Improving the Innovation Ability of Engineering Students: a Science and Technology Innovation Community Organisation Network Analysis

Abstract: Science and Technology Innovation Communities (STICs) are student-led partnerships that bring together businesses, research centres, and university staff. They constitute an effective way of promoting student innovation ability. However, the students' position within the STICs organisation network may condition how their innovation ability is effectively acquired. Using Social Network Analysis (SNA), this study measures how the STICs organisation network promotes the innovation ability of its actors. The paper finds that network centrality and structural holes of the STICs organisation network are positively correlated with student innovation ability. The results are validated through robustness tests in three different STICs, involving engineering students from China's Chang'an University. Semi-structured interviews are also conducted with twenty relevant actors of STICs. The conclusion suggests that a higher involvement of core actors, more support from schools, and more restrictive entry requirements are necessary to improve the organisation management and training level of engineering students in STICs.

Keywords: Engineering Education; Innovation Ability; Social Network Analysis; Science and Technology Innovation Community (STIC); Student Development.

1 Introduction

With the progressive internationalisation of higher education programmes and professional accreditation requirements, the innovation ability of engineering students is becoming a crucial skill (Passow & Passow, 2017). At present, many students in engineering education complete their degrees with very low innovation awareness, leaving them ill prepared for the challenges of their future professional careers (Qin & Xiao, 2017). The overall objective of this paper is to identify effective ways to improve student innovation ability.

There have been initiatives in many countries for engaging students in new types of training experiences, trying to raise awareness and improve their innovation skills (Smithtolken & Bitzer, 2017; Ren *et al.*, 2015). These initiatives are complementary to traditional university lectures and tutorials, and generally take place outside the classroom.

Student communities are one of the typical forms of learning outside the classroom, acting as an important driver for making innovation education more effective in universities (Ebenezer *et al.*, 2018). Science and Technology Innovation Communities (STICs) constitute a significant proportion of these student communities in STEM (Science, Technology, Engineering, and Mathematics) education.

STICs have proven to be very effective in cultivating student innovation ability, and have received considerable research attention (e.g. Ebenezer *et al.*, 2018; Miao *et al.*, 2016; Liang, 2015). Previous research into STICs though has focused on the *macro-level* analysis of STICs and its influence on student innovation ability. In this regard, most research has focused on the competitive challenges of STICs community members (Zhang & Zhang, 2013), the modes of operation of joint school-enterprises (Tian & Wang, 2015) or the construction of teams within STICs (Fan *et al.*, 2016).

However, how innovation ability is effectively and/or differentially acquired by the actors of STICs has not yet been analysed. In particular, it is unclear how innovation ability is passed on from some actors to others, or even how the actors need to be exposed/connected if they want to increase their abilities faster.

These questions appear to be specially suited to Social Network Analysis (SNA), a technique that has been lately used to study online communities (Phillips *et al.*, 2017; Lacalle & Simelio, 2017; Fields *et al.*, 2016; Pan *et al.*, 2016) and learning communities (Liu, 2017; Jankowski-Lorek *et al.*, 2016; Lin *et al.*, 2016). These studies have found that the network structure and location attributes of a community organisation can significantly influence how certain abilities are effectively acquired by its members. However, previous research into the application of SNA in STICs is very scarce. This is an important issue though as, similarly to other types of networks, it is expected that STICs network structures and the members' location attributes will eventually determine how much the latter acquire innovation ability.

A few exceptions are Santonen and Ritala (2014) who focus on STICs management, and Vildósola et al. (2013) who focus on comparative research in STICs.

Therefore, the specific objectives in this study are: (1) to investigate the basic characteristics, and identify existing problems, of the STICs organisation network; (2) to examine the relationship between the descriptors of the STICs organisation network and engineering students' acquisition of innovation ability; and (3) to propose paths to improve the organisation management and acquisition of student innovation ability in STICs.

To achieve these objectives, this study adopts a multi-case SNA approach combined with a questionnaire survey and semi-structured interviews. The combination of these three methods allows us to analyse how the engineering students in STICs effectively and differentially acquire innovation ability. In particular, SNA is used to analyse the members' network location and its correlation with the acquisition of innovation ability, which is measured by the questionnaire survey. The semi-structured interviews with twenty relevant members of STICs combine both lexical and semantic methods. Several case studies are analysed encompassing three STIC networks from China's Chang'an University.

2 Literature Review

In order to identify the necessity and feasibility of the research further, this section first introduces innovation ability and university students, and identifies the measurement indicators involved. It then analyses the relationship between STICs and student innovation ability. Finally, the application of SNA in engineering education is summarized, guaranteeing the feasibility of the application of SNA in this study.

