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Trends of Science Education Research: An Automatic Content Analysis

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Abstract This study used scientometric methods to conduct an automatic content analysis on the development trends of science education research from the published articles in the four journals of *International Journal of Science Education*, *Journal of Research in Science Teaching, Research in Science Education*, *and Science Education* from 1990 to 2007. The multi-stage clustering technique was employed to investigate with what topics, to what development trends, and from whose contribution that the journal publications constructed as a science education research field. This study found that the research topic of *Conceptual Change & Concept Mapping* was the most studied topic, although the number of publications has slightly declined in the 2000's. The studies in the themes of *Professional Development*, *Nature of Science and Socio-Scientific Issues*, and *Conceptual Chang and Analogy* were found to be gaining attention over the years. This study also found that, embedded in the most cited references, the supporting disciplines and theories of science education research are constructivist learning, cognitive psychology, pedagogy, and philosophy of science.

Keywords Science education research · Journal publication · Content analysis · Scientometric method

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Introduction

The importance of science education at different levels has been stressed by educators and researchers as it plays multiple roles in enhancing citizen's scientific literacy, promoting the scientific and technological capacity of the workforce, and fostering next generation school science educators (NSF 1996; NRC 1997, 1999, 2000). Research in science education has been called to be conducted with an aim to critically "inform educational judgments and decisions in order to improve educational action" (Bassey 1995, p. 39) at different levels. It is critical not only to conduct relevant science education research to help science teachers improve their classroom practice and play better roles in enhancing scientific literacy, but also to understand what have been studied in the past in order to know what could be explored further in the future. This study applied automatic content analysis methods from scientometrics to investigate the development trends of science education research. In particular, we proposed a multi-stage clustering technique based on bibliographic coupling to examine with what topics, to what development trends, and from whose contributions that the scientific journal publications constructed as a science education research field.

Curriculum Reforms and Science Education

The development of current research and curricular activities in science education can be traced back to the science education reforms in the late 1950's in the USA (de Jong 2007; Fensham 2004). In his review, de Jong (2007) indicated that the three main waves of science education reform in the 1950, 1980, and 2000's have shifted the foci of curriculum design and brought the evolution of science education research. The science education curriculum reform in the USA started with the recognition of the deficit of the nation in science and technology (de Jong 2007). The relatively low quality of science education was seen as the main cause of the nation's inferiority to the former Soviet Union, who launched the first man-made satellite (Sputnik) in 1957. Instead of memorizing scientific facts, the major science curriculum reform efforts after Sputnik emphasized the understanding of basic scientific concepts and the process in learning science.

The second science curriculum reform in the 1980's was brought by the alarming report, *A Nation at Risk* (National Commission on Excellence in Education 1983). The report warned that the USA had been falling behind in the international economic and industrial competitions because of the weaknesses in the educational system. As de Jong (2007) indicated, this wave of curriculum reform focused on turning the student's passive school learning into an active process and connecting the learning of scientific concepts to their application in daily lives. Researches during this reform also focused on science learning as a conceptual change process.

The understanding of conceptions in science teaching and learning seemed to be overly emphasized after the early 1980's. It was indicated that this approach may prevent students from linking their conceptual learning to the social and cultural context. The later evolution of constructivist views of learning has marked as the third wave of educational reform in the science education researches since late 1990's (de Jong 2007; Jenkins 2001). As a result, social and cultural dimensions and the science-technology-society (STS) issues were brought into the scene of science curricula and research. In addition, new technologies such as computer-assisted instruction and the use of Internet also gained attention (de Jong 2007).

The Development of Science Education as a Research Field

Fensham (2004) used dimensions of structural, intra-research, and outcome in the judgment of the establishment of a discipline or a research field. In the structural dimension, Fensham (2004) indicated that a well established research field is: (1) to create the full professorial appointments to gain *academic recognition*; (2) to have *research journals* to publish quality research and report the research outcomes; (3) to found *professional associations*; (4) to hold *research conferences* periodically so that direct exchange and interaction among researchers can be made; (5) to establish *research centers*; and (6) to have *research training* plans to foster researchers.

For the dimension of professional association and research journals, studies have indicated that the USA was the first country to devote to science education research (Fensham 2004; Treagust 2006). For example, the first journal concentrating on research of science teaching and learning, *Science Education* (SE), was first published in 1916 in the USA. On the other hand, the worldwide acknowledged research association, the National Association for Research in Science Teaching (NARST), was founded in 1928 and still holds international conference annually. Sponsored by the NARST, the *Journal of Research in Science Teaching* (JRST) publishes 10 issues per year and has great impact on research in science education.

With the worldwide spread of journals on research of teaching and learning in science, science education as a distinctive field of research emerged and was developed internationally since mid-1900's (Fensham 2004). Examples of the prominent science education research journals include JRST, SE in North America, *International Journal of Science Education* (IJSE, initially the European Journal of Science Education) in Europe, and *Research in Science Education* (RISE) in Australasia (White 1997).

One developing trend in science education research is that a wider range of countries were participating in research publication activities (Lee et al. 2009; Treagust 2006), which can be evidenced in the country's level in the structural dimension (Fensham 2004). For example, as an active member in the international science education research community, it was not until the 1980's that Taiwan started founding academic science education organizations and research institutes. In the 1990's, publications from Taiwan researchers started to appear in the international English-language journals.

Although the importance of science education had been brought to educational policymakers' attention in the 1970's, it took more than 30 years of gradually development for science education, as seen in the structural dimension (Fensham 2004), to be regarded as a research field in the educational institutions. For example, sponsored by the Ministry of Education of Taiwan, the science education center was established at the National Taiwan Normal University (NTNU) in 1974. Later in 1986, the institute of science education (graduate school) was founded at the NTNU and more graduate schools of science education have been established at other universities since.

In the meantime, during the mid-1980's, the Chinese association of science education (CASE) was founded and a CASE-sponsored science education conference was held annually. In 1993, sponsored by the CASE, the quarterly Chinese Journal of Science Education began to publish academic papers in the research of science education. It was then Taiwan's participation in international academic activities in science education started. For international research journals, it was not until 1993 that the science education scholars from Taiwan published in journals of SE and JRST.

Research in Science Education

To understand how the research field has developed, researchers may investigate from a wide range of the structural perspectives such as educational reform movements (de Jong 2007) and the development level of the academic environment (Fensham 2004) to delineate the scope of science education research. On the other hand, using content analysis approach on literature review was also usually conducted to gain a more detailed view of the development trends (e.g., de Jong 2007; Rennie 1998; Lee et al. 2009; Tsai and Wen 2005; White 1997).

