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Citation for the original published paper (version of record):

Malmqvist, J., Machado, T., Meikleham, A. et al (2019). Bibliographic Data Analysis of CDIO Conference Papers from 2005-2018. Proceedings of the International CDIO Conference: 816-833

N.B. When citing this work, cite the original published paper.

BIBLIOGRAPHIC DATA ANALYSIS OF CDIO CONFERENCE PAPERS FROM 2005-2018

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ABSTRACT

Tools for bibliometric data analysis offer opportunities to analyze the evolution of a field of study over time. VOSViewer is a popular tool for such analyses, allowing the user to create and interpret visualizations of publication data, such as word co-occurrence analysis, co-authorship networks, and geographic patterns of collaboration. Meikleham et al. (2018) previously demonstrated the utility of applying this analysis to engineering education publication data from Scopus and Web of Science. By conducting a temporal analysis, the authors demonstrated how geographic, co-authorship networks and key thematic trends changed over time. A limitation to the results found in Meikleham et al. (2018) was that, at the time of the analysis, publications from the CDIO Knowledge Library (CDIO Initiative, 2018) could not be included due to an incompatible data structure. VOSViewer requires publication metadata to be structured according to a particular standardized format, and this prevented the Knowledge Library data from being used. Over the past year, the data has been restructured for analysis as reported in this paper. The basis of the current work is a revision of the database schema for the CDIO Knowledge Library that has enabled export of CDIO conference papers to the Scopus format and subsequent import into VOSViewer for analysis. The data shows that researchers from 47 countries have contributed to the CDIO Knowledge Library with Sweden taking the lead with the maximum number of publications. Researchers tend to collaborate with the same co-authors over a period of time, thus forming networks or clusters of researchers. Each cluster of researchers tends to publish their work independently of other clusters. A newer network of authors has formed in the past 4 to 5 years who collaborate locally within a geographical region. This indicates a presence of local CDIO communities which have not yet integrated with the global CDIO community. In decreasing order of influence, CDIO Standards 8, 7, 3 and 5 have been the major focus of CDIO publications from 2005 until 2018 as indicated in the data included in this analysis.

KEYWORDS

CDIO, Bibliometric analysis, VOSViewer, CDIO Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The CDIO (Conceive-Design-Implement-Operate) initiative began in the year 2000 as a collaborative effort between four institutions from two countries. The aim of the CDIO initiative was to bridge the gap between newly-educated engineers and their related industries, to ensure that new engineers possessed the abilities to handle real-world scenarios (CDIO Initiative, 2019). This was accomplished by the collaboration of industry representatives, academic professionals, university review committees, alumni, and students to create the CDIO syllabus and CDIO standards which acted as a framework for transforming engineering education around the world. The CDIO initiative has now grown into a global network of more than 140 institutions from around the world. This growth has led to numerous contributions to the CDIO Knowledge Library that date back to the initiative's inception. The CDIO Knowledge Library is an extensive database of all the documents and resources required to implement a CDIO program such as the CDIO syllabus, CDIO standards, conference proceedings, and much more (CDIO Initiative, 2019). With the addition of the annual conference, first held at Queen's University Canada in 2005, contributions to the CDIO Knowledge Library have steadily increased from 24 entries in 2005 to 114 entries being shared in 2018.

Bibliometric data analysis is a quantitative and statistical analysis of a corpus of literature which can be used to gain an overview and insight into the impact of scientific publications (Ellegard and Wallin, 2015). Such analysis can be used to track citation data as well as to generate maps on the historical and geographical trends in publications such as the CDIO initiative (Meikleham et al., 2018). An open-source software tool called VOSViewer is used to construct, analyze and visualize two-dimensional bibliometric networks obtained from datasets. Attributes such as author names, country names, keywords, etc. are called entities in VOSViewer and are represented as circles or rectangles. The size of an entity is directly proportional to the number of occurrences or the number of documents associated with that entity, depending on the type of analysis being performed. The closeness of entities to one another indicates a strong relationship between the entities. The lines or curves connecting different entities represent a link or connection between entities, thicker lines/curves representing stronger links. Colours are used to denote clusters of items or entities that are related or grouped together.

As the CDIO initiative continues to grow and expand, utilizing available data can help to provide decision makers with a triangulation point for future decision making. Meikleham et al. (2018) visualized and analyzed the historical evolution of engineering education and the influence of CDIO by performing bibliometric analysis of relevant literature available from Scopus and Web of Science databases. The total of 1426 records was obtained by Meikleham et al. (2018) of which 881 were conference papers and 131 were proceedings papers. The investigation by Meikleham et al. (2018) revealed that the geographic network of collaborations as indicated by external publication data had expanded to 38 countries with a set of core collaborators and communities over a period of 17 years. These communities of researchers were found to become independent, or isolated, over time. It was also found that China followed by the United States of America were the most significant contributors on the topics of engineering education and CDIO in the databases that were analyzed by Meikleham et al. (2018). Throughout the years, it was found that a high emphasis was placed on learning tools with keywords such as engineering, design, student, and projects finding repeated and consistent mentions in the literature obtained from Scopus and Web of Science

databases. The limitation to the investigation by Meikleham et al. (2018) was that at the time of the analysis, the CDIO Knowledge Library data was in a format that prevented the use of software tool VOSViewer for bibliometric analysis, and therefore it was not possible to gain an understanding of how the internal corpus of literature has evolved over the same time period.

Over the past year, data in the CDIO Knowledge Library has been restructured into the Scopus metadata scheme, allowing for seamless use of the data and ability to compare with results reported in Meikleham et al. (2018). The CDIO knowledge library currently contains more than 1000 papers. Some data clean-up operations were needed to be performed prior to export. As an example, variations in the name of the same author were identified and merged while migrating the CDIO Knowledge Library into the Scopus format. This reduced name duplication in the Scopus export. With the new metadata structuring of the Knowledge Library, geographical collaborations, author collaborations, and topics of interest could also be analyzed using VOSViewer and the methodology previously described in Meikleham et al. (2018). The visualization process offers an ability to gain an insight into past trends and provides some insight into future opportunities for the CDIO initiative.

The main aim of this paper is to analyze the historical and geographical trends over time of the conference paper publications available in the CDIO Knowledge Library as well as to visualize the influence of the CDIO initiative on engineering education around the world. Thus, it is necessary to understand how authors and educational institutions from different countries collaborate with each other as well as how they contribute to, assimilate, and fulfill the visions of the CDIO initiative. Another objective of this paper is to compare how the data available in the CDIO Knowledge Library differs from data available in external databases such as Scopus and Web of Science and described previously in Meikleham et al. (2018). Further, this work provides a description of the process followed by the authors to restructure an existing dataset for integration to available, open-source software, providing readers with a framework that they could follow for other datasets in the future. This work is valuable for those looking to augment their analysis of datasets with VOSViewer. This framework, therefore, provides future authors with the necessary steps required to integrate their own datasets into the Scopus format for integration into VOSViewer and will allow future authors to compare findings with those published in this paper and previously in Meikleham et al. (2018).

METHODOLOGY

The Knowledge Library was restructured and migrated to export data structured analogously to a Scopus data file. Scopus exports bibliometric data structured in columns with the order and arrangement of these specific columns being imported seamlessly into VOSViewer. For example, there need to be two separate columns in the Scopus file format named 'Author Keywords' and 'Index Keywords' for the co-occurrence function of VOSViewer to work correctly. In the same way, author names, affiliation names, keywords, etc. need to be separated by specific punctuation marks to have a homogenous data set. These specific attributes were identified to ensure that the CDIO Knowledge Library export would function properly.