2.1 Innovation Ability and University Students

Innovation ability has been increasingly seen as a key competence of engineering students in recent years, mostly because of the proliferation of engineering education accreditation schemes (Qin & Xiao, 2017). For instance, Matemba and Lloyd (2017) rank innovation as most precious and rare of the abilities of African engineering students, while Dukhan and Rayess (2013) find innovation to be one of the abilities most valued by North American students. Its importance is also highlighted in Qin and Xiao's (2017) recent case study comparing the engineering accreditation requirements of the United States, Germany, and China. They also proposed ways to improve the seemingly lack-of-innovation ability of Chinese students.

However, there is no consensus yet on a set of indicators that can measure student innovation ability. Currently, most engineering accreditation bodies resort to just 'innovation learning' as the sole factor defining the successful acquisition of innovation abilities by graduate students - factor generally measured as a student's academic achievement in subjects that involve innovation as part of their course content. Conversely, most studies of university students break down the 'innovation ability' construct into a series of (sometimes diffuse and overlapping) concepts in terms of learning, knowledge, thinking, practice, environment, awareness, motivation, and skill (Table 1).

Table 1. The evaluation indicators of students' innovation ability in the past 5 years

	A	B	C	D	E	F	G
Liu (2018)	✓		✓	✓		✓	
Keinänen et al. (2018)		✓	✓	✓	✓	✓	
Liu (2017)	✓	✓	✓		✓	✓	✓
Yue et al. (2017)	✓		✓	✓		✓	
Wang et al. (2016)		✓	✓	✓		✓	
Chen (2016)	✓	✓	✓	✓			✓
Fu et al. (2015)	✓	✓	✓	✓	✓	✓	
Zuo (2014)	✓		✓	✓		✓	✓
Zhao et al. (2014)		✓	✓	✓	✓		
Proposed index in this research	✓	✓	✓	✓		✓	

Key: A: Innovation learning ability; B: Innovation knowledge ability; C: Innovation thinking ability; D: Innovation practice ability; E: Innovation environment; F: Innovation non-intellectual (awareness, motivation, etc.) factor(s); G: Innovation skill.

2.2 STICs and the Innovation Ability of Engineering Students

A STIC can be considered a form of student community that is mostly aimed at enhancing the innovation ability of its members (Shi *et al.*, 2015; Song *et al.*, 2016). These student communities are formed by volunteers who run activities to engage their members. The actors involved are generally engaged in mutual learning through hobbies and common interests. Hence, STICs are the epitome of university innovation education outside the classroom, and the platform for students to develop and test innovative products and/or practices.

The beneficial outcomes to students being involved in such communities have long been known (Smithtolken & Bitzer, 2017; Ren *et al.*, 2015). However, it was not until Ren et al.'s (2015) and Padilla-Angulo's (2017) studies that it was realised that student communities' extracurricular innovation training cannot be replaced by any other in-class experience or traditional form of tuition.

Current research into STICs and student innovation ability can be summarised into two categories. On the one hand, many studies have been devoted to trying to improve student innovation ability by perfecting the engineering education system and/or training models (Zhang & Pang, 2015), developing specific community characteristics (Yuan & Liu, 2012), or improving the operation of the communities themselves (Ma *et al.*, 2016; Zhan, 2014). On the other hand, studies have also focused on enhancing student innovation ability by designing science and technology competition activities (Ran & Dan, 2016; Zhang & Zhang, 2013).

However, there are a few studies of the impact of the STIC organisation network on student innovation ability. Of these, Gao and Gu (2014) analyse how knowledge is shared within a STIC depending on its organisational network; Martíneztorres (2014) build an online STIC based on open innovation, and analyse the behaviour of community members using SNA; and Santonen and Ritala (2014) also use SNA to examine the organisational structure and management practices of the International Society for Professional Innovation Management. However, no studies have yet analysed the position of the community members and how that promotes (or hampers) the acquisition of innovation ability within the STIC. Given the varied positions and degrees of involvement that engineering students can have in a STIC, it seems important to understand how these factors effectively condition the eventual acquisition of innovation ability.

2.3 SNA in Engineering Education

Social network analysis (SNA) is a sociological research method that quantifies the structural aspects of a group of entities (people, companies, etc. - generally named *actors*). It can describe the relationship between these actors, while also analysing the internal structure of organisations to which these actors belong (Pappi, 1991). SNA has been widely used in library information, educational theory, management studies, macroeconomics, and sustainable development, among many others fields of study (Sharma *et al.,* 2015). It has also been used intensively in engineering education. Recent examples of SNA applications are studies of the relationship between engineering education and student learning (Mackellar, 2016; Putnik *et al.*, 2016), computational learning skills (Yáñez-Márquez *et al.*, 2014), and team learning (Lamm *et al.*, 2014; Joyce & Hopkins, 2014; Borrego *et al.*, 2013).

