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Research trends in science education from 2013 to 2017: a systematic content analysis of publications in selected journals

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ABSTRACT

Following a series of reviews every 5 years since 1998, this fourth study presents the research trends in science education based on 1,088 research articles published in *Science Education*, *Journal of Research in Science Teaching*, and *International Journal of Science Education* from 2013 to 2017. The top three research topics, that is, the context of students' learning, science teaching, and students' conceptual learning were still emphasized by researchers in the period of 2013–2017. It is also evident that researchers have undoubtedly changed their preferences of research topics in the three journals within the 2 decades. For example, the topic concerning conceptual understanding, alternative conceptions, and conceptual change (Learning-Conceptions) was in continuous decline from 2003 to 2017, although it ranked as the top topic in the 1998–2002 period. The research topic of Teaching continuously ranked second in the 2008–2012 as well as in the 2013–2017 periods. Yet, the declining trend of Goals, Policy, and Curriculum reported in the last review was not observed in the latest period. The analysis of the top 10 most-cited papers unveiled that the issues such as inequality in science education, STEM education, and undergraduate research experiences were gradually highlighted.

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Introduction

In academia, one of the vital activities for researchers is to publish. The motivations to consistently publish may be derived from the passion for disseminating knowledge to the community or for the purpose of advancing their own academic careers for tenure, funding, or merit awards (Tsai & Wen, 2005). However, writing for scholarly publication has never been an easy task for academics (McGrail, Rickard, & Jones, 2006). Many of them may encounter the difficulties of identifying crucial research topics in a particular

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field to generate innovative ideas for their ongoing academic careers. In particular, those who are early career researchers may also have limited understanding of the characteristics of important journals and current research practices in the field. In addition, publications in high-quality refereed journals could not only serve as a channel to communicate with other scholars, but could also foster the development and maturation of a well-established research field (e.g. Hensen, 2003, 2009). Thus, it is crucial to periodically and systematically examine the current status and trends of research in terms of core journal publications. The gained insights would allow researchers to reflect on their own research foci and plan further investigations. Also, educators and practitioners can be aware of the highlighted issues in science education and fulfil a variety of education needs, both locally and internationally.

As previously mentioned, through critically examining research publications in core journals, it allows researchers to capture a clearer view of the past, present, and future practices in a certain field. In the field of science education, there is a gradually-growing body of research on synthesising selected published journal articles to harvest meaningful insights into the current status and future trends (e.g. Chang, Chang, & Tseng, 2010; Eybe & Schmidt, 2001) to provide an overview of recent research trends to inform the community with referable perspectives. For example, Chang et al. (2010) reviewed more than 3,000 articles in several science education journals from 1990 to 2007 by means of the scientometrics method that characterises several research topics such as reasoning skill and problem solving, attitude and gender, scientific concept, instructional practices, and other relevant topics. They concluded that a handful of research topics including professional development, nature of science, and socio-scientific issues, and conceptual change and analogy were frequently studied over the years. However, the analyses of this review article mainly focus on interpreting the results within the automatically-generated topic categorizations and relevant issues such as most productive authors/country and the most-cited articles/references. As indicated in the study of Lin, Lin, and Tsai (2014), such data-driven categorisation of research topics may limit the scope of review and generate less relevant topics instead of covering widely-recognized and comprehensive research topics, suggesting that an established analytical framework may be more useful for categorising available publications.