The following analyses were performed using VOSViewer: co-authorship analysis based on author name; co-authorship analysis based on author country; and co-occurrence analysis of author specified keywords as well as keywords extracted from the conference paper title. Co-

authorship analysis for both author name and author country were performed to visualize changes with different time periods and to perform a comparative analysis with the findings of Meikleham et al. (2018). A minimum threshold value of 3 documents per country was used for co-authorship analysis based on author country, the same as Meikleham et al. (2018). The co-authorship analysis was done for authors who have at least one document and who have collaborated with at least one other author. The punctuations after the author name in the Scopus data file were found to be important as VOSViewer considers punctuations as a new character. Thus, although duplicate author names were merged during the migration of the CDIO Knowledge Library to the Scopus format, VOSViewer was duplicating certain author names and creating false clusters. It is important that each author name ends with a full stop (.) even if it is the last name inside a column. This ensured that the authors were not eliminated from the analysis.

The keyword analysis was done in VOSViewer using the co-occurrence option. Only the author specified keywords could be analyzed from the CDIO Knowledge Library. An additional keyword co-occurrence analysis was done by extracting keywords from the paper title. The VOSViewer option to create a map based on text data was used for these keywords. A minimum of 3 occurrences of a keyword was the boundary condition for the keyword analysis.

The conference papers from the year 2005 to the year 2018 were exported individually to enable a year-wise analysis of the data. This enabled data analysis in the form of groups or clusters of authors, countries, and keywords for each year. The results of these analyses have been discussed without reporting the images. The conference papers were also exported in the following year groups: 2005 to 2007; 2005 to 2010; 2005 to 2012; 2005 to 2014; 2005 to 2016; and 2005 to 2018. This was done to enable the Knowledge Library data to be analyzed and compared with the analysis performed by Meikleham et al. (2018) as well as to understand the historical and geographical trends with time. Due to inconsistencies in the data of certain papers such as absence of author information, conference date and location data, etc., 30 papers were not included in the Scopus export.

RESULTS AND DISCUSSION

The number of archived conference papers per year from 2005 to 2018 is shown in Figure 1. The data shows that there was a rise in the contribution to the CDIO initiative from 2005 until 2011, except for the year 2010. In the period after 2011, there has been a steady number of contributions to the CDIO initiative each year. As Meikleham et al. (2018) point out, the steady state of the number of CDIO conference papers may be due to the absence of major changes to the CDIO approach. However, it is also interesting to note that the year 2018 witnessed the maximum number of conference papers since 2005. It can be further observed that the conferences with the largest number of papers have been held in either Asia or Europe, i.e., the two largest CDIO regions. The conferences with the lowest number of papers during the last ten years have both taken place in the North American region. This is a very important finding for CDIO leadership strategizing about future conference locations. On one hand, holding conferences in emerging areas is important to ensure the initiative continues to expand globally and attract new participants, while on the other hand, a lower volume of publications in that year may have intangible negative downstream effects. Equipped with these findings, CDIO leadership could ponder or implement policies and incentives to encourage participation at conferences in geographic regions with lower attendance rates, which would help mitigate this tradeoff.

VOSViewer Analysis - Co-authorship analysis based on country

The VOSViewer analysis was conducted for each year from 2005 to 2018. The number of participating countries gradually increased from 8 in 2005 to 16 in 2010. In 2011 the number of participating countries increased to 24 and remained nearly the same until 2017. The year 2018 witnessed 31 participating countries, which is the largest number for a single year. Figure 2 to Figure 7 shown below indicate the collaboration links of authors and co-authors across different countries.

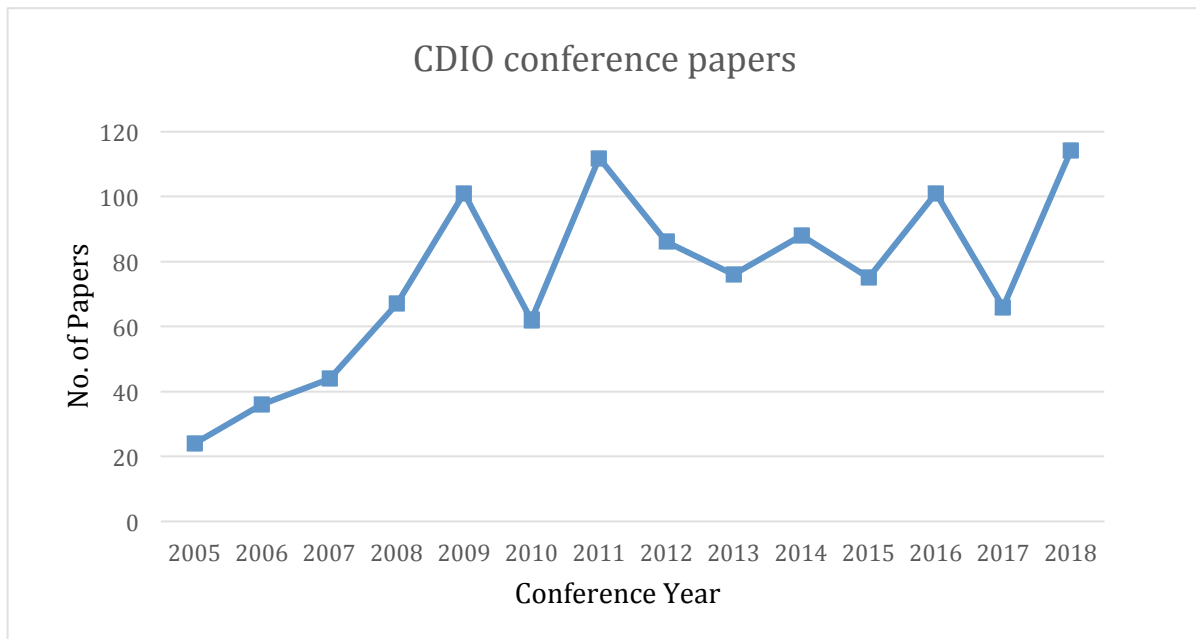


Figure 1. Number of archived conference papers per year in the CDIO Knowledge Library