However, almost all SNA research applications in engineering education have focused on student team learning and professional development (Ferreira-Santiago *et al.*, 2016), mostly neglecting student innovation ability. For example, Korkmaz and Singh (2012), use SNA to analyse team learning in undergraduate sustainable construction courses for engineering students. Thomas et al. (2010) focus on professional development, identifying key assets and measuring the network strength of assets within a sustainable engineering asset management course. Currently, very little research focuses on student communities and their organisation networks, much less on how these organisations can promote student innovation ability. By addressing this research gap, the current study will help universities to better understand (and offer) extracurricular activities that are more effective in promoting the innovation awareness and ability of their students.

3 Research Methodology

An effective methodology is a bond between research questions and results. Hence, this section first proposes two research hypotheses based on theoretical analysis. It then discusses in detail the basic concepts of SNA and its application in this study. Finally, two methods of data collection are designed, one is the questionnaire for constructing the STICs organization network and measuring the students' innovation ability, the other is the semi-structured interview for proposing measures to improve the students innovation ability through STICs.

3.1 Research Hypotheses

Two ego-network SNA indicators are used. These describe the structure of networks (in this case, STICs) whose nodes represent individuals (in this case, engineering students). These are network centrality indicators (in different forms) and the number of structural holes. Network centrality is a measure of the importance of network nodes (actors) in a particular group. This indicator is used to quantify the importance of an actor (member) within his/her STIC network. Community actors with high centrality generally have many direct contacts, as well as easier and quicker access to information. This means that central actors should also be in an advantageous position to receive, filter, and spread innovation-related information. Based on this assumption, the hypothesis is that STIC actors with higher centrality should be in a preferential position to transform innovation-related information into the actual acquisition of innovation ability:

H1: *The centrality of engineering students within a STIC organisation network is positively related to their innovation ability.*

In addition to considering the actors' centrality in the network, the structural holes indicator is also considered in the SNA of student communities. A structural hole is understood as a gap between two individuals with complementary sources of information. For example, a person who connects (serves as a mediator between) two or more densely connected groups of people could gain an important comparative advantage, as all information goes through him/her when being transferred from one group to another. This means that the structural holes reflect the positional advantage of nodes in a social network. In engineering education contexts, positional advantage represents a particular type of social capital.

Some studies analyse the influence of structural holes, and how information flows between nodes. For example, Adamic et al.'s (2003) study of a Stanford University's online community through the Nexus website shows that the community's particular structure helps promote the flow of information between students. In addition, based on the absorptive capacity of graduate students, Zhao and Zheng (2018) find that the structural holes of tutors in a social network has a positive impact on the innovation ability of their graduate students. Similarly, through the structural holes of non-redundant connections in an innovation network, Feng et al. (2014) find that structural holes in the innovation network also have a positive impact on innovation behaviour.

In a STIC organisation network, the actors of the community occupying structural holes should also have prime innovative information and be better positioned to control information. They can not only obtain non-redundant innovative information, but also selectively process and filter the innovation information acquired. Therefore, actors occupying structural holes should be in a privileged position to transform innovative information into actual innovation ability. The second hypothesis is then:

> ***H2:*** *A higher number of structural holes within STIC organisational networks is positively correlated with higher innovation ability.*

3.2 Research Method

A multi-case (three STICs) SNA is carried out from the information gathered in the second section of the questionnaire. The SNA mostly focuses on calculating the centrality and structural holes indicators of the three STICs actors. Then, with the innovation ability assessment from each actor in the third part of the questionnaire, it is possible to establish the correlation between the two SNA indicators and the innovation ability of their actors. The research steps are:

(1) Build the STIC organisation network using questionnaire items 6 and 7 by means of the *UCINET6.212* software.

(2) Identify the network location of all the respondents using the *NETDRAW* software, along with other network descriptive values (network density, cohesion, and E-I index).

(3) Calculate the network location indicators with *UCINET6.212*, using the three measurement indicators available for measuring network centrality: degree centrality, betweenness centrality, and closeness centrality (Pappi, 1991). Additionally, the 1-

Constraint is used as the structural holes indicator (Borgatti *et al.*, 2002; Vasudeva *et al.*, 2013).

(4) Use *SPSS21.0* to calculate the correlations between the network centrality and structural hole measurements with the innovation ability of the actors.

