Mapping Social Networks among Crystallographers in South Africa

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Abstract: The author adopts the premise that technological innovation, a critical factor in the long-term economic growth of any country, can only function successfully within a social environment that provides relevant knowledge and information inputs into the innovative process. This is dependent on the efficient transfer and communication of knowledge and information which in turn relates to the amount and quality of interaction among scientists and technologists. These factors prompted a research project that used social network analysis techniques to investigate knowledge exchange and to map the knowledge network structure and communication practices of a group of scientists engaged with crystallographic research. This paper is based on this research project.

The findings provide clear evidence of a strong social network structure among crystallographers in South Africa. A core nucleus of prominent, well connected and interrelated crystallographers constituted the central network of scientists that provided the main impetus to keep the network active. This eminent group of crystallographers were not only approached far more frequently for information and advice than any of their colleagues, but they also frequently initiated interpersonal and formal information communication acts. It was clear that this core group had achieved a standard of excellence in their work, were highly productive; very visible in their professional community and they generally played a pivotal role in the social network. They generally maintained a high professional profile in the crystallography community and within the general field of science, published profusely, and generally emerged as the archetypal sociometric stars in their field. It is thus clear that high productivity, professional involvement, innovation capacity and network connectivity are intricately interwoven.

The crystallographers' work environment and concomitant work structure clearly affected network interaction. Working in a group structure stimulated network interaction, professional activity and productivity. A further benefit was that the leaders of these groups generally assumed gatekeeper roles that facilitated networking and ensured the importation and interpretation of new information and knowledge. It was clear that social networks operate more effectively in areas, such as Gauteng, where a sufficient number of scientists were amassed.

Keywords: knowledge transfer; information communication; social networks; crystallographers; scientists

1. Introduction

It is this author's conviction that technological innovation is a critical factor in the long-term economic growth of any country. Specifically, if South Africa wishes to compete and even survive in the prevailing competitive and globalised economy it is in urgent need of developing its science and technology endeavours. Concerted efforts should thus be made to create an environment that promotes scientific and technological innovation and development. It is further argued that this can only occur within a social environment that provides incentives and relevant knowledge and information inputs into the innovative process. This, in turn, is largely dependent on the efficient transfer and communication of knowledge and information which is directly related to the amount and quality of interaction among scientists and technologists. The escalating growth of scientific and technological enterprise over the last few decades has however resulted in a concurrent growth in and greater complexity of the communication process and this, in turn, has impacted on the effectiveness of information and knowledge exchange in science and technology.

All these factors thus prompted the author to study the efficacy of the communication process among a defined group of scientists in South Africa and this paper is based on the resultant research project.

2. Key concept clarification

Data, information and *knowledge* are viewed as points along a continuum of increasing value and human contribution. Data is equated to the lowest level of known facts with no intrinsic meaning. If organised, and structured they become information. Knowledge, in turn, implies that human intervention has taken place that interprets, understands, and adds value and meaning to information.

Science is that branch of knowledge that is based on objective principles which are primarily concerned with the functions of the physical world. It is regarded as the generic term that incorporates both *basic* and *applied science*, with the former denoting the more theoretical aspects and the latter the practical applications of science. *Crystallography*, in its general sense, relates to the study of the structure and arrangement of all

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substances by means of various scattering methods. The utilisation of crystallography ranges from its application in technology to its use in basic science.

3. The communication process in science

The ability of all scientists to contribute to the advancement of science depends to a large extent upon the amount and quality of their interaction with fellow scientists. Science, furthermore, is cumulative and each scientist builds on the work of colleagues and predecessors and in the process the body of knowledge in the field grows as each scientist imparts his/her unique contribution to the broader science community. Several studies have, therefore, indicated that scientists spend a far larger proportion of their time on information and knowledge communication activities than most other workers (Gläser 2003; Eisend 2002; Hertzum & Pejtersen 2000).

Scientific endeavour is essentially a corporate activity and a distinctive feature and accepted social norm is the notion of a shared commodity that belongs to everyone (Ziman 2002). Gläser (2003) for example argues that scientific communities constitute a “distinctive mode of collective production which is characterized by decentralized action coordination” and based on this premise communication in science is thus not merely the exchange of previously produced knowledge, but “the transmission of material and components between producers”.