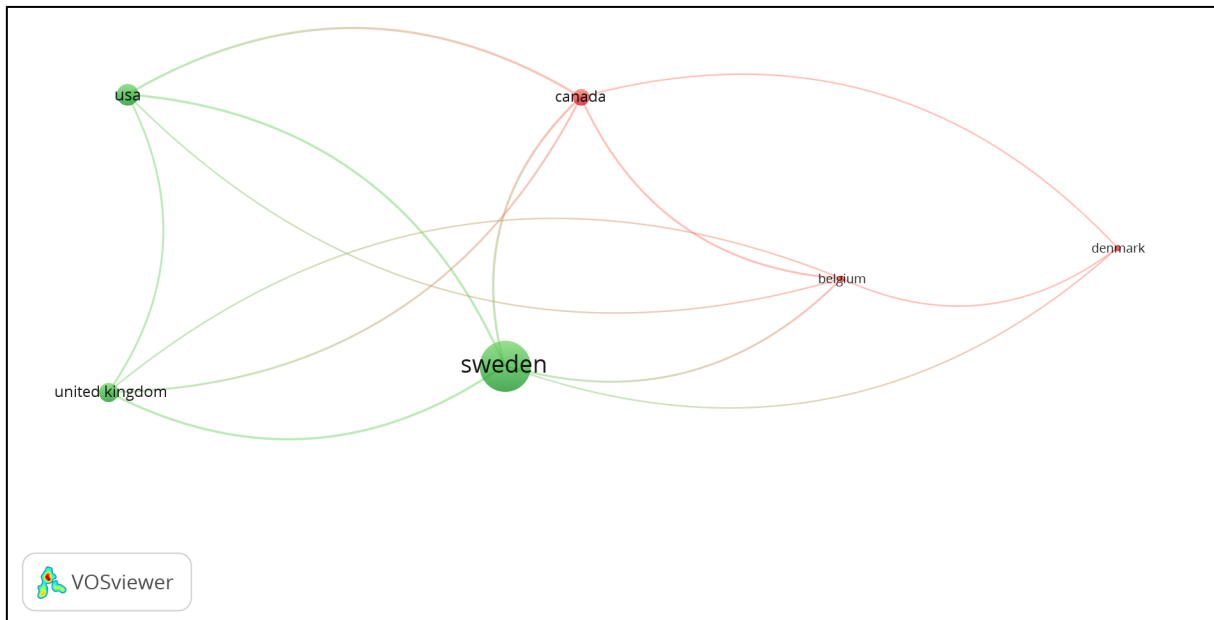


Figure 2. Countries with co-authorship collaboration from 2005 to 2007, 6 countries out of 16 countries with co-authorship links

The country-wise co-author collaboration from 2005 to 2007 as shown in Figure 2 excludes the contributions of China, Singapore, and South Africa as the authors from these countries did not collaborate with authors from outside their home countries. Similarly, the period from 2005 to 2010 in Figure 3 excludes the contribution of Finland, Portugal, Australia, South Africa and Malaysia; the period from 2005 to 2012 in Figure 4 excludes the contribution of Portugal, Japan, Malaysia, New Zealand, South Africa, and Russia; the period from 2005 to 2014 in Figure 5 excludes the contribution of Portugal, Russia, Malaysia, Columbia, and New Zealand; the period from 2005 to 2016 in Figure 6 excludes the contribution of Portugal, Columbia, and New Zealand; the period from 2005 to 2018 in Figure 7 excludes the contribution of Portugal, New Zealand, South Africa, Taiwan and Mongolia.

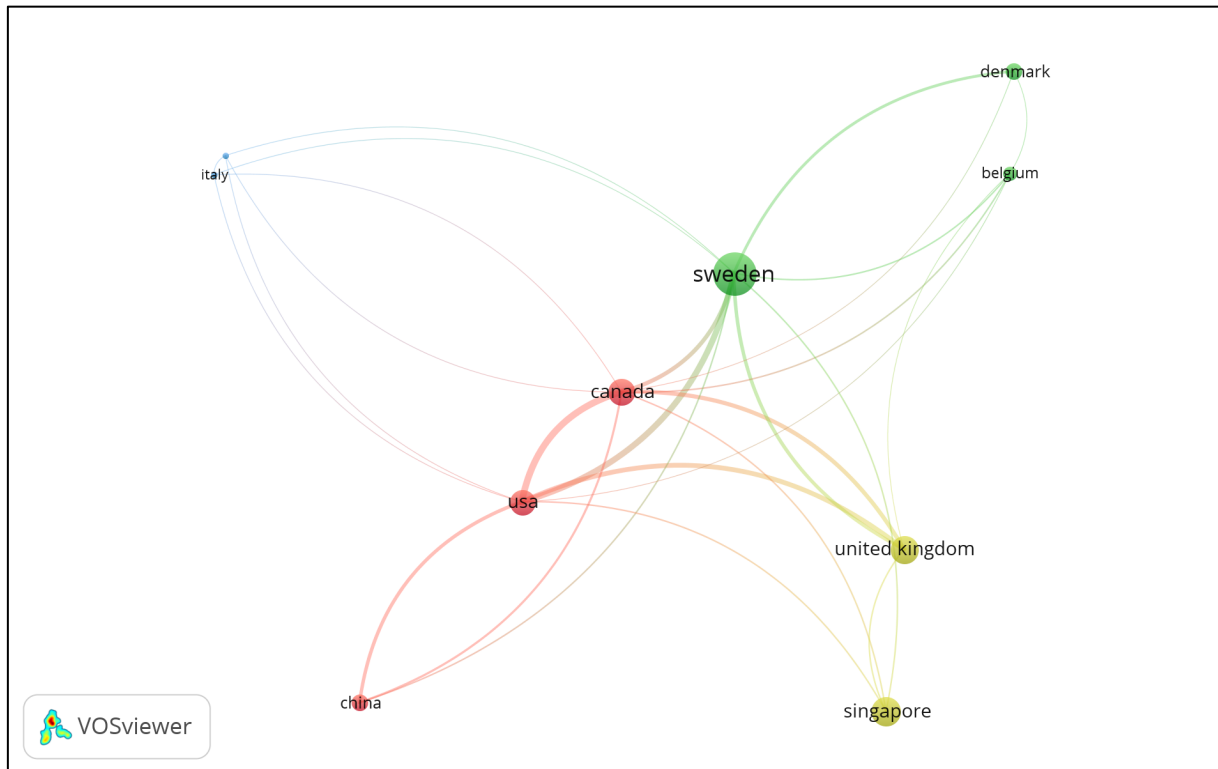


Figure 3. Countries with co-authorship collaboration from 2005 to 2010, 10 countries out of 26 with co-authorship links, 3 clusters formed.

A comparison with Meikleham et al. (2018), who examined CDIO data external to the CDIO Knowledge Library reveals very different co-author collaborations between countries, not only in terms of the links between countries but also in terms of the number of documents from a particular country. The finding that different collaboration patterns are observed in the CDIO internal conference data and the external corpus of literature is an extremely promising result as it provides a level of validation that the CDIO annual conference plays a role in forming collaboration networks that may not have existed otherwise. The difference in collaboration patterns from internal to external may indicate the presence of local CDIO communities who are increasingly publishing papers in external databases independent of the annual CDIO conferences.

The contributions of countries and the co-authorship links from 2005 to 2018 have been summarized in Table 1. As observed from Figure 2 to Figure 7 and Table 1, Sweden is the

country with the highest number of contributions to the CDIO Knowledge Library from 2005 to 2018. However, the Scopus database analysis performed by Meikleham et al. (2018) reports Sweden as the third largest contributor behind China and the United States of America (USA).