3.3 Data Collection

3.3.1 Questionnaire Design

A questionnaire with multiple questions addressing the different dimensions of innovation in Table 1 was created and answered by the actors. The questionnaire was finalised after a pre-survey stage involving a reduced number of STIC actors. It contains a first section eliciting demographic details from the respondents, comprising gender, grade (years at university), time (in the STIC involved), and position (period of membership). The second section extracts SNA-related information, the position of the respondent in his/her STIC, as well as the names of other close friends inside and outside the STICs. The third and final section contains a list of 12 items measuring the degree of the respondent's exposure and motivation to innovation ability-related experiences and his/her interests. This list of items is based on the five innovation ability indicators identified by 'Williams Innovation Tendency Measurement' (http://bit.ly/2PqPbGw) and Princeton's 'Talent Development Company' Innovation Capability Chart (http://bit.ly/2L97Isi). These items were measured by a Likert scale ranging from 1 ('very low' or 'extremely disagree') to 5 ('very high' or 'extremely agree').

3.3.2 Data Collection and Reliability Test

The questionnaires were completed by a sample of 92 Chang'an University engineering students who participated in STICs. Chang'an University is located in the city of Xi'an in

China's Shaanxi province. This is one of the country's strongest engineering education provinces, graduating a large number of high-quality engineering students every year. Chang'an University is one of the State "211 Project" key development universities and one of the State "985 Project" key development universities launching advantageous discipline innovation platforms. There are currently 15 STICs registered in the University, the most representative of which are the BIM Community, with the largest number of students, the Model Community, which is the oldest, and the Shahai Community, which is a newest, but very successful, entrepreneurial community.

A snowball sampling method was used to ensure the validity and authenticity of the data. First, three students were randomly selected as the first respondents from the three communities. From the names of their friends, subsequent students were contacted and asked to provide more names within the scope of the three STICs. This process was continued until all the actors in the three STICs had been named at least once. The questionnaire was distributed through the platforms *WeChat* and *QQ*. The number of questionnaires issued, completed, and considered valid are shown in Table 2.

Table 2. Questionnaires issued and returned

STIC	Nº issued	Nº completed	Nº valid	Recovery	Efficiency	Release	Closure
BIM	45	40	37	88.8%	92.5%	11.4.2018	15.4.2018
Shahai	30	24	21	80.0%	87.5%	14.4.2018	17.4.2018
Model	45	37	34	82.2%	91.9%	14.4.2018	22.4.2018

As can be seen, the recovery (completed/issued) and efficiency (valid/completed) rates exceed 80% in all cases, which is taken as an indication that the responses are sufficiently representative. Cronbach's α is 0.868, greater than the 0.7 cut-off that is generally recommended (Cronbach, 1951).

3.3.3 Semi-structured Interviews Design

Semi-structured interviews are informal interviews based on an open set of predefined questions, but new ideas can also be introduced because of what the interviewee says (Figueira *et al.*, 2016). This type of interview combines the rigor of structured interviews with the flexibility of unstructured interviews. In this study, semi-structured interviews were conducted to identify the problems in STICs and explore potential ways of improving student innovation ability. Consequently, the interviews revolved around three major questions of (1) what problems do you think your STIC has and how those are hindering its development? (2) what measures do you think could be taken to effectively solve or avoid these problems? (3) what aspects do you think could improve the student acquisition of innovation ability in STICs?

3.3.4 Semi-structured Interview Data Collection

Twenty actors with top centrality in the three STICs analysed were selected. Interviews were conducted from 8 to 28 September 2018 by instant messaging, telephone conversations, and face-to-face. The interview time was limited to half an hour. The interview steps were as follows:

(1) Interview outline: this initial stage explained the purpose of the interview to the interviewees, the major questions to be answered, and some ground rules (e.g., time of the interview, answers processing, anonymity issues, and information storage), and retrieved the interviewee's background information.
(2) Formal interview: the interviewer's pre-selected questions were asked and the interviewees' answers recorded. All the interviews were transcribed into written material.
(3) Analysis: using a combination of the lexical and semantic method, three rounds of inductive analysis were conducted of the interview transcriptions. Similar ideas were unified and a classification of the major categories was eventually developed.

4 Results

Based on the three specific objectives, this section first explores the existing problems with STICs through a whole network analysis. It then uses the SNA to calculate the centrality degree and structural holes of engineering students and determines the relationship between the STICs organization network and engineering students' innovation ability through correlation analysis, robustness analysis, and regression analysis. Finally, it proposes three essential ways for STICs to improve student innovation ability through semi-structured interviews.

4.1 Network Location of Engineering Students in the STICs Organisation Network

Fig. 1 shows the network obtained from the three STICs, with the respondent names coded to protect their privacy. The code name contains the community number as the first digit (1: BIM Community, 2: Shahai Community, 3: Model Community) and the next two digits to differentiate the actor number. For example, 124 means the 24th actor of the BIM Community.