Eisend (2002) specifically distinguishes between individual cognition and scientific cognition where the latter relates to the transfer of knowledge in the scientific community after it has been validated and integrated into the body of verified knowledge. He further differentiates between the communication of content and the social and inter-personal dimension of the communication act. It is thus evident that in addition to dependence on the formal structure of knowledge, scientists value informal, interpersonal communication. The important role of interpersonal communication networks has been highlighted by a number of researchers, ranging from the groundbreaking work by Price (1961) on *invisible colleges* to a series of later investigations (Hertzum and Pejtersen 2000). The value of interpersonal communication lies in the interactive nature of the exchange process, the stimulation of collegiate interaction and the provision of an ideal forum to debate and evaluate ideas amongst peer groups. Such social networks assist with “the production of knowledge, dissemination of ideas, reputation building and growth of intellectual fields” (Fry 2006)

A number of studies have further indicated that there is a positive correlation between the intensity of collegiate communication and performance and that performance increases if informal communication links are encouraged (Tenopir and King 2004). Bathelt and others (2004) found that individuals (and even organisations) participating in network associations are more effective and innovative and Crane’s (1972) study specifically showed an exponential increase in publication output when high levels of inter-personal interaction were maintained. There appears to be a distinct difference in the way that applied fields of knowledge and the basic fields communicate. According to Salasin and Cedar (1985) communication links in basic science occur horizontally by means of well-developed person-to-person networks, frequently crossing organisation and discipline boundaries and usually among peers of equal levels of expertise. Applied fields again tend to communicate vertically by exchanging knowledge and information between researchers, practitioners, and others through several different levels of expertise and communication is often constrained within the organisation due to confidentiality restrictions. To overcome the various communication barriers in applied fields, 'middlemen' (or gatekeepers) have thus evolved that bridge organisational and disciplinary boundaries to import and transfer appropriate knowledge and information to all levels in an organisation (Allen 1977).

A further distinction is that publication is regarded by the basic science community to be the culmination of creative effort and the end-product of the research process. This transfer of knowledge into the public domain underpins and drives the communication process (Hurd 2000). The end-product of applied science research, on the other hand, may in many instances never be published, and is often converted directly by industry into new procedures or products or into licences and patents for production purposes. The aim in applied science research is to provide the best solution to a problem. Another distinguishing factor is the difference in work environments. Applied scientists are generally employed by organisations that are profit motivated and the restrictions this imposes generally impedes the free flow of knowledge and information and often prevents the formation of cross-boundary social networks.

3.1 Social networks, elitism and gatekeepers

While it is reputed that Robert Boyle first used the concept *invisible colleges* to describe scientific meetings held in England in the 1640's, the modern use of the term with reference to social networks can first be attributed to Price (1961). The premise is that in each circumscribable area of basic science there exists a group of people, usually engaged in cognate research areas, who communicate often and intensively with each other. Such a network thus acts as a social circle of scientists brought together by their common research interests. Members are usually very productive and contribute materially to research in their field, not merely on a national scale, but also internationally. These scientists meet at select conferences, commute between research centres, collaborate, and often seek each other out to obtain information before searching the literature.

It has further been suggested that these networks are held together by the eminent leaders in the field and these *sociometric stars* or *elites* create a *gravitational force* that holds the field together and improves communication within their *invisible college*. Amick (1973) was one of the first persons who attempted to prove the premise that there is a positive relationship between scientific elitism and communication in basic science. It is presumed that scientific elites are intimately involved with (and often have control over) the scientific communication system and that they tend to cluster at the *basic* end of the basic to applied science continuum.