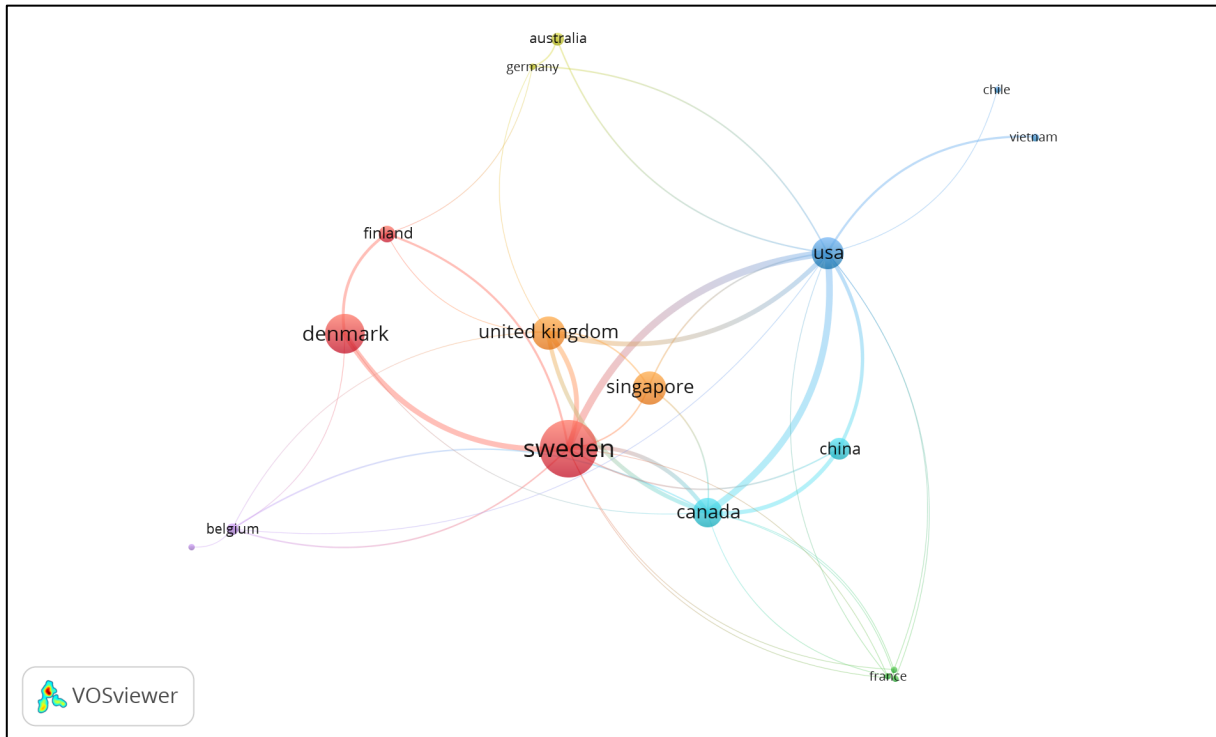


Figure 4. Countries with co-authorship collaboration from 2005 to 2012, 17 countries out of 31 with co-authorship links, 7 clusters formed

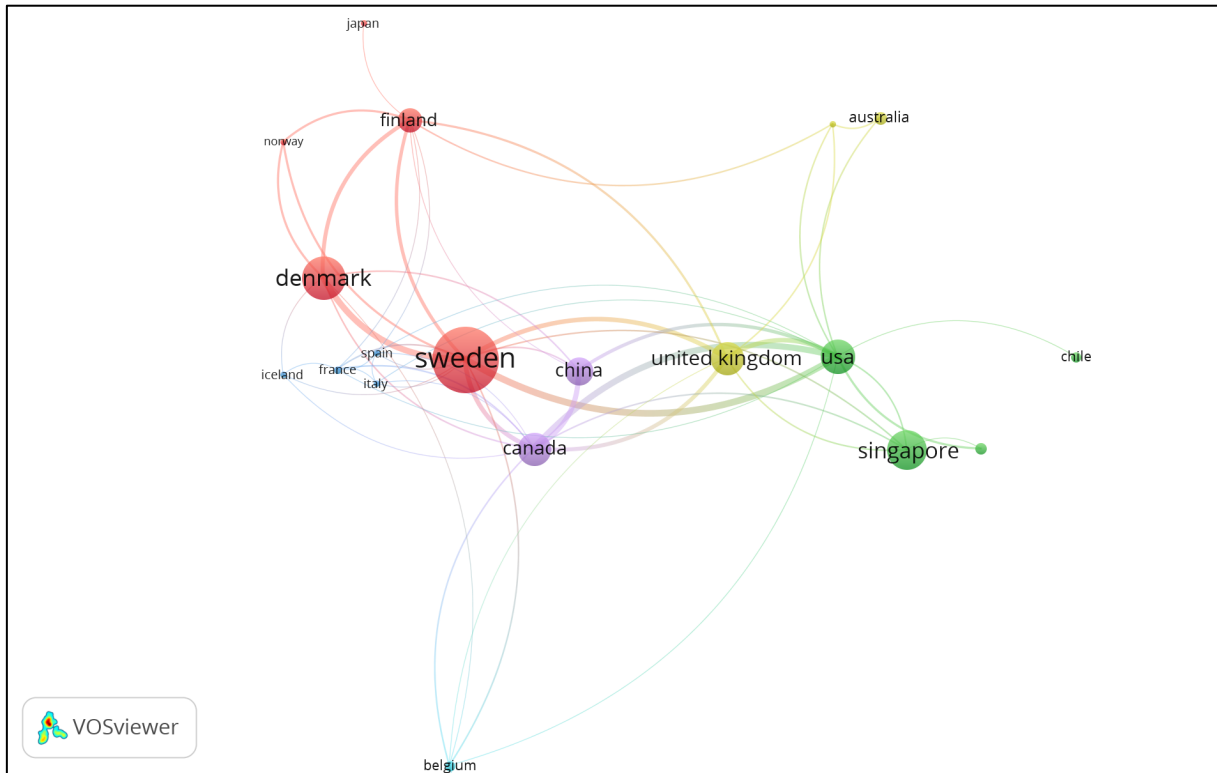


Figure 5. Countries with co-authorship collaboration from 2005 to 2014, 20 countries out of 36 with co-authorship links, 6 clusters formed