In a series of systematic review studies, Tsai and his colleagues (Lee, Wu, & Tsai, 2009; Lin et al., 2014; Tsai & Wen, 2005) have continuously documented researchers' interest in science education research such as research type, topic, and highly-cited papers every 5 years. Following a similar research rationale to that of previous studies, the current study aims to analyse research publications in three main science education journals: *Science Education* (*SE*), the *Journal of Research in Science Teaching* (*JRST*), and the *International Journal of Science Education* (*IJSE*) from 2013 to 2017. This analytic approach allows us to not only gain a periodical outline of ongoing development in the community, but also to provide substantial results for detailed comparisons in the last 2 decades. For instance, the review study conducted by Lin et al. (2014) reveals that the three most-investigated research topics are pertinent to the role of classroom context and learners' characteristics (e.g. affective, motivational, social-political factors), science teaching (e.g. teacher cognition/thinking, pedagogical content knowledge), and students' conceptual learning (e.g. conceptual change, alternative conceptions) in the 2008–2012 period. Derived from the analyses of highly-cited papers, the research articles related to scientific models and modelling, inquiry-based teaching and learning, and argumentation were frequently cited by researchers in that period. In brief, the findings derived from these reviews suggest that science education researchers did in fact shift their investigation interest in different time periods. It is possible that, as a thriving research field, the science education community continues to embrace diverse ideas in order to seek local and global contributions and to place their research efforts on various concentrations (Zeidler & Abd-El-Khalick, 2017). Therefore, a systematic and periodical scrutiny of the current status of science education research is certainly needed to facilitate the advancement of science teaching and learning practices through research.

As mentioned above, the main purpose of this study is therefore to identify the current status of science education research in the 2013–2017 period, and further to compare the findings with our previous reviews (Lee, Wu, & Tsai, 2009; Lin et al., 2014; Tsai & Wen, 2005) with a similar approach to reveal the research trends of the last 2 decades. The research questions are addressed as follows:

(1) Which countries contributed the most to the publications of *SE*, *JRST*, *IJSE* in the period of 2013–2017?
(2) How did the research types of published articles in the three journals vary in the period of 2013–2017?
(3) How did the research topics of published articles in the three journals vary in the period of 2013–2017?
(4) What were the top 10 highly-cited papers among the three journals in the period of 2013–2017?
(5) How did the research trends in terms of country contribution, research type, research topic, and top 10 highly-cited papers published in the three journals vary in the last 2 decades (1998–2017)?

Method

Based on the research purposes, this study analysed authors' nationality, research types, research topics, as well as highly-cited papers in the three science education journals, namely *SE*, *JRST*, and *IJSE*. All published articles in the three journals from 2013 to 2017 constituted the initial sample for the current study. We then excluded 'editorials,' 'commentaries,' 'responses,' and 'book reviews' to fit the research aims. The final number of retrieved papers in this study was 1,088 research articles. It should be noted that, in order to reveal the current status of science education research and relevant trends in the most recent 2 decades, we adopted the same coding schemes for analysing research types and research topics in the previous review studies (Lee et al., 2009; Lin et al., 2014; Tsai & Wen, 2005). This analytic approach allowed us to make proper comparisons across the different 5-year periods from 1998 to 2017.

Two experienced science education researchers involved in this study categorised the research types and research topics of the target papers. The two researchers independently conducted the categorisation works and then assigned only one *best-fit* research type as well as research topic to each paper. In particular, to decide the best-fit research topic category for an article, the researchers at first carefully read the title, abstract, and keywords for an overview of the paper. Then, the research purpose and questions shown in the text were scrutinised for appropriate categorisation, wherever possible. The remaining sections of the article were also considered, if necessary, to serve as a calibration criterion. The percentage of overall agreement for research type achieved 0.92, while the agreement for research topic was 0.90. After the first round of the coding procedure, the two researchers met and negotiated to deal with the varied opinions. They then re-examined and discussed until agreement on re-categorization was achieved. The frequencies and corresponding percentages of the research types and research topics were then counted for subsequent analyses and comparisons. The details of the analyses are therefore articulated in the following sections.