These elites comprise the eminent men of science who have been accorded recognition in their disciplines, they have achieved a standard of excellence in their work, they are highly productive, and are generally highly visible in their professional community. They process more information and have more narrowly defined and less diffuse research interests than their 'non-elite' counterparts. Allen and his colleagues first identified the *technological gatekeeper* as the intermediary in an organisation who indirectly ensures the flow of outside information into the organisation and the subsequent dissemination of that information within the organisation (Allen 1977). *Gatekeepers*, thus, accomplish the important function of coupling the organisation to outside activity and Bathelt and others (2004) have stated that “the role of internal gatekeepers and boundary spanners becomes crucial for translating externally produced knowledge into a form that can be internally understood within the organisation”. *Gatekeeper*s thus play a particularly significant role in closed environments and in situations where cognitive congruence is lacking among members of a group. They generally hold key positions in an organisation; are well integrated into both domestic and international networks; and they have the ability to cut through communications barriers that prevail in industry. By maintaining contact among themselves, they increase their effectiveness as linking agents. In this way a two-step information flow process is created by means of which the average worker in industry is enabled to stay abreast with external technological developments.

3.2 Pressure on the system

It is clear that the system of scientific communication that has evolved over several centuries is now undergoing a transformation catalysed by a number of environmental, economic, and structural factors. Of the most pervasive are those caused by the effect of increased collaborative practices, increasing specialisation and growth in interdisciplinary fields, the exponential growth rate of information and the concomitant information overload; ever changing and often decreasing funding models, and structural changes in employing organisations (Correia and Teixeira 2005, Hurd 2000). The effect of all these factors is further compounded by the electronic environment that we live in. The ubiquitous adoption of information technology has affected the communication system in a number of ways, ranging from new modes of one-to-one communication to electronic modes of publication, to the impact of the Internet and the World Wide Web (Smith 2007). The question thus arises to what extent these factors have affected communication behaviour in science. Has it created fundamental qualitative and quantitative changes to the process and affected behavioural patterns, or has it been absorbed by science communities as many other innovations have in the past? The author is further of the opinion that South Africa presents a number of unique environmental, socio-political and other factors that could impact on the communication process.

4. The empirical study

Social network analysis techniques (employing both qualitative and quantitative approaches) were used to investigate information transfer and knowledge exchange and to map social network structures amongst a group of scientists engaged with crystallographic research in South Africa. The decision to select this research community was based on the fact that these scientists manifested a variety of attributes that ranged from the various ways that they applied crystallography (the basic study of the field [the *pure* crystallographers], its utilisation as an analytical tool in various areas of science, and its application in industry), to variation in their work environments (universities, research institutes, and R & D facilities in industry). A longitudinal research design was adopted and data was first collected in 1990/1 and again in 2001/2 to establish trends and changes over the designated time span. The International Union of Crystallography's *World directory of crystallographers* (1986; 1997) was selected as the appropriate sampling frame from which the study sample was selected. There was a 65% communality between the first study population of 80 crystallographers and the second group of 78 respondents. Data was collected by means of a series of focus group interviews, personal interviews, telephone interviews and e-mail questionnaires.

5. Findings of the study

5.1 Interpersonal communication

To obtain a picture of the dynamics of the communication process within the South African crystallographic community, the respondents were questioned on the personal contacts that they maintained and received with respect to their work situation. From this data a matrix was created for both studies. The contacts to crystallographers listed in the *World directory of crystallographers* were identified and a distinction was drawn between South African and foreign contacts. The total number of contacts as well as the average number of contacts for each category is represented in Table 1. It is clear that the level of interpersonal communication, and particularly the contacts maintained abroad, had increased from the first to the second study (the t-test for two dependent samples indicated significant results at $p \leq .05$). The increases in interpersonal communication in the second study can mainly be explained by the greater international mobility of South Africans since 1994, the general move to global interaction and collaboration, and the ubiquitous use of electronic modes of communication that has made communication over long distances feasible and far more affordable. It is further evident that the largest proportion of contacts was maintained between the crystallographers in South Africa (i.e. interaction between the respondents). In 2001/2 this was followed by contacts maintained with listed crystallographers abroad, while in 1990/1 the ratios were almost equal for the other three categories of contacts.