In comparing different editions of Handbook of Research on Teaching, White (1997) pointed out that research styles and research topics were two major changes in science education research since the second edition of the handbook published in 1973. In his study, a content analysis of journal articles was conducted to further examine the above observed changes. White (1997) used science education research articles in the Education Resources Information Center (ERIC) database and the journal RISE as sources of data. His analysis on research topics trends was done by counting the keywords of the articles from 1965 to 1995. The investigation of research style trends was across three decennial reference points of 1975, 1985, and 1995. The analysis concluded that science education research has shifted from laboratory-style experiments to observation and description of classroom practice while interviewing as research tool has become common.

With a focus on the quality of research, Rennie (1998) and Eybe and Schmidt (2001) examined science education literature from the perspective of how to report research results and to improve research quality. After examining research articles published in the five journals of IJSE, JRST, RISE, SE, and *Research in Science and Technological Education* (RSTE) in 1996, Rennie (1998) illustrated and provided recommendations on how to present and improve the quality of quantitative research. Eybe and Schmidt (2001) investigated the research trends in chemical education through a review of 81 studies published in the journals of JRST and IJSE from 1991 to 1997. As a result, quality criteria were suggested to include six categories: theory relatedness, quality of the research question, methods (for quantitative and qualitative studies), presentation and interpretation of results, implications for practice, and competence in chemistry.

In two time periods of 1998–2002 and 2003–2007, a series of content analysis comparing three major science education journals of IJSE, JRST, and SE were conducted (Lee et al. 2009; Tsai and Wen 2005). In these studies, researchers' nationalities, research types, and topics were analyzed and the trends were compared. It was indicated that researchers from the English-speaking countries contributed to most of the research products during the two time periods although the researchers from non-English speaking countries had increasing number of research articles, especially during the period of 2003–2007. As revealed, empirical study was the major research type during the two time periods while most of the empirical articles employed qualitative method in 2003-2007. In the studies, the research topics were categorized by the adapted NARST conference strand categories. The analysis found that the topics of "Learning-Context" and "Teaching" were gaining more attention from 1998 to 2007 while the topics of "Learning Conceptions" and "Culture, Social and Gender" were in decline.

de Jong (2007) also adapted conference themes, from the NARST and European Science Education Research Association (ESERA), as a pre-set framework to analyze research topics trends of science education for the 2 years of 1995 and 2005 in three selected journals of JRST, IJSE, and SE. The analysis revealed that the researches were becoming small-scaled in research design while more qualitative data collection methods were used. The top three research topics in 1995 were "students' conceptions", "practical work", and "teachers' content knowledge." In 2005, "practical work" was still in top three research topics, but "students' conceptions" and "teachers' content knowledge" were replaced by the topics of "teachers' pedagogical content knowledge" and "STS and context-based issues."

Scientometrics on Research Trends of Science Education

As seen from the above literature analysis, the reviews of science education research varied in purposes. There were researchers aiming to provide guidance for improving research quality (Eybe and Schmidt 2001; Rennie 1998); while others focusing on identifying major features and contributors such as authors, topics, and research types (de Jong 2007; Lee et al. 2009; Tsai and Wen 2005; White 1997). In addition, attention was also paid to point out what have missed and might be done in future research (White 1997). Although various trends of science education research have been identified through literature reviews, variables such as researchers' personal interests, level of professional knowledge, and use of traditional narrative review method could have led the reviews to subjective interpretations. Further, by using a pre-set category structure as analysis framework, the research topic ranking would depend on the category that the researchers choose to use (de Jong 2007). That is, different category structures could generate different topic ranking results when analyzing the same data.

To present a comprehensive and longitudinal overview, this study used the scientometrics method (Braun 2007) to conduct a development trends analysis of science education research. A total number of 3,039 articles from four of major science education research journals, namely IJSE, SE, JRST, and RISE, during the period from 1990 to 2007 were analyzed. With the application of the automatic content analysis method, this study analyzed the structure of science education research by identifying the major study topics, the development of research threads, the countries and the leading authors, and the most cited references on which the research community was formulated.

Instead of matching the articles reviewed with a pre-set topic structure, the research topic categories in this study were developed inductively as emerging from the entire corpus of the four journals from 1990 to 2007. This grounded approach took root on the materials to provide educators, researchers, and policymakers of science education an overview of the structure and evolution of the field. It was expected that this study would help educators and researchers reflect on the trends and issues in science education research, advance their understanding in science education, and pursue further exploration and practice in research and teaching. This study would also report on how automatic content analysis technique was used to explain and interpret the trends of science education research to yield information useful for further application of scientometrics in science education research.

Methods

Scientometrics is itself a science concerned with measuring and analyzing a field of science of interest (Leydesdorff 2001; Moed 2005). Among its various approaches to reveal quantitative features and characteristics of a science, content or citation analysis based on existing scientific publications is often used. For years, scientometricians have developed some sort of standardized processes to analyze these data. Our approach follows this advancement with latest information technology. Specifically, given a corpus of publications, our automatic content analysis method takes the following steps:

1. *Text segmentation*: identify the title, authors, citations, and other fields of each article in the corpus.
2. *Similarity computation*: calculate the similarity between each pair of articles (or clusters) based on their common objects (such as keywords or citations).
3. *Multi-stage clustering*: recursively group similar articles (or clusters) into larger clusters based on the above similarities until a number of reasonable and manageable topics emerged from the collection.
4. *Cluster labeling*: generate cluster descriptors for ease of cluster interpretation.
5. *Facet analysis*: cross-tabulate detected topics with other facet data such as authors, countries, citations, and publication years to know the most productive or influential agents, and other worth-noting events.
6. *Visualization*: create a topic map based on the multi-dimensional scaling (MDS) technique for revealing the relations among the detected topics.

To collect a corpus for the above analysis, we searched and downloaded the science education bibliographic records from the online ISI Web of Knowledge (WoK) service of Thomson Reuters, due to its relative completeness in data preparation, cleansing, normalization, and indexing. The search criteria are listed in Table 1. It was done on April 27, 2008 and resulted in 3,039 records. The WoK service allows users to download the search results 500 records a time. So it took seven runs to download all the desired records.

Text Segmentation

Each record contains about 40 fields, including title, authors, authors' addresses, and publication years, etc. We identify at least eight of them for use in our analysis. Below lists their abbreviations, meanings, and examples:

- AU: authors, e.g., ROTH, WM; ROYCHOUDHURY, A.
- TI: publication title, e.g., METALEARNING AND CONCEPTUAL CHANGE
- SO: journal title, e.g., SCIENCE EDUCATION.
- AB: publication's abstract.
- C1: first author's country (extracted from the first author's address in the original C1 field).
- CR: normalized citations, e.g., DRIVER R, 2000, SCI EDUC, V84, P287.
- PY: year of publication, e.g., 2000.
- UT: primary key of the publication used in WoK, e.g., ISI:A1996VF74600009.