Authors' nationality

To allow for the comparison of the results in the series of investigations (Lee et al., 2009; Lin et al., 2014; Tsai & Wen, 2005), we utilised the formula proposed by Howard, Cole, and Maxwell (1987) to examine authors' nationality in the final sample papers. It is worth noting that the formula is useful to quantitatively identify an author's contribution to a paper, including those papers with multiple authors. The formula estimates the contribution of each author of the paper in a relatively neutral manner based on both number and order of authorship (Lee et al., 2009). According to the following formula, one point was first assigned to each of the sample papers. We then identified the total number of authors (n) and the order of every author (i) in each paper to calculate the score that the author(s) gained from the one point. For example, in the paper published by Lee, Kim, and Yoon (2015), the three authors scored 0.47, 0.32, and 0.21 respectively.

$$\text{Score} = \frac{(1.5^{n-i})}{\sum_{i=1}^{n} 1.5^{n-i}}$$

After calculating all the scores of each author of each paper, we identified the authors' nationalities. In the same example paper published by Lee et al. (2015), the first author gained a score of 0.47 for Singapore. The second author from Canada contributed 0.32 to her country, while South Korea received 0.21 because the third author's institution was located in that country. The same method was applied to calculate the country scores for each paper. We further conducted comparisons of the accumulated scores of all nations according to both published year and publication title to gain a better understanding of the authors' nationality in the three major journals of science education.

Research type

As previously mentioned, this study intended to unveil the recent development of science education research associated with the research trends of the past 20 years. Coding schemes identical to those utilised in previous studies are therefore necessary to conduct fair comparisons among the findings of the current study and of the published series of research. First, the coding scheme for research type proposed by Tsai and Wen

(2005) was adopted to classify the sample papers with five codes as follows: (1) 'Empirical' represents studies with empirical data adopting the quantitative, qualitative, or mixed-method research approaches; (2) 'Position' represents papers focused on researchers' strong positions of specific issues in science education instead of presenting empirical data. In other words, the authors attempted to present arguable opinions or proper stances with respect to an established research issue (e.g. Schizas, Psillos, & Stamou, 2016); (3) 'Theoretical' represents papers in which science educators proposed certain theories or conceptual frameworks of theories. Oftentimes, a comprehensive framework integrated with relevant studies or theories is proposed by the authors to enlighten the practice of science education research (e.g. Oyao, Holbrook, Rannikmae, & Pagunsan, 2015); (4) 'Review' represents studies that summarised and synthesised the existing literature to reveal current status and emerging trends; (5) 'Other' represents papers with content that was unable to be tallied with previous categories, such as presenting the educational reform programme of a certain nation.

Research topics

The current study also applied the coding scheme derived from the research strands of the *National Association for Research in Science Teaching* (*NARST*) conference to examine the research topics in the sample papers. To make the findings comparable with those of previous studies, we coded the research topics in the sample papers according to the categories originally proposed by Tsai and Wen (2005). The nine categories are: (1) Teacher Education (e.g. pre-service teacher education or in-service professional development); (2) Teaching (e.g. teacher thinking/behaviours or instructional strategies); (3) Learning - students' conceptions and conceptual change (Learning-Conceptions) (e.g. alternative conceptions or instructional approaches to conceptual change); (4) Learning – Classroom Contexts and Learner Characteristics (Leaning-Context) (e.g. learners' motivation/affective domain or teacher-student interaction); (5) Goals and Policy, Curriculum, Evaluation, and Assessment; (6) Culture, Social, and Gender issues; (7) History, Philosophy, Epistemology, and Nature of Science; (8) Educational Technology; and (9) Informal Learning. The detailed and precise identification of the research topics is described in our previous investigations (i.e. Lee et al., 2009; Tsai & Wen, 2005).

It should be noted that *NARST* has extended some strands according to their biographical nature in recent years. For example, in the current *NARST* strands, science teaching at different academic levels (i.e. Grades preK-6, 5–12, and 13–20) was formed from the original 'Teaching' strand. Pre-service and in-service education of science teachers were separated from 'Teacher education'. In contrast, the conceptualisation of major categories revealed in previous studies including 'Learning-Conceptions' and 'Learning-Context' remains the same in the *NARST* strands. The popularity of these two categories may be to some extent attributed to the varied sub-topics within them. Yet, it is difficult to identify proper criteria to classify certain sub-topics as a single category. The current *NARST* strands also indicate that the academic community of science education still deems research ideas relevant to these categories as a whole. We hence preserved the categorisation framework of research topics in this follow-up study.