Table 1: Interpersonal contacts

TABLE 1. INTERPERSONAL CONTACTS

	Sum	% of Total	Mean	Min	Max	Std.Dev.
1990/1 Data (valid N = 80)						
CONTACTS MADE						
Contacts made in SA	312	58	3.9	0	15	3.06
Contacts with SA Crystallographers	200	37	2.5	0	9	2.27
Contacts made abroad	223	42	2.8	0	12	2.8
Contacts: Crystallographers abroad	104	19	1.3	0	10	2.43
Total contacts with Crystallographers	304	57	3.8	0	18	3.61
Total contacts made	535	100	6.7	0	27	5.08
CONTACTS RECEIVED	205	38	2.6	0	25	4.45
2001/2 Data (valid N = 78)						
CONTACTS MADE						
Contacts made in SA	309	52	4.0	0	20	3.12
Contacts with SA Crystallographers	202	34	2.6	0	10	2.48
Contacts made abroad	284	48	3.6	0	18	4.09
Contacts: Crystallographers abroad	156	26	2.0	0	10	3.46
Total contacts with Crystallographers	358	60	7.6	0	22	5.13
Total contacts made	593	100	4.6	0	32	6.33
CONTACTS RECEIVED	239	40	3.1	0	29	4.87

Descriptive Statistics: Contacts maintained 1990/1 & 2001/2

5.1.1 Interpersonal communication according to sub-categories of the population

It was found that when the data for the two studies were further analysed according to the various sub-categories of the population and the different categories of interpersonal communication that the pattern of increased contact levels in 2001/2 was maintained for all sub-categories. ANOVA/MANOVA tests were further conducted to establish the effect of the independent variables on the dependent variables and it was seen that variation in work environment, work structure, position, age and qualification had all produced significant results ($p \leq .05$).The respondents in industry, closely followed by those at the research institutes, were generally more active in initiating and maintaining interpersonal communication links than their counterparts at the universities. The only instance where this pattern changed was for contacts with foreign crystallographers where the research institute respondents, followed by the university crystallographers, initiated more contacts. The situation is, however, reversed when the data relating to contacts received is examined. It is abundantly clear that the university respondents received by far the most contacts (the research institute respondents received approximately half and the industry respondents a quarter of the contacts that they received). Comments made during the interviews indicated that the industry respondents were very conscious of their closed work environments and their need to import new knowledge and to actively seek out scientists at the forefront of research in their field. The research institute environment was, again, resolute that their scientists should interact with leading scientists both locally and abroad. It is thus clear that while there was a need for the other two environments to network so that they could tap into external expertise and knowledge, the university scientists were more self-reliant.

The type of work structure clearly affected interaction: the respondents who worked in more structured and group-forming environments were collectively the more active communicators and were approached by other crystallographers more frequently. The respondents working in unstructured groups ranked second, while those respondents who worked on their own made and received the least number of contacts. These results, together with observations made during the interviews, suggest that working in a group structure stimulates interpersonal communication and the flow and exchange of knowledge. The effect of qualification levels on communication showed that interpersonal interaction was at the lowest level for those respondents with the lowest qualifications and at a far higher level for the respondents with a doctorate. An interesting observation is that the respondents who held foreign doctorates were slightly more active in instigating contacts in South Africa, while the respondents with local doctorates maintained slightly more contacts with local crystallographers and received more contacts. This latter aspect can be attributed to the fact that all but one of the eight crystallographers that emerged as the leaders in the field held South African doctorates.

A strong correlation further emerged between the level of seniority of the respondents and interpersonal communication: the more senior the respondents, the more they received and initiated communication acts. This is not surprising as one would expect the more junior researchers to depend on their senior colleagues to maintain external links, interact widely and import new knowledge. When the data was analysed according to age categories, it emerged that interpersonal communication was at the highest level for the middle age category (36-50), followed by the oldest age group. This was an unexpected outcome since one would have expected that interpersonal networks are built up over time and thus with increase in age.

5.1.2 The geographical spread of interpersonal communication

When the geographical spread of communication activity was analysed it was seen that interaction was far higher in Gauteng and this would suggest that this area contained a sufficient critical mass of expertise in the field to obviate the need to communicate extensively outside the area. The respondents in all the other areas communicated far more widely with persons outside their own area. This could also be partially attributed to the fact that all the research institutes and the majority of the industries in the study were situated in Gauteng (the universities, however, were more evenly distributed throughout South Africa).