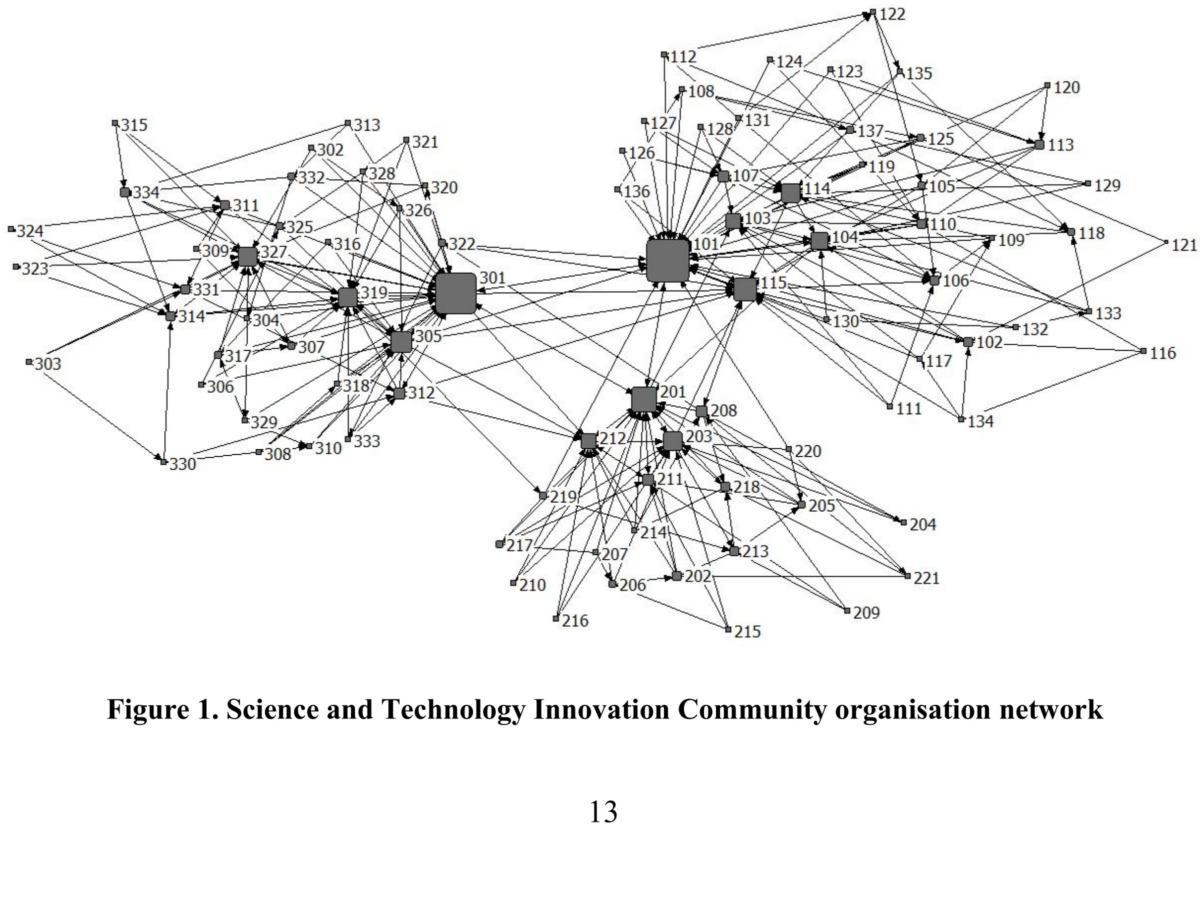

Figure 1. Science and Technology Innovation Community organisation network

The size of the nodes represents the centrality of the actors. Actors 101, 203, and 301 are the nodes with the highest centrality degree in each community. This indicates that they have many direct contacts and exert a great influence on their communities. Actors 115, 114, 104, 201, 212, 208, 319, 305, and 327 also have a large centrality degree, indicating that they are quite active and influential actors. Actors 101, 203, and 301 are the chairpersons of each community; 114, 104, 201, 212, 208, 319, and 305 are ministers (deputies), whereas 115 and 327 are actors that appear to be well-liked community actors. Therefore, most core actors within these communities seem to be concentrated in the management team.

The whole network density is 0.1015, the average distance is 1.315, cohesion is 0.467, and the E-I index is -0.766. These measures indicate that the links between the actors are sparse, the cohesion is moderate, and that most actors' ties are internal within their own STIC. Overall, this means there are few links between different STICs (contacts are mainly concentrated between the actors who belong to the same community). This is detrimental to STICs enhancing student innovation ability.