Top ten highly-cited papers

This study further identified the most influential research efforts at present by analysing the top 10 papers with the most frequent citations per year in different time periods (i.e. cumulative years from 1998 to 2017, plus every 5 years within that period, namely 1998–2002, 2003–2007, 2008–2012, and 2013–2017), retrieved on 1 March 2018 from the citation database of the 'Web of Knowledge.' The values of cited times per year of the retrieved top 10 highly-cited papers in every 5-year period ranged from 17.35 to 38.06 (1998–2002), 22.4 to 56 (2003–2007), 16.6 to 31.88 (2008–2012), and 7.4 to 11.4 (2013–2017). For the cumulative 2 decades, the values of cited times per year were from 26.25–56. In other words, these screened top 10 highly-cited papers of varied time periods were cited at least 7.4 times per year. After the analyses of the top 10 highly-cited papers, the obtained top 10 papers in this study were then compared with the findings of Lin et al. (2014) to discuss the research trends of science education research.

Results and discussion

For this study, we first analysed the retrieved journal articles in *SE*, *JRST*, and *IJSE* from 2013 to 2017 from the database of the 'Web of Knowledge', and then the derived findings of this study in terms of authors' nationality, research type, and research topic were compared with the series of previous studies (Lee et al., 2009; Lin et al., 2014; Tsai & Wen, 2005). Next, the top 10 highly-cited papers among the three journals at present were also identified in the past 20 years as well as for every 5-year period and, then, compared with those reported in the study of Lin et al. (2014) to further unravel the shift of research foci in science education research.

Published paper by authors' nationality

Analyses of published papers during 2013–2017

In Tables 1 and 2, the authors' nationalities were analysed to show the country ranks of publications by year and by journal from 2013 to 2017, respectively. As indicated in Table 1, among the top five countries, three were English-speaking countries, namely the United States, the United Kingdom, and Australia, in addition to two non-English-speaking countries (Germany and Taiwan) in the 2013–2017 period. When analysing the research contribution by journal (Table 2), the ranking of these countries varied. That is, authors from the United States, Germany, and Taiwan published most in *IJSE*. For *JRST*, most authors came from the United States, Israel, and Canada, while the United States, the United Kingdom, and Swedish researchers had more publications in *SE*. It seems that several non-English-speaking countries such as Taiwan, Germany, Sweden, and Israel also had substantial contributions in addition to the English-speaking countries, the United States, the United Kingdom, and Canada, in the three science education journals. In terms of percentages of publications in each journal from 2013 to 2017, the authors from English-speaking countries contributed 82.2% to *JRST* and 75.6% to *SE*, but only 44.8% to *IJSE*. In other words, *IJSE* tended to publish relatively more papers from non-English-speaking countries from 2013 to 2017 than the other two journals. This phenomenon, which concurs with the findings of our previous studies (Lee et al., 2009;

Table 1. Country ranks of publications from 2013 to 2017 (top 10) for the three journals (*SE*, *JRST*, and *IJSE*)

	2013–2017 (*N* = 1088)		2013 (*N* = 208)		2014 (*N* = 216)		2015 (*N* = 227)		2016 (*N* = 230)		2017 (*N* = 207)	
Rank	Country	Score	Country	Score	Country	Score	Country	Score	Country	Score	Country	Score
1	US	508.28	US	81.77	US	94.17	US	118.97	US	109.61	US	103.76
2	UK	64.15	UK	19.42	Germany	16.92	Australia	12.28	Germany	14.65	Germany	14.18
3	Germany	59.75	Taiwan	10.78	Taiwan	13.20	Taiwan	12.60	UK	11.64	Sweden	9.79
4	Taiwan	56.74	Canada	9.38	UK	12.31	UK	12.46	Taiwan	10.95	Taiwan	9.21
5	Australia	43.20	Sweden	7.71	Sweden	8.46	Germany	8.00	Australia	10.23	UK	8.32
6	Sweden	37.10	Israel	6.84	Australia	8.39	Norway	5.60	Sweden	8.22	Australia	6.50
7	Canada	29.41	Spain	6.48	Singapore	6.82	Netherlands	5.00	Canada	6.89	Spain	6.47
8	Israel	25.51	Germany	6.00	Canada	5.44	Israel	4.70	Netherlands	6.00	Turkey	5.08
9	Netherlands	20.74	Australia	5.81	Israel	4.60	Switzerland	3.60	Israel	4.68	Israel	4.68
10	Spain	20.61	Singapore	4.24	Norway	3.40	Canada	3.07	Greece	4.00	China	4.64

Table 2. Country ranks and percentages of publications in individual journals from 2013 to 2017 (top 10).