5.2 Active communicators

It further surfaced that there was a relatively small nucleus of crystallographers (approximately 25% of the population for both studies) who were the most active communicators and who were driving the communication process. Within this group eight crystallographers (approximately 10% of the population for both studies) further stood out as being even more highly connected and vigorous communicators. In Chart 1 the difference in intensity and level of interaction between the active crystallographers (top 25% and 10%) are compared with that of the population aggregate and it can clearly be seen that the core groups received and instigated far more exchanges than the population aggregate. It was further seen that a substantial majority of the contacts that were maintained were to listed crystallographers and that over half of these were South African (both studies). The identification of this core body of highly active communicators within the crystallographic fraternity would thus suggest the presence of an *invisible college* phenomenon within this community (cf. also Map 1 (Fig 2). that illustrates these links).

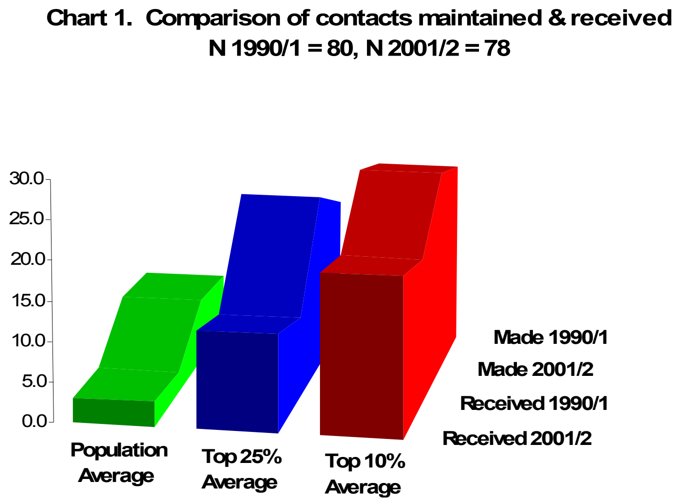

Figure 1: Comparison of contacts maintained and received

The nucleus of crystallographers who received the most contacts mostly worked at universities, usually in either a formal or loosely structured group, they were almost all basic scientists who were either 'pure' crystallographers (in chemistry or physics) or used it as a 'tool' (in chemistry, geology, or biology). Almost all of these respondents were in senior positions in the 36-50 age category with slightly more holding South African than overseas doctorates. The majority worked in Gauteng. This profile varied only slightly between the two studies and it was seen that there was a 75% correspondence between the central networks of the two studies.

When the profile of the core group of crystallographers who received the most contacts is compared with that of the respondents who initiated the most communication acts, a number of differences surface. The active communication initiators were far more equally distributed among the three work environments and as a consequence there was a shift away from a preponderance of respondents conducting *pure* crystallographic research and using it as an analytical tool in basic science, to those who applied crystallography in industry and the research institutes. The subject distribution thus also shifted more towards the applied disciplines such as materials science and mineralogy. Even more of this category worked in structured groups and none on their own. This category also mostly held senior positions (with only a slight shift to the middle position) and the predominant age was even more embedded in the 36-50 age category. There was further a shift to a large majority with South African doctorates and again most worked in Gauteng. There was hardly any variation between the two studies for this data.

The eight most highly connected crystallographers were contacted considerably more frequently than the other members of the central network and they generally also appeared to be the most prominent members of the crystallography fraternity. The membership of this nucleus of very active crystallographers did not vary between the two studies and they all held senior positions, mostly headed structured groups (6), or were leaders of unstructured groups (2), three held overseas doctorates and five held local doctorates, they were mostly between 36 and 50 years of age (there was a slight shift to the older age category in the 2^{nd} study), they mostly conducted *pure* crystallographic research at universities, mostly worked in the field of chemistry and they were mostly located in Gauteng. Of these eight respondents, one crystallographer emerged as the person who was by far the most frequently approached for advice in general. A number of respondents referred to him as the "doyen" crystallographer in South Africa. This 'doyen' crystallographer and the other seven dynamic communicators all served on a number of important boards, committees, etc. within the general field of science, they were actively involved in their professional associations and played a leading role in these institutions, they published profusely, they served on editorial committees, were sought out for external examining purposes and generally emerged as the archetypal 'sociometric stars' in their field.