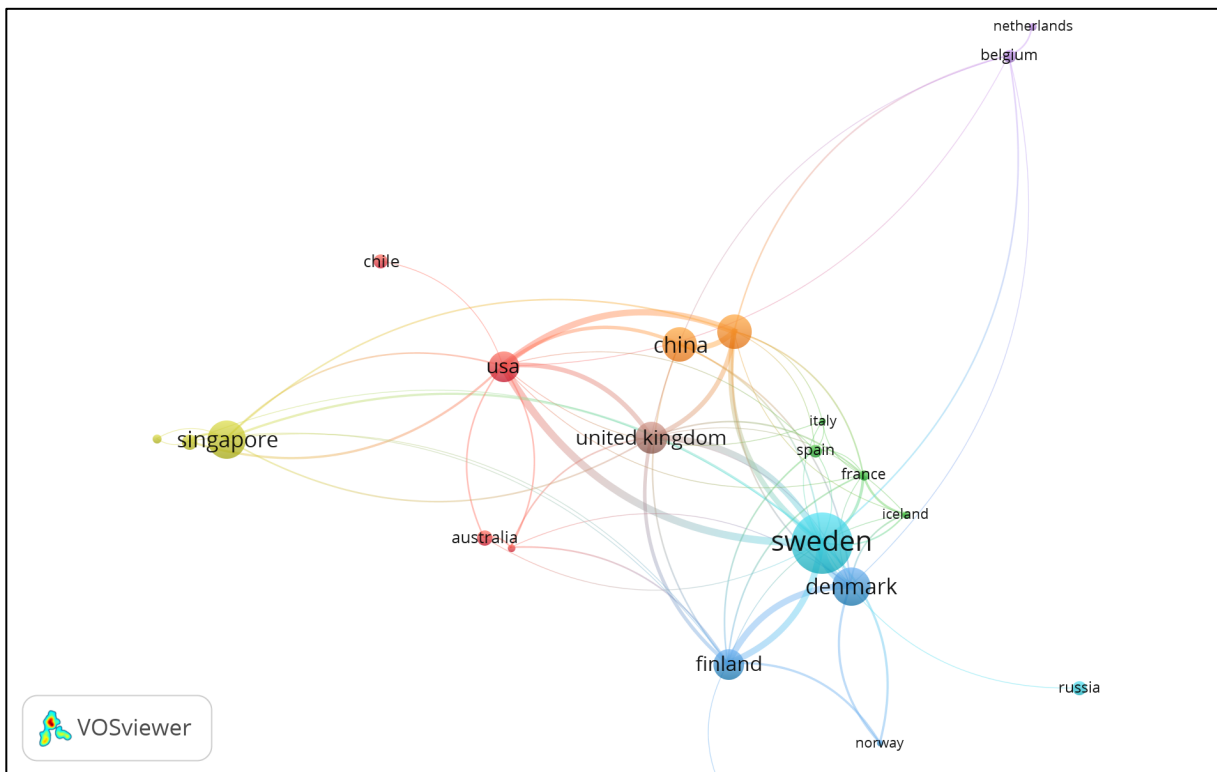


Figure 6. Countries with co-authorship collaboration from 2005 to 2016, 22 countries out of 38 with co-authorship links, 8 clusters formed (Out of frame- Japan)

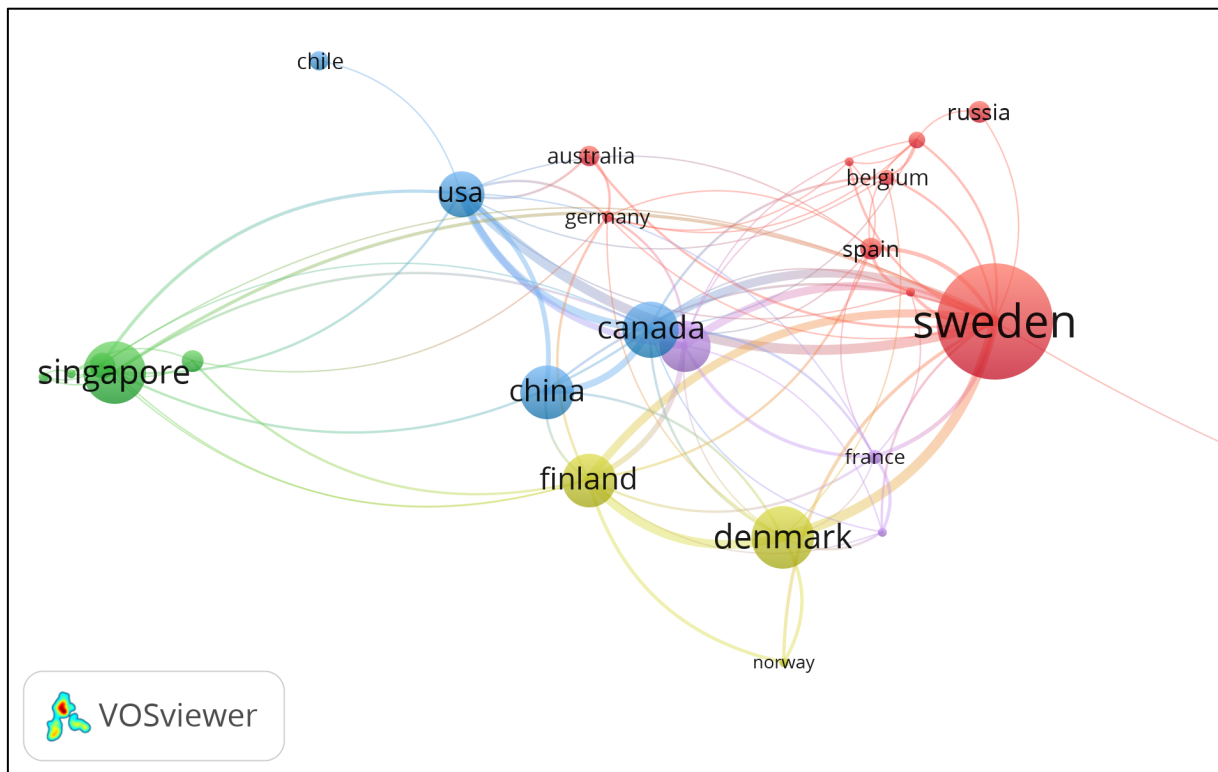


Figure 7. Countries with co-authorship collaboration from 2005 to 2018, 26 countries out of 47 with co-authorship links, 6 clusters formed (Out of frame- Colombia)

Examining only the CDIO Knowledge Library, China and Finland have been contributing significantly to the CDIO Initiative since 2010, China is the largest contributor in 2015, which coincided with that year's conference location (Chengdu, China). It can also be noted that Japan contributed significantly to the CDIO initiative in 2018, which coincided with the 2018 conference being held in Kanazawa, Japan. A repeating trend is observed for individual conferences wherein the maximum number of contributions to the CDIO knowledge library come from the country hosting the CDIO conference.

Table 1. Country Wise Co-authorship from 2005 to 2018 (Minimum 3 documents)

No.	Country	Documents	Collaboration Links
1	Sweden	219	90
2	Denmark	104	37
	Singapore	104	16
3	Canada	91	49
4	Finland	85	43
	China	85	19
5	United Kingdom	80	41
6	United States of America	70	49
7	Vietnam	36	12
8	Japan	29	5
	Russia	29	2

9	Spain	28	15
10	Australia	26	6
11	Chile	24	1
12	Portugal	23	0
13	Netherlands	22	10
14	Belgium	20	9
15	Columbia	18	1
16	France	17	19
17	Germany	13	14
18	Malaysia	12	3
19	Iceland	11	10
20	Brazil	9	2
	New Zealand	9	0
21	Italy	6	9
22	Norway	5	9
	Ireland	5	5
	South Africa	5	0
23	Thailand	4	5
24	Mongolia	3	0
	Taiwan	3	0

As mentioned in the introduction, VOSViewer forms clusters or groups entities together, with different colours used to indicate different clusters. From Figure 2 to Figure 7 it can be observed that certain clusters of collaborators have remained relatively the same over the years, with certain clusters splitting among themselves. For example, while Sweden, Denmark, and Finland have had close collaborations over the years, Figure 7 shows that Sweden split away and formed its own cluster after 2015. Conversely, Canada, China, United Kingdom, and the USA have grown closer over the years in terms of close collaborations with each other while Singapore has shown a trend to form its own cluster among south-east Asian countries such as Vietnam and Malaysia while being distanced away from American and European collaborators. This may reflect a difference in geographic agendas and requires further investigation in future work. From Table 1 and Figure 7, it can also be observed that among the top 6 contributors to the CDIO Knowledge Library, Sweden and Singapore have become very independent CDIO hubs which maintain good collaborations within their respective geographical areas.

An interesting observation is that the contributions and collaborations from China to the CDIO Knowledge Library have reduced drastically after 2015. While the results of individual year-wise co-authorship have not been displayed in this paper, it has been observed that the contributions from the USA have reduced to a great extent after 2013. Alternatively, the findings of Meikleham et al. (2018) show China and USA as the major contributors within CDIO and engineering education which implies that Chinese and American authors are increasingly publishing papers in databases external to the CDIO Knowledge Library. This is an important finding and could potentially signal an area of future intervention for CDIO leadership to bring these researchers back into the fold. Additionally, countries such as Russia, Portugal, Columbia, and Chile have steadily increased their contributions to the

CDIO Knowledge Library as shown in Table 1 and Figure 7, but their collaborations with other countries are minimal, and as a result their appearance in the VOSViewer visualization is reduced in comparison to the findings of Meikleham et al. (2018). This is an indication of the presence of localized CDIO communities around the world which may receive additional benefit through co-authorship collaborations outside of their country or regions.