	SE (*N* = 193)		*JRST* (*N* = 263)		*IJSE* (*N* = 632)	
Rank	Country	Score(%)	Country	Score(%)	Country	Score(%)
1	US	122.85(63.7%)	US	191.20(72.7%)	US	194.23(30.7%)
2	UK	12.66(6.6%)	Israel	9.67(3.7%)	Germany	46.32(7.3%)
3	Sweden	9.72(5.0%)	Canada	9.33(3.5%)	Taiwan	46.20(7.3%)
4	Germany	7.00(3.6%)	UK	8.22(3.1%)	UK	43.27(6.8%)
5	Norway	6.01(3.1%)	Australia	7.38(2.8%)	Australia	30.71(4.9%)
6	Canada	5.24(2.7%)	Germany	6.42(2.4%)	Sweden	27.20(4.3%)
7	Australia	5.11(2.6%)	Taiwan	5.53(2.1%)	Spain	17.13(2.7%)
8	Taiwan	5.00(2.6%)	Spain	2.79(1.1%)	Turkey	15.62(2.5%)
9	Netherlands	5.00(2.6%)	Netherlands	2.00(0.8%)	Singapore	15.26(2.4%)
10	Israel	3.00(1.6%)	France	1.79(0.7%)	Canada	14.84(2.3%)

Lin et al., 2014; Tsai & Wen, 2005), continued in the recent 5 years. It is worth noting that it seems that *IJSE* has gradually increased the percentage of papers from non-English-speaking countries during the last 2 decades, suggesting that more international research community members have tended to show interest in publishing their research findings in this particular journal.

Comparison of published papers in the 5-year periods from 1998 to 2017

The results in Table 3 show the 5-year period comparisons of the country rankings in *SE*, *JRST*, and *IJSE* in the recent 2 decades. In the first three 5-year periods, the United States, the United Kingdom, and Australia contributed most to the three journals. Yet, in the 2013–2017 period, German authors ranked third in terms of contributing publications to the three journals. The publication contributions made by Taiwanese authors have been ranked in the top five countries for the last 15 years from 2003 to 2018. In addition, in the recent 5 years, authors from Germany and Sweden made more contributions to the three journals than in the first three periods, resulting in substantial escalation in their ranking.

It is not surprising that researchers from English-speaking countries appeared in the top 10 ranking, and contributed most of the published articles. It is worth noting that researchers from English-speaking countries may only publish their works in English journals as their main channels. In contrast, those of non-English-speaking countries may

Table 3. Comparisons of country ranks of publications among 1998–2002, 2003–2007, and 2008–2012 (top 10) for the three journals (*SE*, *JRST*, and *IJSE*).

	1998–2002 (*N* = 802)		2003–2007 (*N* = 869)		2008–2012 (*N* = 990)		2013–2017 (*N* = 1088)	
Rank	Country	Score	Country	Score	Country	Score	Country	Score
1	US	346.35	US	477.16	US	356.82	US	508.28
2	UK	121.76	UK	70.13	UK	92.28	UK	64.15
3	Australia	69.18	Australia	56.30	Australia	50.02	Germany	59.75
4	Canada	37.48	Taiwan	37.92	Canada	43.68	Taiwan	56.74
5	Israel	29.75	Israel	33.76	Taiwan	42.04	Australia	43.20
6	Spain	24.20	Netherlands	28.83	Israel	38.64	Sweden	37.10
7	Taiwan	20.40	Germany	26.97	Spain	28.79	Canada	29.41
8	South Africa	14.68	Turkey	26.87	Netherlands	21.24	Israel	25.51
9	Netherlands	14.47	Canada	26.73	Turkey	16.67	Netherlands	20.74
10	Germany	12.08	Sweden	26.00	South Africa	15.16	Spain	20.61

need to publish articles not only in English-language journals but also in their national language journals in order to maintain their research visibility, both internationally and locally. Nonetheless, the increasing number of publications from non-English-speaking authors is still undoubtedly evident within the 2 decades.