To graphically depict the interpersonal interactions that were maintained between the core actors in the crystallography community in South Africa a social network map was constructed using the CmapTools software (see Fig 2.).

The map indicates the key players as nodes and the linking lines the strength (thickness of the line) and direction (arrow and commentary) of the interaction. The nodes are shape- and colour coded, with the blue rectangular nodes indicating universities, green oblong nodes industry and the red squares the research institutes. The eight key actors in the community are indicated as follows: UC1 was the so-called doyen crystallographer at a university in Gauteng, the other role players in Gauteng were UB1, UD1 (both at universities), RC1, and RB1 (at research institutes), IA1 (in industry); UH1 at a university in Natal; and UI1 at a university in Cape Town. The sub-networks that surround them are also depicted.

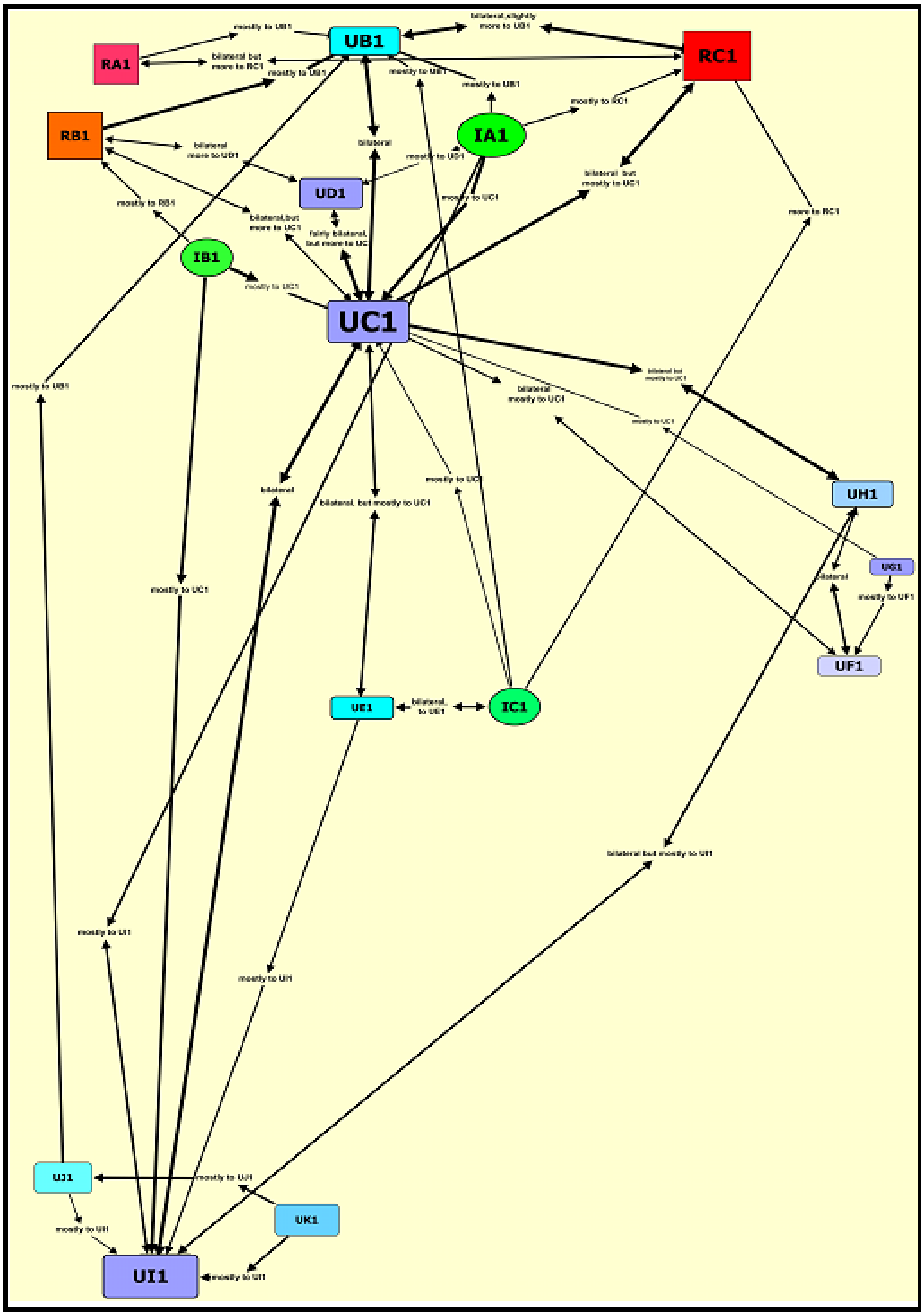

Figure 2: Main crystallographic network in South Africa

5.3 Professional activity and communication intensity

Reference was made in section 3 to the number of studies that have indicated that high levels of interpersonal interaction and professional activity or productivity are closely related. To establish whether these patterns were evident amongst the crystallographers the author queried the respondents on their involvement in professional activities (e.g. whether they had acted as journal referees or members of editorial boards; involvement with professional institutions, etc.) and also asked them to provide research output details. This data was then compared with the communication activity data.

Correlation with the research output data showed that all the crystallographers who were the recipients of the most information communication approaches and 65% of those who initiated the most communication acts were among the group of crystallographers with the highest research output counts. The aggregate annual research output count of the most active communicators was 8.0 in 1991 and 10.1 in 2001/2 and this compares very favourably with Garfield's (1990) longitudinal study that established that the so-called *elite* scientists were producing approximately nine papers a year.

Correlation of the communication activity data with the professional activity data once again showed high levels of communality between the active information communicators (particularly the recipients of information contacts) and professional activity. It was further seen that there was a direct correlation between the professional activity and high research output data and thus also with the high communication data. It would thus appear that the more active a person is in interacting with colleagues, the more prominent a role such a person plays in his/her professional life and the more productive they are.

6. Concluding remarks