Table 1 Search criteria for bibliographic data in science education

Set	Results	Search condition[a]
# 5	3,039	#4 OR #3 OR #2 OR #1
# 4	141	SO = (RESEARCH IN SCIENCE EDUCATION)
# 3	1,216	SO = (INTERNATIONAL JOURNAL OF SCIENCE EDUCATION)
# 2	1,007	SO = (JOURNAL OF RESEARCH IN SCIENCE TEACHING)
# 1	675	SO = (SCIENCE EDUCATION)

[a] Databases = SCI-EXPANDED and SSCI, Timespan = 1990–2007, document type = (Article), where SO denotes "source of the records to be searched"

Similarity Computation

After identifying each field, similarities between each pair of articles are calculated based on the common citations normalized by the individual citations each article has. Specifically, the Dice similarity between two articles X and Y (Salton 1989) was used:

$$\mathrm{Sim(X,Y)} = 2 * |\mathrm{C(X)} \cap \mathrm{C(Y)}|/(|\mathrm{C(X)}| + |\mathrm{C(Y)}|)$$

where C(X) denotes the set of references that article X cites (i.e., X's citations), |C(X)| denotes the number of elements in C(X) (i.e., the number of citations), and C(X)∩C(Y) is the intersection of the sets of C(X) and C(Y) (i.e., the common references that both X and Y cite). The value of this similarity ranges from 0 to 1, denoting from most dissimilar to most similar. Although there are other similarity measures (Salton 1989), the dice similarity is among the simplest ones to implement.

This kind of similarity forms the basis of *bibliographic coupling* in scientometrics, where it is believed that the more the same references two articles cite, the more likely the two articles are about the same topic. As an example, if X cites 10 references and Y cites 15 references, and if there are five common references among them, then the similarity between X and Y is 2*5/(10 + 15) = 10/25 = 0.4, or X and Y are bibliographically coupled with a measure of 0.4.

Multi-Stage Clustering

Next, the knowledge structure underlying the corpus was detected by a clustering algorithm, called *complete linkage clustering* (Salton 1989). The basic idea of this algorithm regards each article as a singleton cluster at first. It then groups the most similar pair of clusters (with similarity larger than a threshold) into a larger cluster. The same grouping rule applies again to the remaining clusters and newly created ones, where the similarity between any two clusters is defined as the minimum similarity between any pairs of articles each resides in the opposite cluster. This process repeats until no clusters can be merged. In this way, each of the articles is assigned to a cluster automatically.

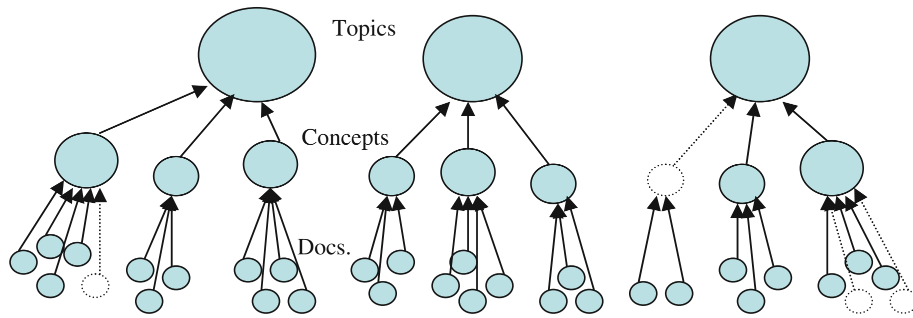
From the 3,039 articles in science education, 669 clusters resulted with the similarity threshold set to zero (which means that no common reference exists between any two clusters). Among them, only six clusters contain more than 20 articles, 38 clusters contain 10–19 articles, 177 clusters contain 5–9 articles, and the remaining 458 clusters contain less than five articles.

The above result did not yield ideal cluster sizes and manageable cluster numbers for manual analysis. A *multi-stage clustering* strategy was therefore adopted, by first eliminating the outliers (clusters having low similarities with others), then by treating each remaining cluster as a virtual article (i.e., the references of the cluster is the union of all the references of the articles in the cluster), and finally by clustering the virtual articles in the same way described above. The same process repeats stage by stage, with proper thresholds set for each stage (0.05 for each stage in our implementation). In this way, articles are grouped into concepts, which are further clustered into topics, which in turn can be grouped into categories or domains, as shown in Fig. 1. Although this is not always the case, it represents an expected ideal knowledge structure for the corpus. Through this multi-stage clustering, nine clusters eventually emerged from the science education corpus, which represents a logical self-organization of the corpus based on bibliographic coupling.

Cluster Labeling

Although articles are now organized into clusters, analysts need to browse the titles or even abstracts to know their content. To help analysts spot the topic for each cluster without much effort, a text mining approach (Tseng et al. 2007) is used to generate cluster descriptors automatically. First, a stop list of non-semantics bearing words (e.g., *the*, *of*, *and*, etc.) is created to filter words in the titles and abstracts. Second, important terms are extracted from each article's text fields (i.e., title and abstract) based on an algorithm which extracts maximally repeated words and phrases (Tseng 1998, 2002). The correlation coefficient is then computed between each term T and each cluster C by the following formula:

Fig. 1 A conceptual sketch of the multi-stage clustering approach, where *dashed white circles* denote outliers



$$\mathrm{Co(T,C)} = \frac{(\mathrm{TP} \times \mathrm{TN} - \mathrm{FN} \times \mathrm{FP})}{\sqrt{(\mathrm{TP}+\mathrm{FN})(\mathrm{FP}+\mathrm{TN})(\mathrm{TP}+\mathrm{FP})(\mathrm{FN}+\mathrm{TN})}}$$

where TP (true positive), FP (false positive), FN (false negative), and TN (true negative) denote the number of articles that belong or not belong to C while containing or not containing T, respectively, as shown in Table 2. By sorting the correlations of a cluster in decreasing order, the top few terms (top five terms in our implementation) can be selected as the cluster's descriptors.

The correlation method is effective for large number of clusters having short documents in them. But it tends to select specific terms that are not generic enough for clusters having a few long documents, because it does not take into account the number of occurrence of a term in the cluster (i.e., the sum of the term's occurring frequency in each of those articles inside the same cluster). In other words, it is effective for the smaller clusters resulted from the initial clustering stage, but it does not yield proper descriptors for the larger clusters from the higher clustering stage. As a remedy for the higher stage clustering, we use the multiplication principle to combine the correlation coefficient and the number of occurrence of a term in the cluster to rank the terms for more effective descriptor generation (Tseng et al. 2006).

Facet Analysis

Once the topics have been detected, it becomes easy to cross-tabulate the topics with other facet information, because the data from WoK contain rich fields for describing an article. This kind of cross analysis often leads to more information than single facet analysis can provide.