For the sake of brevity, only an excerpt of the three centrality indicator values (degree centrality, betweenness centrality, closeness centrality) of all community actors and the structural holes is shown in Table 3.

Table 3. Example of the network analysis data

Member number	Degree centrality	Closeness centrality	Betweenness centrality	Structural holes
101	34.066	56.875	39.395	.887
102	7.692	39.912	2.652	.605
…	…	…	…	…
137	5.495	37.603	.521	.618
201	19.780	51.705	17.777	.799
202	6.593	36.255	.690	.593
…	…	…	…	…

221	4.396	31.058	.107	.594
301	31.868	55.152	36.086	.874
302	3.297	36.546	.018	.160
…	…	…	…	…
334	7.692	30.435	.414	.643

4.2 Correlation between Network Location and Innovation Ability

4.2.1 Sample Descriptive Analysis and Attribute Data Variance Analysis

Sample descriptive analysis describes the basic features of data; for example, the summary statistics of the scale variables and measures of the overall proportion (impact) on the sample from each variable. Kline (2015) proposes that, providing the sample skewness remains between -3 and +3 and kurtosis is below 10, it can be assumed that the data distribution is approximately Normal. The skewness and kurtosis are 2.263 and 8.094 respectively, which fulfills both conditions. Therefore, the data are deemed valid for the Levine's test for homogeneity of the effect on innovation ability shown in Table 4.

The results of the independent *t-test*s in Table 4 summarise whether the values of the individuals' attribute variables (gender, grade, time, and position in the community) have a significant effect on innovation ability.

Table 4. Homogeneity tests of variances and mean differences on innovation ability

Attribute data	Sort	Number	Levene test of variance equality		t-test of mean equality	
			F	Significance	t	Sig. (2-tailed)
Gender	Male	74	.029	.865	.394	.694
	Female	18				
Grade	Sophomore and below	77	.014	.905	-1.535	.128
	Sophomore or more	15				
Time	≤ 1 academic year	58	5.137	.026	-1.876	.067

	≥ 1 academic year	34				(Bootstrap)
Position	Non-community actor	61	.576	.450	-4.350	.000
	Community actor	31				

The significance values of the *F-tests* of the actors' gender, grade, and position in communities all being greater than 0.05 is taken as an indication that the sample is sufficiently homogeneous, as the p-value for the variable 'time' is lower than 0.05, bootstrapping is used to correct its variance, eventually allowing it to be treated as homogeneous too. However, of all the t-tests, only the variable 'position' is regarded as relevant in conditioning innovation ability.

4.2.2 Correlation Analysis

The relationship between the actors' position, centrality, and structural holes in the STIC organisation network with their innovation ability is summarised in Table 5. Spearman's non-parametric correlation coefficient is preferred here, as each variable represents sequential data (the series of community actors). The correlation results of each independent community are consistent with the test results of the combination of the three communities (the ones shown in Table 5). More precisely, although all the correlation coefficients in Table 5 are lower than 0.5, all are significant at the 0.01 level. Therefore, there seems to be a significant positive correlation between the actors' positions (0.304, $p<0.01$), centrality (0.438, $p<0.01$), structural holes (0.362, $p<0.01$), and their innovation ability in STICs. The results are consistent with the correlation tests of the separate communities.

Table 5. Binary correlation coefficients between variables

		Mean	Std. Error	position	degree centrality	structural holes	innovation ability
STIC	1.position	1.1400	.3500	-			
	2.degree centrality	6.5220	5.4222	.400**	-		
	3.structural holes	.4377	.2310	.156	.660**	-	

4.innovation ability	3.7649	.6088	.304**	.438**	.362**	-

Note: ** denotes being significantly correlated at the .01 level (two-tailed).

4.2.3 Robustness Analysis

Network centrality can be measured in different, but complementary ways. Pappi (1991), for example, has proved the connection between betweenness centrality and structural holes, whereas degree centrality and closeness centrality are also close concepts. In order to ascertain whether different conceptions of centrality produce different results, a sensitivity analysis is conducted by replacing degree centrality and structure holes in Table 5 with the closeness centrality and betweenness centrality indicators. Table 6 presents these results, showing that these correlations, despite being weaker, are all still significant at the 0.05 level. Therefore, there appears to be strong evidence suggesting that there is indeed a significant positive correlation between the actors' positions, their centrality, and structural holes with their innovation ability in STICs.