VOSViewer Analysis - Co-authorship analysis based on author

Visualizing author networks in VOSViewer was a difficult task. Our initial analysis yielded unexpected results wherein significant authors were not visible in the analysis, which was similar to the findings described in Meikleham et al. (2018). The final cleaned up results of the co-authorship analysis based on author names are shown from Figure 8 to Figure 13.

The co-authorship analysis based on authors in VOSViewer showed consistent results wherein researchers tend to collaborate with the same people frequently and over a period of time. Additionally, there are many clusters of researchers who tend to publish independently. This is consistent with the findings of Meikleham et al. (2018), wherein a dispersed and flat cluster distribution of authors was identified. These clusters can also be seen in Figure 8 to Figure 13. Co-authorship mapping between 2015 and 2018 shows the emergence of new networks of co-authorship. However, these new co-author clusters are from the same geographical area, often with the same affiliation. While they are contributing to the CDIO initiative, they do not seem to integrate with the global CDIO community, rather forming local CDIO clusters. Tracking and documenting the key individuals in these network clusters is important because these groups have very real impacts on how other authors will interact with the initiative. Active members often act as “gate-keepers” within their institutions, responsible for a main fraction of a certain university’s external CDIO collaboration.

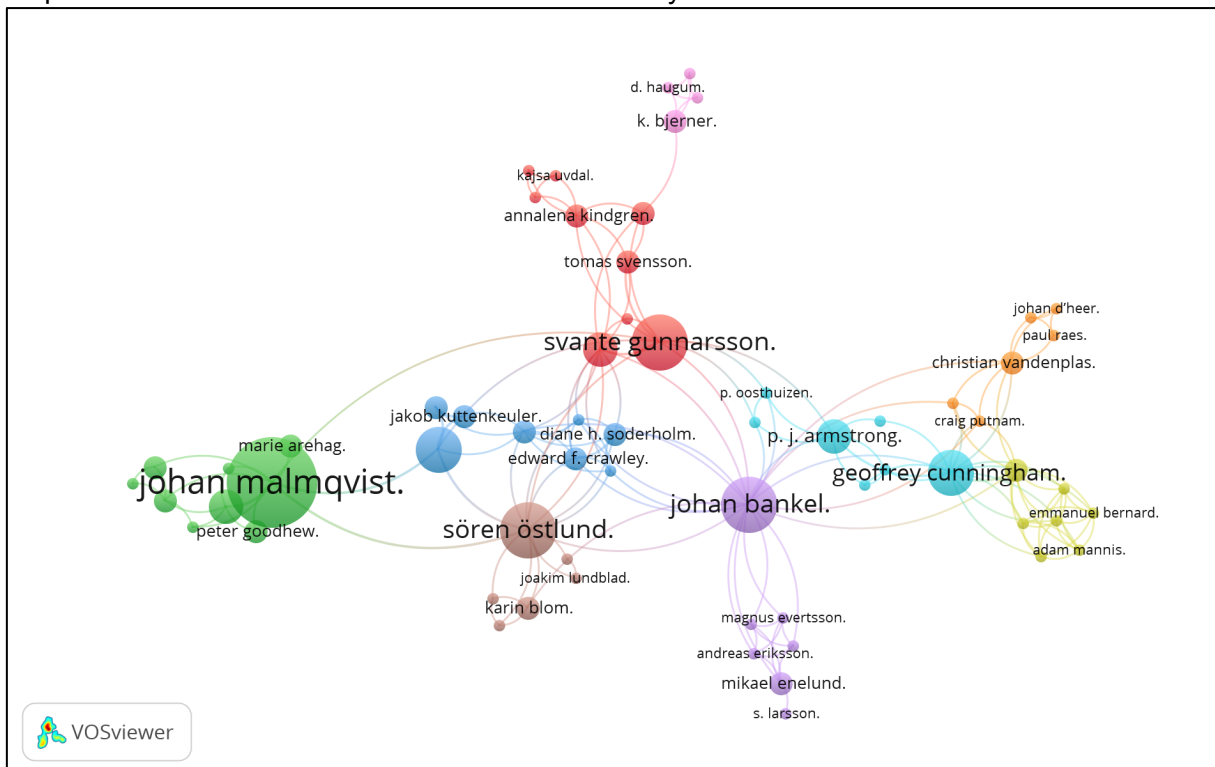


Figure 8. Authors with co-authorship links from 2005 to 2007, 224 authors, 63 relevant authors

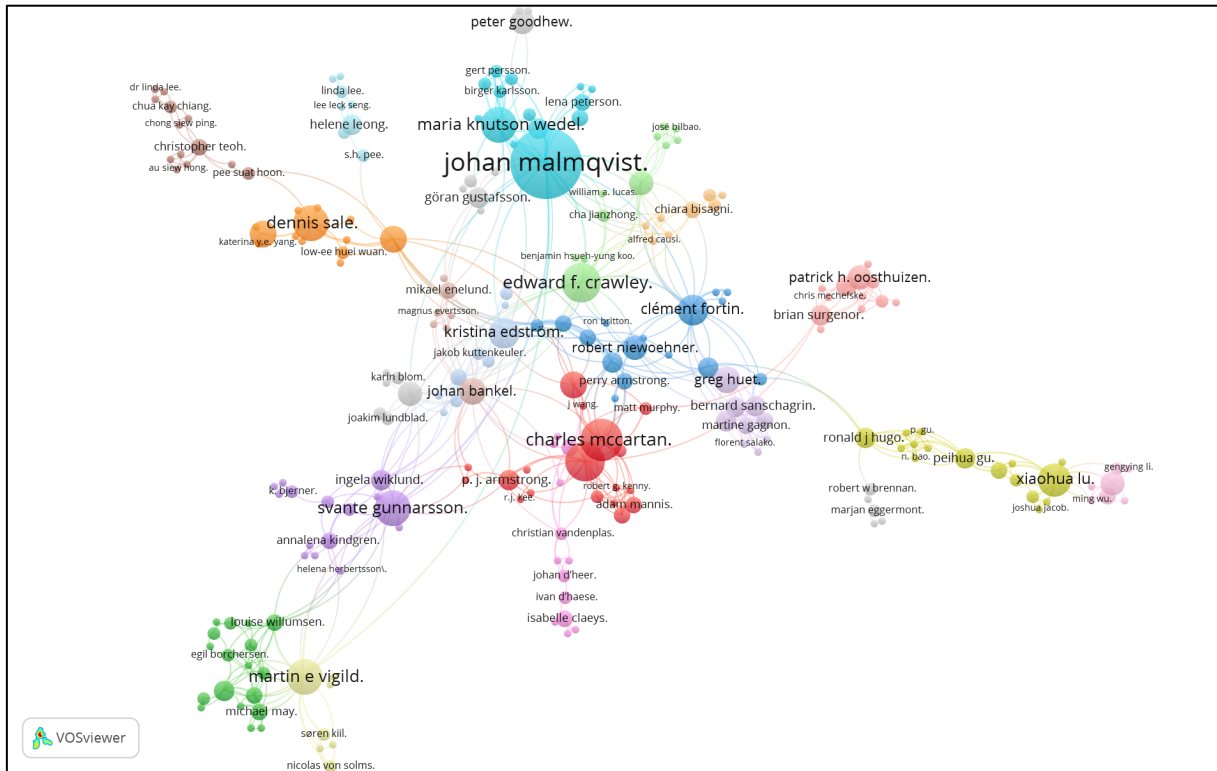


Figure 9. Authors with co-authorship links from 2005 to 2010, 605 authors, 237 relevant authors