Table 2 Confusion matrix for the number of articles (not) containing terms inside (outside) clusters

	Term (T)		
Cluster (C)		Yes	No
	Yes	TP	FN
	No	FP	TN

For example, it is possible to know the topic distribution of all productive authors (and thus the major domains of their expertise), instead of knowing only their productivity. Such analyses are the major focus of our study and are the main differences of ours from the others. We shall see more cross analysis examples in the next section.

Visualization

To represent the detected knowledge structures, two techniques are used: one is the previously introduced MSC (multi-stage clustering), the other is MDS (multi- dimensional scaling) (Kruskal 1997). Based on the pre-calculated similarities between each topic, the MSC method organizes the topics in a hierarchical way. This creates a structure that is readily available to a folder tree or topic tree representation, as shown in Fig. 2. Similarly, from the pair-wise similarities, the MDS technique computes the coordinates of each topic in the specified dimensions of Euclidean space, which are usually two or three for ease of visual interpretation. With these coordinates, a topic map (as seen in Fig. 3) is created by a plotting tool. We use the MDS program in the RuG/L04 freeware package (Kleiweg 2008) for coordinate computation and the GD module in the Perl programming language (Wall et al. 2000) for plotting.

These two representations allow different ways to explore the corpus. From the topic tree, the results from each clustering stage correspond to the folders in the tree, which reflects the topic hierarchy imposed on the clustering results. From the topic map, relations among the detected topics are visualized in a two-dimensional space, which help understand the inter-cluster relationship by distance and orientation.

Results

Nine Science Education Research Topics

With the use of the automatic content analysis, nine categories of science education research topic emerged from the published articles in the four journals of IJSE, SE, JRST, and RISE during years from 1990 to 2007. The

Fig. 2 A topic tree for the science education research corpus from 1990–2007

- 1401 docs. : 0.0146
  - 315 docs. : 0.0667 (problem, reason, analogy, conceptual change, conception)
    - 235 docs. : 0.0988 (school student, conceptual change, conception, energy, mental)
      - 88 docs. : 0.0694(concept, energy, equilibrium, conception, pupil)
      - 147 docs. : 0.0646(analogy, conceptual change, astronomy, electricity, children)
    - 80 docs. : 0.0712(reason, mole, reason skill, formal, problem-solving)
  - 1086 docs. : 0.0241 (practice, inquiry, elementary, high school, chemistry)
    - 1022 docs. : 0.0458 (teach, practice, education, science teacher, inquiry)
      - 983 docs : 0.0813 (science teacher, practice, conception, education, conceptual)
        - 893 docs. : 0.1272 (science teacher, nature, conception, practice, education)
          - 340 docs. : 0.1341(nature of science, science teacher, view, writing, practice)
            - 149 docs. : 0.0562(teacher, science teacher, identity, practice, urban)
            - 191 docs. : 0.1057(nature of science, view, argumentation, scientific, issue)
          - 553 docs. : 0.0662(concept map, conceptual change, science education, conception, children)
        - 90 docs. : 0.0637(teacher, elementary, constructivist, primary, practice)
      - 39 docs. : 0.0588(urban, peer review, expand, design-based, inquiry science)
    - 64 docs. : 0.0618(gender, attitude, attitude toward science, difference, interest)

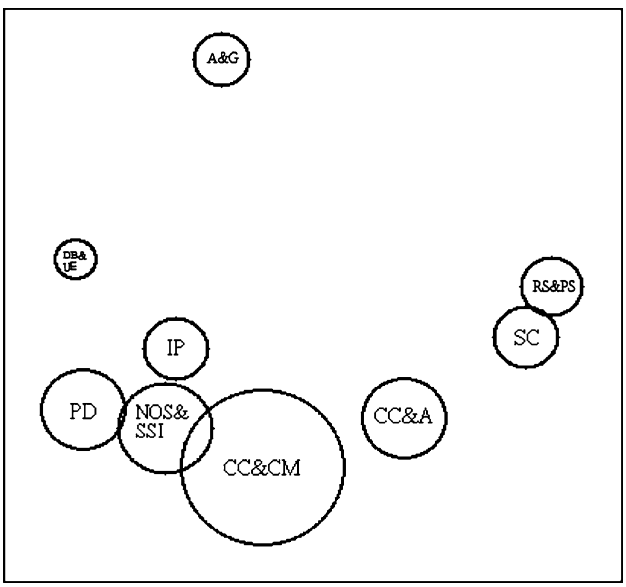


Fig. 3 Topic map rendered by multi-dimensional scaling (MDS) from multi-stage clustering of the science education journal publications

cluster descriptors included in each topic categories are listed in Table 3. Based on the descriptors, the nine topics were then manually tagged by the themes for ease of discussion. These tags and their sub-topical descriptors, as shown in Table 3, were: (1) *scientific concept* (SC); (2) *instructional practice* (IP); (3) *conceptual change and conceptual mapping* (CC & CM); (4) *professional development* (PD); (5) *conceptual change and analogy* (CC & A); (6) *nature of science and socio-scientific issues* (NOS & SSI); (7) *reasoning skills and problem solving* (RS & PS); (8) *design-based and urban education* (DB & UE); (9) *attitude and gender* (A & G).

The nine topics cover 1,401 articles of the original 3,039 (due to the outlier removal during the MSC) and the distribution among the four journals is listed in Table 4. It is a common phenomenon that more than half of the articles were regarded as outliers in scientometric analysis. That is, although many articles deal with major topics, there are many more dealing with independent and probably less-noticed issues, which is a phenomenon similar to the long tail effect reflected in the online book sales statistics. Since the independent issues are in large number, they were excluded in the discussion of this article.

As seen in Table 4, the topic of CC & CM was ranked as the most published for all of the four journals. Among the nine topics, CC & CM, CC & A, and NOS & SSI were mostly published by the journal of IJSE; while papers on the topics of PD, RS & PS, DB & UE and A & G were mostly published by the journal of JRST.

Based on the MDS technique, the spatial relations among these topics are mapped in Fig. 3, where a circle denotes a topic and the size of the circle is designed to reflect the number of articles in it. As can be seen, the research topic of CC & CM emerged as the most popular topic in the field of science education research. There are 553 articles under this topic, amounting to 39% of the 1,401 networked researches from 1990 to 2007. According to topic map shown in Fig. 3, the research topics of IP, CC & CM, PD, and NOS & SSI have relatively closer relations. There are some issues within the three topics overstretched to each others. On the other hand, the science education research on topics among SC, CC & A, and RS & PS are closer to each other. Figure 3 also shows that DB & UE and A & G are two relatively independent topic groups that not related to or overlapped with other topics.