Besides, the abovementioned results may reflect the co-existing phenomenon of globalisation and localisation in science education research and practice. On the one hand, because of the global competition in large-scale international assessment programmes such as the Programme for International Student Assessment (PISA) and Trends in Mathematics and Science Study (TIMSS), various stakeholders, including policy makers, researchers, and practitioners, are able to rethink their current plans to improve students' science learning performance in their respective countries (DeBoer, 2011). Take Germany and Sweden as examples; the publications of these two European countries ranked highly in the recent 2 years (i.e. 2016 and 2017). This result, as suggested in the study of Ringarp (2016), may indicate that these two countries underwent the so-called 'PISA shock' that led to close scrutiny of the educational system and improvements in education through research efforts to avoid being marginalised in such a global society. On the other hand, the increasing diversity of authors' nationality may also imply that the three journals, *IJSE* in particular, published and valued those studies contextualised in specific cultures. Such discourses between the globalisation and localisation of science education may allow international researchers to formulate new questions and methods to potentially provide new insights and opportunities to the science education community (Carter, 2008).

Published papers by research type

Analyses of published papers during 2013–2017

According to Table 4, empirical studies were the main adopted type of publication in *SE*, *JRST*, and *IJSE*. Literature reviews (2.3%), position papers (2.2%), theoretical papers (0.4%), and other types of papers (0.7%) were less published in this period. Table 4 also indicates a detailed analysis of research type by journal. That is, the percentages of empirical studies indicate that this category was the most published in all three journals, ranging from 91.2% to 96.0%. It should be noted that *SE* published relatively more position papers (6.7%) than *IJSE* and *JRST*, while *IJSE* published more review papers (2.4%) than the other two journals. Nevertheless, the percentage of published position papers in each journal was still very low.

Comparison of published papers in the 5-year period of 1998–2017

Table 4 also presents the comparisons of research type among the four different 5-year periods. In general, in the last 2 decades, it is evident that the major research type of publication was the empirical study in the science education community. Besides, the percentage of empirical research type has gradually increased from 86.9% to almost 95% in the last 2 decades. Nevertheless, the percentage of position papers gradually declined from 9.4% to 2.2% from 1998 to 2017. This finding implies that, with the progressive growth in the field of science education, those position papers proposed in the early years may have guided researchers to conduct more relevant empirical studies in the later years, indicating the maturation and prosperity of this field to a certain extent. Besides, considering

Table 4. Comparisons of frequencies and percentages of research types among 1998–2002, 2003–2007, 2008–2012, and 2013–2017 for the three journals (*SE*, *JRST*, and *IJSE*).