Table 6. Robustness tests

		Mean	Std. Error	Position	Closeness centrality	Betweenness centrality	Innovation ability
STIC	1.position	1.1400	.3500	-			
	2.closeness centrality	37.0553	5.2515	.373*	-		
	3.betweenness centrality	1.9417	6.0218	.428*	.766**	-	
	4.innovation ability	3.7649	.6088	.304**	.377*	.356**	-

Note: ** and * denote significantly correlated at the .01 and .05 level (two-sided) respectively

4.2.4 Regression Analysis

In order to test whether the influence of different explanatory variables on the regression model's coefficient is significant, regarded the engineering students' innovation ability as the outcome variable, the centrality (model 1) and structural hole (model 2) as independent variables are gradually included in the model for regression analysis. The test results for model collinearity show that the model does not have serious collinearity problems. Table 7 shows that both models 1 and 2 pass the significance test. Compared with Model 1, the R^2 of Model 2 has increased, indicating that the adjunction of structural holes has significantly improved the explanatory power of the model, and therefore the saliency of the model and explanatory power are guaranteed. The regression test results show that, within a certain range, the centrality and structural holes have a significant contribution to improve student innovation ability.

Table 7. Results of the multiple linear regression analysis

	Model 1	Model 2
degree centrality	.377***(.011)	.277**(.012)
structure hole		.246*(.277)
constant	2.147	2.287
Adj-R^2	.377	.439
F-test	14.879	10.623
VIF	1.000>.1	1.195<10

Note: ***, ** and * denote significantly correlated at the .001, .01 and .05 level (two-sided) respectively. The standard error is shown in brackets after the coefficient.

4.3 The measures that STICs can improve engineering students' innovation ability

After observing the relationship between the STICs organizations network and engineering students' innovation ability, this section continues to explore the problems of STICs and the effective approaches to improve the acquisition of student innovation ability through the STICs organization network. The top twenty central actors were interviewed, the output of which were recorded mainly in writing. These texts were then combined and analyzed lexically and semantically by the research team. Three major measures were identified (as shown in the Table 8).

Table 8 Results of the semi-structured interview

Measures	Examples of Suggestions/Ideas	Member	%
Give full play to the core actors and foster the students' innovation ability by competitions	... the activities we take can be changed to matches or competitions ...; ... STIC core members always lead. The activities organization could be rearranged to be more competitive	107;211;327;114;212;104;203;115;208;101;319;301	60%
Improve the institutional governance system of the STICs to stimulate the organization development more effectively	... adopt attendance systems and reward measures ...; ... change the management approach of the community, increase the entry standards for community access	211;313;102;327;201;115;212;312;305;101	50%
Increase the teachers' support and strengthen cooperative learning between different STICs	... strengthen communication and cooperation with lecturers …; ... cooperate with the lecturers who are in charge of community guidance	107;211;103;115;305;101;301;208	40%

5 Discussion

The analysis indicates that the innovation ability of engineering students is significantly and positively correlated with the actors' centrality and structural holes within the STIC organisation network. This confirms both *H1* and *H2*, and is also consistent with observations from the few existing studies of STICs.

Firstly, STIC actors with a higher network centrality tend to be more recognised by other actors and more active in their community. They are also more likely to obtain innovative information first-hand, exchange innovative knowledge, generate innovations, and have stronger innovative knowledge and skills. They can also take advantage of their network location to have a greater impact on their innovation undertakings.

Secondly, STIC actors that lie in structural holes have more innovative information and more control over information. They can not only shape the innovative information of the community, but also obtain innovative information from other communities. Therefore, the actors who occupy more structural holes have a greater potential to transform innovative *information* into actual innovation *ability* by using their location characteristics. Eventually, this also allows them to have a greater impact on the innovation ability of the community.

Additionally, the whole network analysis showed that the community's cohesion is weak, the connection between actors is sparse, and most core actors are concentrated in the management team. This is similar to the result of the semi-structured interviews. Moreover, three measures are proposed through semi-structured interview, which aim to solve or avoid STICs problems and improve the student acquisition of innovation ability in STICs. The three measures are to:

(1) Give full play to the core actors and foster the students' innovation ability by competitions. 60% of the interviewees believe that "core actors should lead other actors when participating in competitions … allow others to organise competitions … [or] receive competition training". Many also agreed on that core actors should "try to engage [other] actors in community activities … [and] incorporate the results of the competitions into the [university] assessment system". In actor 208's words:

> *The BIM community in which I participated has hosted some BIM Modelling Competitions, and the results achieved are not bad. It is obvious to see that my progress in the community is substantial. However, in the community, sometimes I feel a little powerless, because of the members' insufficient awareness of community activities. We should vigorously explore the advantages of community activities, organise more competitions, and incorporate activity achievements into the assessment system. Promoting the enthusiasm of members about activities is necessary, as well as helping actors to master relevant innovative knowledge and*