Table 3 Nine topic categories in science education research in four journals of IJSE, SE, JRST, and RISE from 1990 to 2007 ($n = 1{,}401$ articles)

Topics	Code: docs	Research topics
Topic 1	41:88	Scientific concept (SC)
3 Items	72:30	1. Misunderstanding; intuitive rule; concept; game;
	110:33	2. Thermodynamic; adult; energy; constructive; idea
	106:25	3. Photosynthesis; chemical equilibrium; cycling; two-tier; plant
Topic 2	60:90	Instructional practice (IP)
3 Items	31:29	1. Grid; repertory; prospective; electrochemistry; conceptual
	79:27	2. Referent; metaphor; action; practice; anecdote
	338:34	3. Elementary teacher; science teach; pre-service; primary; implementation
Topic 3	50:553	Conceptual change and concept mapping (CC & CM)
3 Items	374:220	1. Children; conceptual; conception; conceptual change; idea
	433:264	2. Science; practice; science education, scientific; classroom
	23:69	3. Concept map; validity; technique; concept-mapping; usefulness
Topic 4	80:149	Professional development (PD)
3 Items	471:56	1. Identity; urban; science; teacher; practice
	114:58	2. Science teacher; knowledge; professional; practice; elementary
	33:35	3. Writing; language; science; heuristic; literacy
Topic 5	56:147	Conceptual change and analogy (CC & A)
3 Items	160:24	1. Analogy; physiological; physiological concept; analogical; generate
	156:81	2. Model; mental; conceptual; mental model; novice
	35:42	3. Astronomical; earth; moon; astronomy; children
Topic 6	6:191	Nature of science and socio-scientific issues (NOS & SSI)
3 Items	44:49	1. Evidence; scaffold; epistemic; university; science
	22:95	2. Nature of science; view; teacher; history; history; pre-service
	277:47	3. Socio-scientific; literacy; scientific; socio-scientific issue; science
Topic 7	36:80	Reasoning skill and problem solving (RS&PS)
2 Items	321:38	1. Reason; skill; proportional; reason ability; college
	261:42	2. Problem; mole; solve; chemistry; amount
Topic 8	75:39	Design-based and urban education (DB&UE)
2 Items	195:17	1. Design-based; inquiry science; internet; acknowledge; technology-rich
	86:22	2. Urban; peer; review; peer review; participatory
Topic 9	64:64	Attitude and gender (A&G)
2 Items	93:46	1. Attitude; attitude toward science; adolescent; effect; interest
	289:18	2. Gender; ethnicity; race; difference; gender

Table 4 Numbers of articles by topics in the four journals of IJSE, SE, JRST, and RISE from 1990 to 2007 ($n = 1{,}401$ articles)

Topics	IJSE	SE	JRST	RISE
1. Scientific concept (SC)	40	9	39	0
2. Instructional practice (IP)	23	31	31	5
3. Conceptual change & concept mapping (CC & CM)	222	130	181	20
4. Professional development (PD)	35	40	57	17
5. Conceptual change & analogy (CC & A)	81	20	46	0
6. Nature of science & socio-scientific issues (NOS & SSI)	78	62	43	8
7. Reasoning skill & problem solving (RS & PS)	25	8	47	0
8. Design based & urban education (DB & UE)	3	13	18	5
9. Attitude & gender (A & G)	17	13	34	0
Total docs (%)	524 (37%)	326 (23%)	496 (35%)	55 (4%)

Development Trends in Research Topics

Figure 4 shows the development trends for the nine topics and Table 5 shows their detailed time series of publications over time. As mentioned above, the topic of CC & CM attracted most studies in the field of science education research. They were mainly focused on students' conceptual understanding, conceptual change in learning process, and the use of concept mapping as a tool in science education. Figure 4 and Table 5 show that there were in average 30 articles published every year. A sharp increase in the number of articles was observed in the period of 1997–1998, with an annual average reached to around 45 papers. Although the research interests have become slightly declined in the 2000's, it was still the most popular research topic in the field of science education research.

The studies in the PD, NOS & SSI, and CC & A were analyzed as the topics that have gradually gained attention over the years. In fact, they are at the top when all the topics are ranked with their trend indices based on time series in Table 5 (Tseng et al. 2009). Specifically, less than two papers were published on PD per year before the mid 1990's and it has gradually developed to have about eight papers published from the late 1990's to the early 2000's. After the year 2002, there have been in average 18 papers published every year. For the topic of NOS & SSI, there had less than six papers in average in the 1990's and have increased to have in average 17 papers published in the 2000's. As can been seen in Table 5, with a total of 44 papers published in the past 2 years from 2006 to 2007, the NOS & SSI has been increasingly gained researchers' attentions. The publications in the two areas of RS & PS and SC had shown a declining trend in the past two decades. Again, when ranked by the trend indices, they are at the bottom among all the topics. There were, in average, nearly from eight to nine papers published every year in the early 1990's, four to five papers in the late 1990's, and then, less than two papers in the 2000's.

Major Contributed Countries

A total of 83 countries/regions have made contributions in science education research in the four journals of IJSE, SE, JRST, and RISE during the years from 1990 to 2007. As can be seen in Table 6, for the top 10 countries, the English-speaking countries, including USA, England, Australia, Canada, produced the major proportion of the science education journal articles. The researchers from the USA have dominated the leading role in research production of all the nine topics in these four journals. Except for the topic of IP, England was ranked as one of the top 10 countries in almost every topic groups and contributed most of the efforts in the studies of CC & CM and NOS & SSI. Researchers from Australia and Canada have devoted most of their research efforts to the topic of CC & CM. In addition to the above mentioned English speaking countries, the non-English-speaking countries such as Israel, Taiwan, Spain, Netherlands, and Turkey were also ranked in the most productive top 10 countries. For Israel, the major effort was made on the topic of CC & CM, while the researchers from Taiwan have showed their research interests in the topic of NOS & SSI.