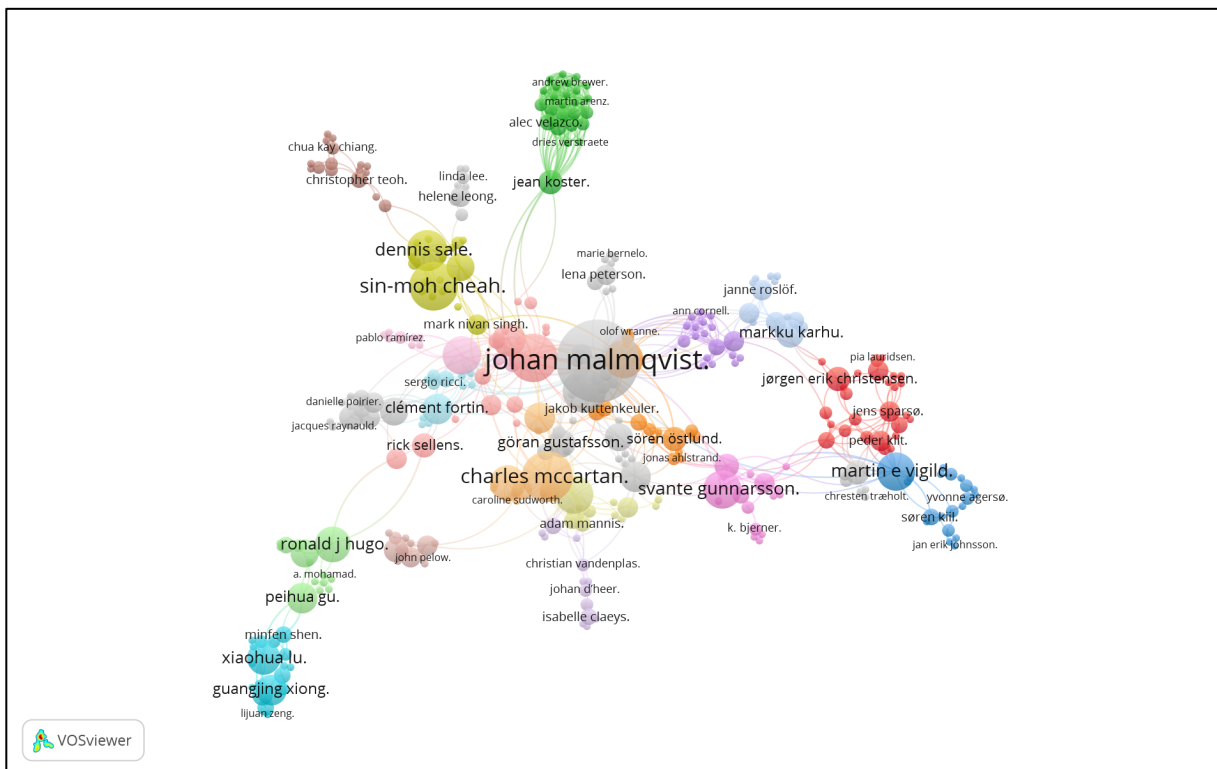


Figure 10. Authors with co-authorship links from 2005 to 2012, 980 authors, 353 relevant authors

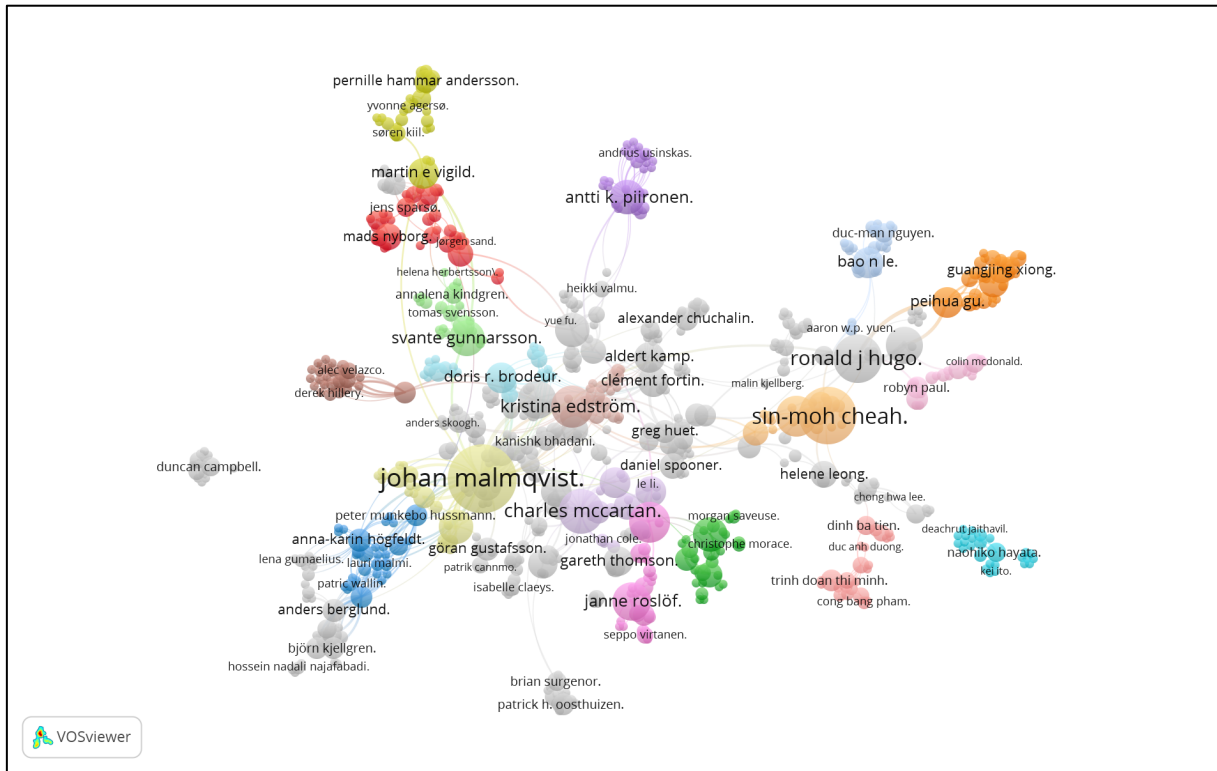


Figure 13. Authors with co-authorship links from 2005 to 2018, 1957 authors, 730 relevant authors