The findings provide clear evidence of a strong social network structure, or *invisible college* phenomenon, among crystallographers in South Africa. This network was driven by a core nucleus of prominent, well connected and interrelated crystallographers who provided the main impetus to keep the network active. These eminent crystallographers played a pivotal role - they were not only more frequently approached for information and advice than any of their colleagues, but they also regularly initiated communication acts; they had achieved a standard of excellence in their work; maintained a high profile in the crystallography community as well as in the general field of science; were highly productive and published profusely – they generally emerged as the archetypal *sociometric stars* in their field. This *elite* group of crystallographers thus clearly fit Price (1961) and Amick's (1973) profiles of scientific eminence. It was further observed that the *elites* tended to cluster more at the basic science (and specifically the 'pure' crystallography side) of the basic to applied spectrum and they mostly worked in environments that were conducive to collegiate interaction.

A distinctive feature of integration into the social network was the interrelation with productivity and professional involvement - the more vigorous the interaction with colleagues, the more productive and influential the crystallographers were. It is thus clear that high productivity, professional involvement, innovation capacity and network connectivity are intricately interwoven.

The crystallographers' work environment was clearly an important factor that affected network interaction. The organisational ethos that prevailed in industry, the research institutes and the academic institutions generally predicated specific work structures which again impacted in varying ways on interpersonal interaction. Working together in formal or loosely structured groups clearly stimulated network interaction, professional activity and productivity. A further benefit was that the leaders of these groups generally assumed *gatekeeper* roles that facilitated intra- and cross-boundary networking and further ensured that new information and knowledge was imported, interpreted and then disseminated internally. The g*atekeeper* phenomenon was particularly prevalent and important in the more applied environments where they assisted in overcoming communication barriers caused by confidentiality restrictions and in providing interpretive interventions to help transcend the divide between applied and basic science.

Other factors such as level of seniority, age and qualification also played a significant role in the dynamics of the network process. It is further evident that for social networks to coalesce and interact vigorously, a sufficiently large critical mass of contributors is required. The number of scientists was clearly sufficiently large in the Gauteng area to engender significantly higher communication activities than elsewhere in South Africa. It was further evident that although the basic social network model remained fairly constant from the first to the second study, certain changes did surface. These were predominantly caused by the impact of the escalating electronic environment, a new political dispensation in South Africa, as well as financial and structural changes in the work environments.

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