Most Productive Authors

Table 7 shows the most productive researchers in each of the nine research topics in science education. Several researchers have shown their research interests in more than one research topics with abundant publications. For example, Kenneth Tobin, Wolff-Michael Roth, Angela Barton, and Michael Barnett, in addition to be ranked as the top 10 most productive authors in various topics, have also

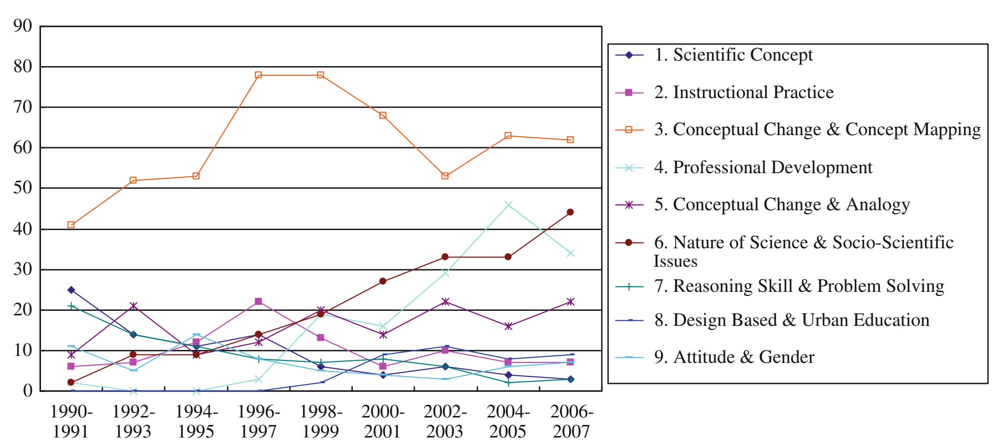


Fig. 4 The development trends of the nine topics in science education research from 1990–2007

Table 5 Numbers of articles by topic and by year in the journals of IJSE, SE, JRST, and RISE from 1990 to 2007 ($n = 1{,}401$ articles)

Year	Topic 1 Scientific concept	Topic 2 Instructional practice	Topic 3 Conceptual change & concept mapping	Topic 4 Professional development	Topic 5 Conceptual change & analogy	Topic 6 Nature of science & socio-scientific issues	Topic 7 Reasoning skill & problem solving	Topic 8 Design based & urban education	Topic 9 Attitude & gender
1990	16	4	27	1	5	2	10	0	5
1991	10	2	19	1	6	1	11	0	6
1992	6	4	17	0	8	6	7	0	4
1993	8	3	35	0	13	3	7	0	1
1994	5	8	29	0	3	4	6	0	4
1995	6	4	24	0	6	5	5	0	10
1996	6	8	32	1	6	4	5	0	4
1997	8	14	46	2	6	10	3	0	4
1998	3	2	45	8	12	6	5	1	2
1999	3	11	33	11	8	13	2	1	3
2000	1	2	35	7	7	13	7	2	2
2001	3	4	33	9	7	14	1	7	2
2002	4	6	27	19	10	14	4	6	1
2003	2	4	26	10	12	19	2	5	2
2004	2	5	32	27	8	20	1	2	3
2005	2	2	31	19	8	13	1	6	3
2006	1	4	29	16	10	25	0	6	4
2007	2	3	33	18	12	19	3	3	3
Total docs (%)	88 (6%)	90 (6%)	553 (39%)	149 (11%)	147 (10%)	191 (14%)	80 (6%)	39 (3%)	63 (5%)

shown one common research interest in the topic of DB & UE. To identify the active authors ranked highly in each of the research topics would help stakeholders recognize the works to be referenced and followed. However, it should be emphasized that, as this study employed the technique of bibliographic coupling in grouping the authors in the same topics, some very productive researches in science education missing in the table were either classified in several topics or were removed from the corpus during the multi-stage clustering analysis.

Most Cited References

The use of reference citations is to support the framework of knowledge, assumption, or theory of a study. The most cited references in each of the nine topics and in all science education research during the period from 1990 to 2007 are presented in Table 8 and Table 9. The literatures might serve as essential materials that help science education researchers and educators grasp what has been explored in certain research topics. They also could help make links with relevant issues for further study development. For example, as seen from the most cited references on conceptual change in topic 3 and 5 (Table 8), albeit central to science learning, different views have been provided for literature reviews about how conceptual change occurs (diSessa 1993, Posner et al. 1982; Vosniadou and Brewer 1992). Posner et al. (1982) emphasized the importance of conceptual ecology to conceptual change model as it is the key for students to be able to ask questions, reason answers, and distinguish relevance and irrelevance about certain phenomena. Vosniadou and Brewer (1992) asserted that conceptual change is a process in which learners organize their existed sensory experiences and to form synthetic models in their minds. On the other hand, to diSessa (1993), conceptual change is, drawing from naïve epistemological resources, to systematize various kinds of knowledge in a manner that is sensitive to context.

The most cited references can be regarded as the most influential literature in the field of science education research. As can be seen in Table 9, research report, journal article, and book/book chapter are the three most cited types of documents. Among the top ten influential documents, only two studies were from the four journals reviewed (SE and JRST). Embedded in the references of the most cited documents are the different disciplines and theories that serve as the framework for science education research. These foundational works including curriculum guidelines (e.g. AAAS 1993; NRC 1996), constructivist learning (e.g. Driver et al. 1994; Lave and Wenger 1991),

Table 6 Most productive countries/regions in science education research by topic in the journals of IJSE, SE, JRST, and RISE from 1990 to 2007 ($n = 1{,}401$ articles)

Cluster 1 Scientific concept (88 docs)	Cluster 2 Instructional practice (90 docs)	Cluster 3 Conceptual change & concept mapping (553 docs)	Cluster 4 Professional development (149 docs)	Cluster 5 Conceptual change & analogy (147 docs)	Cluster 6 Nature of science & socio-scientific issues (191 docs)	Cluster 7 Reasoning skill & problem solving (80 docs)	Cluster 8 Design based & urban education (39 docs)	Cluster 9 Attitude & gender (64 docs)
Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)	Country docs (%)
USA 23(26%)	USA 44(49%)	USA 190(34%)	USA 95(64%)	USA 52(35%)	USA 73(38%)	USA 28(35%)	USA 33(85%)	USA 25(39%)
England 6(7%)	Australia 22(24%)	Canada 50(9%)	Australia 20(13%)	England 12(8%)	England 35(18%)	Spain 4(5%)	Canada 7(18%)	England 5(8%)
Israel 5(6%)	Canada 3(3%)	Australia 43(8%)	Canada 13(9%)	Brazil 5(3%)	Taiwan 21(11%)	Israel 4(5%)	Israel 3(8%)	Australia 4(6%)
Portugal 3(3%)	Turkey 2(2%)	England 37(7%)	Netherlands 11(7%)	Scotland 4(3%)	S. Africa 8(4%)	Greece 3(4%)	England 1(3%)	Greece 3(5%)
Australia 3(3%)	Italy 1(1%)	Spain 22(4%)	England 6(4%)	Spain 4(3%)	Spain 8(4%)	Korea 3(4%)	Russia 1(3%)	Ireland 2(3%)
S. Africa 2(2%)	China 1(1%)	Israel 19(3%)	Israel 6(4%)	Taiwan 4(3%)	Norway 6(3%)	Scotland 2(3%)	Australia 1(3%)	New Zealand 1(1%)
Greece 2(2%)		Taiwan 15(3%)	Brazil 5(3%)	Israel 4(3%)	Israel 6(3%)	England 2(3%)	Taiwan 1(3%)	Nigeria 1(1%)
Spain 2(2%)		Netherlands 9(2%)	Finland 2(1%)	Netherlands 3(2%)	Canada 5(3%)	Australia 2(3%)	Pakistan 1(3%)	Denmark 1(1%)
Taiwan 2(2%)		Korea 9(2%)	Greece 2(1%)	Norway 3(2%)	Australia 4(2%)	Venezuela 2(3%)		Turkey 1(1%)
Netherlands 1(1%)		S. Africa 8(1%)	Turkey 2(1%)	Turkey 3(2%)	Portugal 3(2%)	S. Africa 1(1%)		Taiwan 1(1%)

