attracted with the works of Alberti and Pacioli on mathematics and art, especially works on proportions. He learnt the mathematical secrets of art from Pacioli. His treatise ‘Underweisung des Messung mit dem Zirkel und Richtscheit’, ranked him as one of the most important Renaissance mathematician [20].

Nicholas Copernicus (1473-1543) was not only a famous astronomer but also an expert in trigonometry. During the university education at Krakow, Copernicus studied Latin, astronomy, mathematics, geography and philosophy and at Bologna University, he studied Greek, mathematics and astronomy. On 18 october 1538, Copernicus left Wittenberg and went to Nuremberg, the native place of Johannes Schoner (1477-1547), who had been a Roman Catholic priest first and later a professor of mathematics and astrology at the Melanchthon High school in Nureberg during 1526 to 1546. Copernicus and Schoner have made conversations for long time. The work ‘De Revolutionibus Orbium Coelestium’ Published in 1543 was an evidence for the mathematical skill of Copernicus. This work contains many important trigonometrically results. Another mathematician, flourished during 1479 and 1566 was a French native, Charles de Bovelles who wrote several mathematical works, among which only some had been survived. Oronce Fine helped Charles De Bovelles him in preparing his work ‘La Geometric Practique’ [21].

Juan de Ortega was born in 1480 and expired in 1568, had no university education and earned for his living by teaching commercial arithmetic. He wrote a book ‘A Tractado Subtilisimo D’arithmetica de Geometria’, consists of commercial arithmetic and rules of geometry and was published in 1512 [20].

Gaspar Lax (1487-1560) studied arts and theology at Zaragoza. He taught mathematics and philosophy at the University of Zaragoza in 1525. He was more famous as a mathematician than a logician or philosopher. At the Studium Generale of Zaragoza, Lax taught mathematics and philosophy from 1525 until his death. Among his works the notable were, Arithmetica Speculativa and Proportiones, were published during 1515 at Paris [22].

A German mathematician, Michael Stifel (1487-1567) studied mathematics at the university of Wittenberg, who became a mathematics lecturer in the university of Konigsberg [21], had read a Latin translation of Euclid’s Elements. Christoff Rudolff’s (1499-1543) Coss, arithmetic text of Adam Ries and so on.

At Erfurt, Adam Ries (1492-1559), the German scholar started a school Rechenmeister and Hofarithmeticus in 1518, and as a result he got the opportunity to make contacts with academics and these contacts were very beneficial for him in his mathematical achievements. He met regularly, Georg Sturtz (1490 - 1548), who is an academic at this university. Ries got a collection of manuscripts on algebra and arithmetic from Sturtz, which was given to Sturtz by Johannes Widman, who was a German mathematician, lived during 1462 to 1498 [23].

Oronce Fine was born in 1494 and lived up to 1555 and was a French native. After his education, he was appointed to the chair of mathematics in 1531 at Royal College. He worked on several fields of mathematics such as geometry, arithmetic, optics, gnomonic, astronomy and instrumentation [24]. Francesco Maurolico (1494-1575) was a mathematician and astronomer and was from Sicily, who had prepared treatises on mathematics [20].

Henricus Grammateus (1495 - 1525) was a German mathematician [25] and a mathematics teacher from 1517 to 1521 at the university of Vienna, where he taught Christofer Rudolph. After this period he went to Nuremberg and then to Erfurt [26]. Christofer Rudolph (1499-1543) was a mathematician who was known to be the author of the first German text book on algebra. Michael Stifel extended Rudolph's Coss by adding some important materials of his own and published in 1553 [26].

Next was a German scholar, Peter Apianus (1495-1552), who studied mathematics and astronomy at the university of Leipzig and Viana. Peter Apianus's Cosmographia Seu Descriptio totius orbis was published in 1524, which provided an introduction to astronomy, geography, cartography, surveying, navigation, weather and climate, the shape of the earth, map projections and mathematical instruments. This most valuable work led him to the chair of mathematics at the University of Ingolstadt in 1527, even though the work was not a best seller. In his Instrumentum Sinuum Sive primi mobilis (1534), he described the values of sines for every minute, with the radius divided decimally [27].