> *improve their innovation ability. Only in this way, we will be able to promote the development of [our] communities ...*

(2) Improve the institutional governance system of the STICs to stimulate the organisation development effectively. Namely, 50% of the interviewees mentioned that the entry requirements to STICs, as well as the recognition of its actors, should be reconsidered. They proposed measures such as “raising the threshold for community access”, “establishing an attendance system” and “creating a reward system” to ensure the quality of communities. This is because “the STICs have higher professional requirements for actors”, believing that “the establishment of a community access system can attract excellent students for communities, and avoid mediocre ones”. This would also ensure that “only those students who are really interested would join the communities”. As actor 305 said:

> *I think our community is generally okay, but there are still some problems, such as cohesion is not high and the enthusiasm of actors is not strong. I think there are two reasons. First, the interest and ability of the actors does not often match the requirements of the STIC. STICs [in Chang'an University] nowadays have strong professional requirements for actors. However, many students only enter the community out of curiosity. After joining, they find their abilities are not suited to that community and withdraw from all activities and the management of community. Second, community activities are not fully integrated with the assessment system. The community activities are entirely voluntary and 'vocational'. Sometimes this is not conducive to long-term development. I think we should establish a community access system to ensure that the prospective students' interests match those of the community ...*

(3) Increase the teachers' support and strengthen the cooperative learning between different STICs. 40% of the interviewees mentioned that “[engineering] schools should increase their support for community activities”. 35% proposed that schools could provide more support by “sharing more teachers” or “bringing in more

professionals”. Judging by the three STICs network density descriptors, it is clear that the STICs cohesion is not strong enough and there are few links with external actors of other communities. As actor 104 commented:

> *I think the role of teachers is the biggest influence on the development of STICs. Teachers are always more familiar with our professional development or the technical prospects of our studies. Teachers can organise some science and technology lectures to identify and work on relevant socio-technical needs, and mostly to improve student interest in innovation. In addition, I hope that the school can invest in more professional teachers to guide students to participate in competitions, fully use the role and support of the school platform, strengthen cooperation and learning among the communities, and promote the development of communities ...*

6 Conclusion

Innovation ability is considered one of the most important abilities engineering graduates can possess, and recent research in STICs has found that student-led communities can play an important role on nurturing its acquisition. This is the first study to focus on the relationship between the STIC organisation network and the innovation ability of engineering students. SNA is used in three Chang’an University STICs and reveals that the network structure of STICs has a significant influence on how these communities cultivate such innovation abilities. In particular, the network centrality and structural holes of their actors are significantly and positively correlated with the acquisition of the actors’ innovation ability.

The implications of these findings are varied. For example, it is now known that STICs can promote higher levels of innovation ability by optimising their organisational networks. This could be achieved by increasing the number of connections between STIC actors (e.g. through more competitions, common events, or training opportunities), and establishing more contacts with actors from other STICs. The study also used semi-structured interviews with top central STIC actors, inviting them to provide ideas of how to improve the governance of STICs. Some recurring ideas include leveraging core actor values by competitions, strengthening cooperative learning by increasing teacher guidance, and requesting more restrictive entry requirements to the STICs by the host institutions.

The study is limited by the sample size analysed (three STICs) and its single-country focus. Certainly not all countries face the same challenges regarding innovation, nor even have STICs. Still, recent research ranks innovation as one of the most precious and rare abilities of engineering students of different continents. However, that some countries do not have STICs does not necessarily mean their higher education institutions cannot eventually create them. Similarly, it is expected that the structural network correlations with the students' acquisition of innovation ability will be similar in other countries or regions, although perhaps with a different intensity. Future research in a more representative set of locations (regions and countries) should be able to corroborate this.

A further limitation arises from having measured the students' innovation ability by asking the students themselves. Individuals' self-perception, as is well known, may be imprecise and biased. In addition, in the absence of a standard scale for measuring innovation, this study resorted to the "William's Innovation Tendency Measurement Scale" and "Princeton's Talent Development Company Innovation Capability Chart". Future research will benefit from the use of more representative and standard scales of innovation that also enable more rigorous comparisons to be made between different studies.

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Table 1. The evaluation indicators of students' innovation ability in the past 5 years.

Table 2. Questionnaires issued and returned.

Table 3. Example of the network analysis data.

Table 4. Homogeneity tests of variances and mean differences on innovation ability.

Table 5. Binary correlation coefficients between variables.

Table 6. Robustness tests.

Table 7. Results of the multiple linear regression analysis.

Table 8. Results of the semi-structured interview.

Figure 1. Science and Technology Innovation Community organisation network.