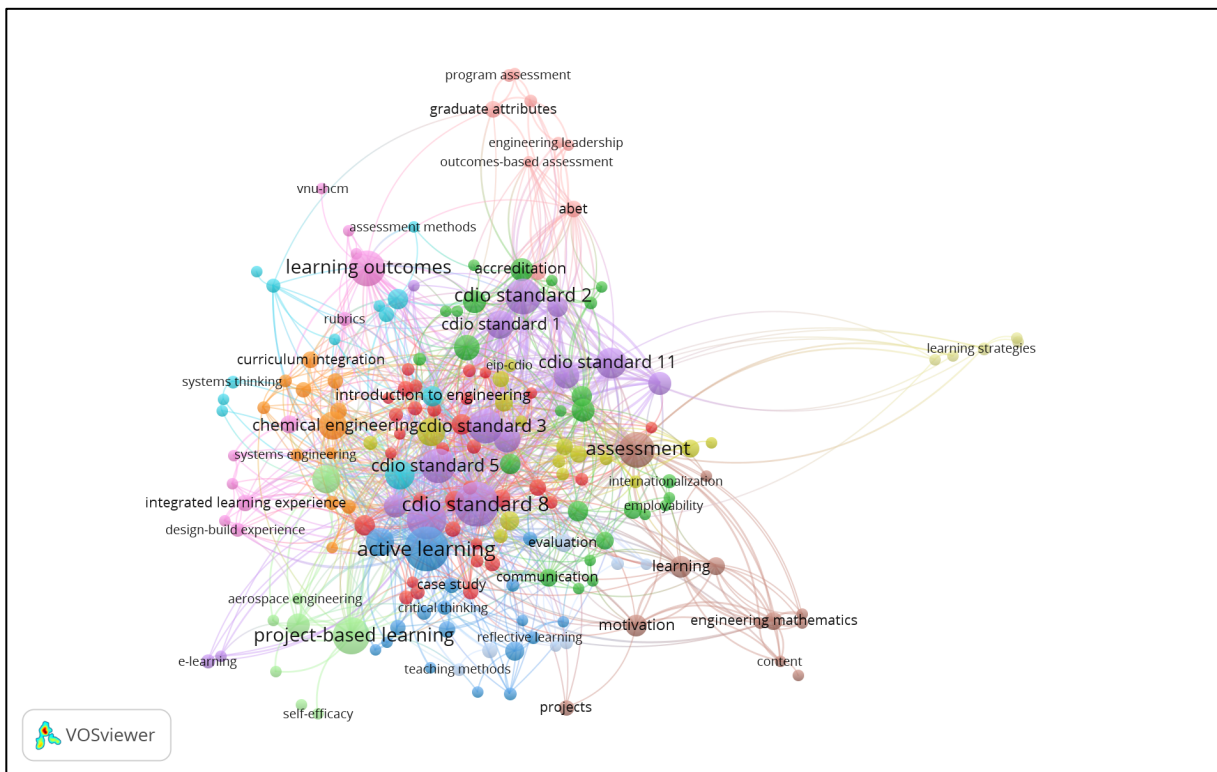


Figure 14. Author specified keyword co-occurrence map from 2005 to 2014

A possible explanation is that authors that have applied CDIO to mechanical engineering have considered this to be the default, whereas authors active in civil or chemical engineering have had a motive to mark their discipline in their keywords in order to make the paper stand out. This may indicate an area of opportunity for adding clearer instructions or constraints for authors when having them self-report data upon submission of their CDIO papers. Being aware of the differences in user reporting tendencies will be important if CDIO plans to leverage data more heavily in the future.

According to Figure 14, the CDIO standards that are most prominent are Standard 8 - Active learning, Standard 7 - Integrated learning experiences, Standard 3 - Integrated curriculum and Standard 5 - Design-implement experiences. Comparing these standards to the period from 2005 to 2014, it can be concluded that the focus of the CDIO initiative has largely remained unchanged throughout the years. Many of the findings of keyword usage by Meikleham et al. (2018) are consistent with the findings from the keyword analysis of the CDIO Knowledge Library. For example, literature efforts within CDIO concentrate on teaching, student learning and teaching assessment. Learning outcomes has been used frequently throughout the years.

The year 2018 saw a peak in the number of participating authors as well as countries. Projects and experience for students were the main keywords extracted from the title field with at least three occurrences of the same keyword for the year 2018. The main author keywords were CDIO Standard 8, Standard 7 and Standard 3. There is a risk of diluting the uniqueness of the CDIO initiative if the perceived focus begins shifting solely towards project-based learning (Meikleham et al., 2018).

The author keywords and title-based keywords are almost the same for 2016, 2017, and 2018. It will be interesting to analyze the proceedings of the 2019 conference to examine if the CDIO initiative is following a trend of similar publications that have been evident since 2016. Since the CDIO Knowledge Library is comprised of over 1000 archived papers, the co-authorship networks and keyword networks created in VOSViewer are huge. Thus, the images generated from VOSViewer shown from Figure 2 to Figure 15 are only indicative of the entities that appear on the screen. Certain significant entities may get hidden under the bibliometric network cloud generated by VOSViewer. For example, in the co-authorship links based on authors, certain significant authors/entities who have a huge number of contributions to the CDIO Knowledge Library may be missing in the images shown from Figure 8 to Figure 13. However, these entities can be viewed by zooming in on the bibliometric network cloud in VOSViewer. Additionally, since these entities are separated into clusters, the exact visualization of the clusters can only be gained by zooming in on the cluster within the bibliometric cloud. Thus, certain results have been reported based on such individual visualizations within VOSViewer, with only the most relevant images being used in this paper.

CONCLUSIONS

The CDIO initiative has grown and influenced many educational institutions around the world. As of 2018, 47 countries have been part of the CDIO initiative, with 2018 witnessing the maximum number of conference papers in the annual conference. However, the number of publications per year have been relatively constant in the period after the initial peak of 2011. Sweden has been the major contributor to the CDIO initiative with the maximum number of publications and has strong collaborations with various countries. Denmark and Singapore

are the second biggest contributors to the CDIO initiative followed by Canada, Finland and China. While China has made significant contributions to the CDIO initiative, there has been reduced participation by China after the 2015 CDIO conference in China. Similarly, the Japanese contribution to the CDIO initiative peaked during the 2018 CDIO conference in Japan, coinciding with the CDIO conference being held in Japan. Thus, the geographical location of the CDIO conference has a great influence on the contributions to the CDIO Knowledge Library. Since 2015 there has also been the emergence of newer author networks who collaborate locally. This suggests the presence of local communities, which have not become fully integrated with the global CDIO community. The exact reason for the lack of global collaboration is unclear, however it was hypothesized that this finding reflects geographic differences in research agendas. This finding requires further investigation and could be investigated by future authors by conducting a thematic analysis of these geographic clusters and verifying whether the themes are convergent or divergent.

The CDIO Standards 8, 7, 3 and 5 are the most frequently cited in CDIO conference paper keywords, implying a strong focus on project-based learning.

The CDIO paper data available in the CDIO Knowledge Library is to some degree different from the Scopus and Web of Science data analyzed by Meikleham et al. (2018) and in this paper. One major difference is that Chinese and American authors are increasingly publishing their CDIO papers in Scopus-registered journals.

The findings from this analysis along with the findings of the analysis by Meikleham et al. (2018) can be used to identify areas of improvement for the CDIO initiative as well as in higher education. While this paper demonstrates how historical publication trends have changed over time within the CDIO community it has also provided insight into the potential to leverage existing internal data to provide leadership with insights that can support strategic decision-making for the initiative. While the analysis of this library data has provided valuable insights that can be used to influence decision-making, it also demonstrates that there may be an opportunity to crowdsource new data points via the publication process which could allow the CDIO initiative to synthesize unique global community insights that were previously not possible. With the world moving towards globalization and sustainability, it is becoming necessary to collaborate with different countries around the world. The growth of the CDIO initiative around the world is testament to the outreach and the potential that the initiative has to transform higher education for a beneficial future.

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