Table 7 Most productive authors in the nine topics of science education research in journals of IJSE, SE, JRST, and RISE from 1990 to 2007 ($n = 1,401$ articles)

Topic 1 Scientific concept (88 docs) Author docs	Topic 2 Instructional practice (90 docs) Author docs	Topic 3 Conceptual change & concept mapping (553 docs) Author docs	Topic 4 Professional development (149 docs) Author docs	Topic 5 Conceptual change & analogy (147 docs) Author docs	Topic 6 Nature of science & socio-scientific issues (191 docs) Author Docs	Topic 7 Reasoning skill & problem solving (80 docs) Author docs	Topic 8 Design based & urban education (39 docs) Author docs	Topic 9 Attitude & gender (64 docs) Author docs
Marek, E. A. 6	Tobin, K. 10	Roth, W. M. 44	Hand, B. 12	Brown, D. E. 4	Lederman, N. G. 14	Lawson, A. E. 19	Tobin, K. 8	Crawley, F. E. 5
Abraham, M. R. 5	Tabachnick, B. R. 5	Treagust, D. F. 16	Prain, V. 10	Greca, I. M. 3	Tsai, C. C. 12	Niaz, M. 9	Roth, W. M. 6	Shrigley, R. L. 5
Trumper, R. 4	Hewson, P. W. 5	Galili, I. 12	Van Driel, J. H. 9	Patel, V. L. 3	Abd-El-Khalick, F. 9	Kwon, Y. J. 3	Songer, N. B. 3	Greenfield, T. A. 4
Stavy, R. 5	Garnett, P. J. 4	Taber, K. S. 8	Bianchini, J. A. 7	Heywood, D. 3	Sadler, T. D. 8	Deberg, K. C. 3	Barton, A. C. 3	Mares, K. R. 2
Tirosh, D. 3	Appleton, K. 4	Harrison, A. G. 8	Yore, L. D. 6	Parker, J. 3	Zeidler, D. L. 7	Dori, Y. J. 3	Buxton, C. A. 3	Koballa, T. R. 2
Renner, J. W. 3	Lemberger, J. 4	Kelly, G. J. 8	Verloop, N. 6	Kaufman, D. R. 3	Akerson, V. L. 7	Roth, W. M. 3	Barab, S. A. 3	Stake, J. E. 2
Linn, M. C. 3	Ritchie, S. M. 3	Johnson, P. 8	Barton, A. C. 6	Barnett, M. 3	Osborne, J. 7	Tsaparlis, G. 3	Krajcik, J. 2	Rennie, L. J. 2
Westbrook, S. L. 3	Meyer, H. 3	Liu, X. F. 7	Varelas, M. 5	Atwood, R. K. 3	Lubben, F. 5	Staver, J. R. 2	Lee, H. S. 2	Murphy, C. 2
Maskill, R. 2	Krockover, G. H. 3	Tytler, R. 6	Bryan, L. A. 4	Christopher, J. E. 3	Leach, J. 5	Lumpe, A. T. 2	Fortus, D. 2	Beggs, J. 2
Williamson, V. M. 2	Park, H. J. 3	Jones, M. G. 6	Abell, S. K. 4	Blown, E. J. 3	Bell, R. L. 5	Hameiri, M. 2	Barnett, M. 2	Dulski, R. E. 2

Table 8 Most cited references in the nine topics by the journals of IJSE, SE, JRST, and RISE from 1990 to 2007

Topics	Times cited
Topic 1 Scientific concept (SC)	
Watts (1983)	18
Erickson (1979)	16
Posner et al. (1982)	15
Driver and Erickson (1983)	14
Erickson (1980)	12
Topic 2 Instructional practice (IP)	
NRC (1996)	19
Pajares (1992)	15
Posner et al. (1982)	14
Tobin et al. (1990)	12
Erickson (1986)	12
Topic 3 Conceptual change and concept mapping (CC & CM)	
Posner et al. (1982)	157
NRC (1996)	102
Novak and Gowin (1984)	60
Lemke (1990)	60
Driver (1985)	48
Topic 4 Professional development (PD)	
NRC (1996)	71
Lemke (1990)	32
Shulman (1986)	26
AAAS (1993)	25
Shulman (1987)	25
Topic 5 Conceptual change and analogy (CC & A)	
Chi et al. (1981)	35
Vosniadou and Brewer (1992)	26
diSessa (1993)	25
Posner et al. (1982)	22
Brown and Clement (1989)	19
Topic 6 Nature of science and socio-scientific issues (NOS & SSI)	
Lederman (1992)	70
NRC (1996)	50
Driver et al. (1996)	49
Abd-El-Khalick et al. (1998)	40
Gallagher (1991)	39
Topic 7 Reasoning skills and problem solving (RS & PS)	
Inhelder and Piaget (1958)	22
Lawson (1985)	20
Lawson (1978)	19
Pascal-Leone (1970)	18
Gabel (1984)	18
Topic 8 Design-based and urban education (DB & UE)	
NRC (1996)	14
Barton (2001)	9
Sewell (1992)	8
Tobin et al. (1999)	7
Haberman (1991)	7
Topic 9 Attitude and gender (AG)	
Simpson and Oliver (1990)	18
Fishbein and Ajzen (1975)	15
Ajzen and Fishbein (1980)	14
Schibeci and Riley (1986)	14
Kahle and Lakes (1983)	12

cognitive psychology (e.g. Posner et al. 1982; Driver 1985; Novak and Gowin 1984), pedagogy (e.g. Shulman 1986) and philosophy of science (e.g. Lemke 1990) are the major disciplines that help direct the development of research in science teaching and learning. For example, Novak's works on conceptual mapping found its origin in constructivist learning theories that stress learner's active construction of knowledge; while his works on learning were based on the cognitive theories of assimilation that emphasized the role of prior knowledge in learning new concepts.