Niccolo Fontana Tartaglia (1499-1557) was a victim of an attack by the French. He earned his livelihood by taking simple mathematics teachings [13]. In order to draw the network diagram of European mathematicians lived and worked during 1300 to 1499, 38 mathematicians whose main contributions discussed above are considered as vertices. These mathematicians are labeled by using numbers from 1 to 38 in chronological order, which is listed below.

1. Levi ben Gershom(Gersonides) (1288-1344).
2. Richard of Wallingford (1292-1336)
3. Thomas Bradwardine (1295-1349)
4. Simon Bredon (1300-1372)
5. Immanuel ben Jacob Bonfils (1300-1377)
6. Nicole Oresme (1323-1382)
7. Richard Swineshead (1340-1354)
8. William Batecumbe (Fl.1348)
9. Antonio De'mazzinhi (1353-1383)
10. Paolo Dal Pozzo Toscanelli (1397-1482)
11. Nicholas of Cusa (1401-1464)
12. Pierro Della Francesca (1420-1492)
13. Georg Peurbach (1423-1461)
14. Antonio Manetti (1423-1497)
15. Johannes Muller (Regiomontanus) (1436-1476)
16. Nicolas Chuquet (1445-1500)

17. Luca Pacioli (Fra Luca Di Borga) (1445-1517)
18. Francesco Pellos (1450-1500)
19. Leonardo Da Vinci (1452-1519)
20. Johannes Widmann(1462-1498)
21. Scipione Del Ferro (1465-1526)
22. Johannes Werner (1468-1522)
23. Estienne de La Roche (1470-1530)
24. Albrecht Durer (1471-1528)
25. Nicolus Copernicus (1473-1543)
26. Johannes Schoner (1477-1547)
27. Charles de Bovelles (1479-1566)
28. Juan de Ortega (1480-1568)
29. Gaspar Lax (1487-1560)
30. Michael Stifel (1487-1567)
31. Georg Sturtz (1490-1548)
32. Adam Ries (1492-1559)
33. Oronce Fine(1494-1555)
34. Francesco Maurolico (1494-1575)
35. Henricus Grammateus (1495-1525)
36. Peter Apianus (1495-1552)
37. Christoff Rudolff (1499-1543)
38. Niccolo Fontana Tartaglia (1499-1557)

The connections between these mathematicians are listed as follows;

Table 2: Lists of Arcs

Total Vertices 38	
Arcs	**Edges**
1 5 1	10 11 1
11 27 1	12 17 1
17 18 1	12 19 1
17 23 1	13 15 1
17 24 1	16 23 1
20 32 1	17 19 1
22 36 1	22 24 1
32 30 1	25 26 1
33 27 1	30 37 1
35 37 1	31 32 1

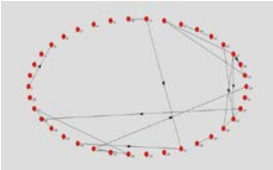

Figure 2: Network Diagram of European Mathematicians in the Period 1300 -1499.

3. Conclusion

Number of actors in European school is much higher than the number of actors in Kerala School. Number of connections which represents either collaboration or any king of dependence among the mathematicians is also higher among the European mathematicians**.** Various centrality measures computed using Pajek software is given in the following table, which enable us to compare the activities of both schools. It is also interesting that average degree and betweenness centralization of European School is less than the corresponding measures of Kerala School. But all degree centralization of European school is greater than that of Kerala School. Similar studies must be conducted for the remaining period. Structure of the network obtained in each period must be compared. Performance of both schools must be compared for much longer period.

Table 3: Comparison of Various Social Network Measures

	Kerala School	European School
Density (Loops Allowed)	0.33333333	0.02077562
Density (Loops not Allowed)	0.40000000	0.02133713
Average Degree	2.66666667	1.05263158
Network Input Degree Centralization	0.24000000	0.03360117
Network Output Degree Centralization	0.48000000	0.11687363
Network All Degree Centralization	1.00000000	2.08333333
Network Betweenness Centralization	0.25000000	0.00854233

Acknowledgment

This research was completed with the financial assistance of University Grants Commission, India. First author is grateful to University Grants Commission for sanctioning a major research project titled, "Modeling of social ties; a modified approach", No. F. No. 40 - 243/ 2011 (SR).

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