Discussions and Implications

This research trend analysis aimed at providing an overview to novice or young researchers in the field of science education research. As Fensham (2004) indicated, for a progressive research field, "researchers will be heeding the work of others, building from one set of studies to another" (p. 7). The significance of this study was therefore to provide directions and help make decisions on which topics to explore further while indentifying experienced researchers in the field, whose contributions would be valuable in forming research problems of the domain and to be included in literature review. On the other hand, this study offered an example of conducting an automatic content analysis from scientometrics to investigate the trends of science education research. With the normalized references from the WoK database, the data similarities among the articles were analyzed based on bibliographic coupling. With these similarities, the MSC and MDS techniques were used to provide visual representation of a complex set of relationships (Young and Hamer 1994).

It was shown in the results that not only did the above method help categorize the research topics, but the approach also visually demonstrated the relations and trends among the categories. For example, the closeness between topic 3 (CC & CM) and topic 6 (NOS & SSI) showed the shifting/extending emphasis of research in conceptual change over the past decades. It is significant that this study reported how MDS analysis method could help explain the closeness/similarity among the research

Table 9 Top 10 most cited references by the journals of IJSE, SE, JRST, and RISE from 1990 to 2007

Rank	Cited references	Document type	Times cited
1	NRC (1996)	Research report	449
2	Posner et al. (1982)	Journal article (Science Education)	340
3	AAAS (1993)	Research report	237
4	Lemke (1990)	Book	221
5	Driver (1985)	Book article	160
6	Novak and Gowin (1984)	Book	149
7	Shulman (1986)	Journal article (Educational Researcher)	139
8	Lederman (1992)	Journal article (Journal of Research in Science Teaching)	133
9	Driver et al. (1994)	Journal article (Education Researcher)	122
10	Lave and Wenger (1991)	Book	120

topics to reveal the development of trends in science education research. An immediate advantage of this approach is that such analysis can be conducted easily from time to time for research review and to provide future research directions because it takes only a few minutes to analyze a corpus of about 3,000 articles.

The findings on the development trends in this study echoed the evolution of research topics identified in previous reviews (e.g., de Jong 2007; Lee et al. 2009; Tsai and Wen 2005). de Jong (2007) observed that in the early years, cognitive psychology had great impact on the study of conceptual change in science learning, which was later expanded to include the social-cultural and science technology society (STS) dimensions. In this study, this same trend was also observed (Fig. 4; Table 5). Another example of this development trend is the adoption of the concept of pedagogical content knowledge (Shulman 1986, 1987), which has had great impact on science education (Gess-Newsome and Lederman 1999). In his review, de Jong (2007) indicated that the research interest has shifted from teachers' "content knowledge" to teachers' "pedagogical content knowledge" between 1995 and 2005. This study identified that Shulman's works on pedagogical content knowledge (1986, 1987) were ranked in the top five most cited references, while the research on teachers' teaching knowledge (in topic 4 of PD) have gained much more attentions by science education researchers in the 2000's. In addition, this study also confirmed a prior research that the number of research on SCs and conceptual change was in decline (Lee et al. 2009) although the conceptual change related topics have been and still are ranked as the most popular study topic in science education research.

As shown in the cross analysis, the English-speaking countries/regions including the USA, England, Australia, and Canada have contributed most of the journal articles in science education research. When counting the most productive countries, the non-English speaking countries such as Israel, Taiwan, Spain, Netherlands, and Turkey were also significant contributors. It has been a developing trend that the field of science education research is incorporating a broader range of cultural backgrounds (Jenkins 2000; Treagust 2006; Tsai and Wen 2005; Lee et al. 2009). This finding paralleled somehow with the Fensham's (2004) structural dimension criterion for the development of the science education research activities. For example, after the establishment of academic institutes and research associations to support research activity, science education publications from Taiwanese researchers have been gradually appeared in the international science education journals in the 1990's and showed a rapid growth in this century, with an increasing rate of 518%. The increasing appearance of researchers from the non-English speaking countries in the English-language journals also showed the recognition of their contribution by the international journals. In addition, for researchers from the non-English speaking countries to share their research findings and perspectives to the international community is to enrich the international dialogue and diversity.

The five "w" question of "who says what in what channel to whom with what effect?" as proposed by Lasswell (1964) in defining the framework of communication development, manifests the core elements of content analysis. The automatic content analysis in this study focused its investigation on the questions of who (who the researchers), what (what topics investigated), when (when getting increased/decreased), and where (which countries) in science education research in the four journals of IJSE, JRST, SE, and RISE (what channels). This approach could help educators and researchers quickly grasp the major themes in the area, the developing trends, and who have devoted efforts in what topics during a certain period of time.

While study investigated the studies published in the science education journals, the ultimate questions of "to whom" and "with what effect" that the research outcomes had influenced would require further explorations. For example, although the input of the non-English speaking country scholars has been acknowledged internationally, the question of "with what effect" remains important, as it represents how the international research community responds to the research studies. It was suggested that citation analysis may help investigate the impact level of a research study (Shih et al. 2008). Citation analysis studies can further examine the impact of a publication through analyzing the frequency cited. For example, in their study, Gokceoglu et al. (2008) found that the sharp rise of international publication by Turkish scholars in earth science since the 1990's was not accompanied with increasing impact as measured by citation frequency. Thus, systematic studies on the impact of science education research of the non-English country researchers can help understand to what extent their research products have informed other researchers.

On the other hand, further automatic content analysis of science education research may investigate the authorship by identifying the author collaboration graph with the leading and collaborating authors in certain topics and thus the collaboration networks among researchers. In other words, by identifying the significant authorship features such the key researchers in certain topics and their co-authoring collaborators would help draw a collaboration graph of the science education research community. It is expected that, by identifying research networks among researchers, the systemic and comprehensive understanding on certain research topics could be enhanced.

Science as a subject matter usually refers to the disciplines of physics, chemistry, life science, biology, and earth science. Science education, on the other hand, is more of an inter-disciplinary subject in nature (Duit 2007). From the perspective of IP improvement, Duit (2007) argued that science education research needs to stress how to balance "content issues and issues concerning learning this content." (p. 12) From the most cited references in this study, it was revealed that, other than the science subject matter, disciplines and theories that support science education research are from fields of constructivist learning, cognitive psychology, pedagogy, and philosophy of science. These disciplines and theories constructed a framework from which the issues of science teaching and learning can be better investigated and analyzed.

In addition to the disciplines and theories, this study revealed the seemingly influential role of curriculum guidelines in science education research, The reports of national science education standards (NRC 1996) and benchmarks for science literacy (AAAS 1993), for example, were among the top 10 most cited references in this study. For K-12 science education, the two reports detailed what (standards) and how (benchmarks) to implement in the school classrooms. The standards-based education directed the teaching and learning of science on which science education research is based. However, with the high frequency of citation, how much the science education research has been guided by the reports was not clear. The reports may have been cited as research background reference or may have been cited for theoretical support of the studies. This question remains to be investigated in future studies.

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