	1998–2002(*N* = 802)				2003–2007(*N* = 869)				2008–2012(*N* = 990)				2013–2017(*N* = 1088)			
Type	SE (*N* = 180)	JRST (*N* = 258)	IJSE (*N* = 364)	ALL	SE (*N* = 223)	JRST (*N* = 242)	IJSE (*N* = 404)	ALL	SE (*N* = 223)	JRST (*N* = 255)	IJSE (*N* = 512)	ALL	SE (*N* = 193)	JRST (*N* = 263)	IJSE (*N* = 632)	ALL
Empirical	151 (83.9%)	229 (88.8%)	317 (87.1%)	697 (86.9%)	175 (78.5%)	237 (97.9%)	351 (86.9%)	763 (87.8%)	183 (82.1%)	234 (91.8%)	481 (94.0%)	898 (90.7%)	176 (91.2%)	244 (92.8%)	607 (96.0%)	1027 (94.4%)
Position	23 (12.8%)	21 (8.1%)	31 (8.6%)	75 (9.4%)	20 (9.0%)	1 (0.4%)	15 (3.7%)	36 (4.1%)	14 (6.3%)	5 (2.0%)	7 (1.4%)	26 (2.6%)	13 (6.7%)	6 (2.3%)	5 (0.8%)	24 (2.2%)
Theory	0	2 (0.8%)	4 (1.1%)	6 (0.8%)	16 (7.2%)	2 (0.8%)	12 (3.0%)	30 (3.5%)	19 (8.5%)	7 (2.8%)	5 (1.0%)	31 (3.1%)	0	1 (0.4%)	3 (0.5%)	4 (0.4%)
Review	2 (1.1%)	5 (1.9%)	6 (1.6%)	13 (1.6%)	7 (3.1%)	1 (0.4%)	18 (4.5%)	26 (3.0%)	7 (3.1%)	8 (3.1%)	15 (2.9%)	30 (3.0%)	4 (2.1%)	6 (2.3%)	15 (2.4%)	25 (2.3%)
Other	4 (2.2%)	1 (0.4%)	6 (1.6%)	11 (1.4%)	5 (2.2%)	1 (0.4%)	8 (2.0%)	14 (1.6%)	0	1 (0.4%)	4 (0.8%)	5 (0.5%)	0	6 (2.3%)	2 (0.3%)	8 (0.7%)

the increasing number of empirical papers within the 2 decades, the number of review studies did not seem to increase in popularity. This may imply that the researchers tended to target their review studies in those journals that specifically aimed to publish review papers (e.g. *Studies in Science Education*) other than the three journals.

It is argued here that the importance of position papers cannot be neglected by science education researchers. For instance, Posner, Strike, Hewson, and Gertzog (1982) proposed a model of conceptual change embedded in a set of epistemological assumptions which explicate how people learn and organise their own ideas. Another example comes from Driver and her colleague (Driver & Easley, 1978). She argued that children's ideas and cognitive development are dependent on their existing 'alternative frameworks' about certain phenomena, rather than merely the Piagetian stage theory of development. The above-mentioned two works have made substantial impacts on how researchers approach their investigations. Thus, an influential position paper may lead researchers to reconsider their research practices and, in turn, result in a paradigm shift of the whole research community. This declining trend in terms of the publications of position papers may indicate that these journals, in some way, should encourage good position papers to be published and then guide future academic development in the field.

Published papers by research topic

Analyses of published papers during 2013–2017

The results illustrated in Table 5 indicate that the three journals published the most papers on the topic of Learning-Context (36.7%), followed by Teaching (17.7%) and Learning-Conceptions (10.2%). It is evident that the category Learning-Context steadily ranked in the first place from 2013 to 2017. In other words, during 2013–2017, researchers had the greatest interest in exploring the issues regarding classroom context and learners' characteristics. Research issues of Teaching such as teacher knowledge and teaching strategies also attracted researchers' attention. Besides, science education researchers still showed considerable interest in issues such as learners' conceptual understanding, alternative conceptions, or conceptual change. It should be noted that the Goals, Policy, and Curriculum (9.7%) category also gained substantial attention from science education researchers, especially in 2015 and 2017. On the contrary, the research topics of Informal Learning (4.4%) and Educational Technology (2.0) were the two least researched topics during the 2003–2007 period.

Table 5. Frequencies and percentages of research topics from 2013 to 2017 for the three journals (*SE*, *JRST*, and *IJSE*).

Research Topic	2013–2017 (*N* = 1088)	2013 (*N* = 208)	2014 (*N* = 216)	2015 (*N* = 227)	2016 (*N* = 230)	2017 (*N* = 207)
Teacher Education	70(6.4%)	14(6.7%)	9(4.2%)	18(7.9%)	12(5.2%)	17(8.2%)
Teaching	193(17.7%)[b]	43(20.7%)[b]	28(13.0%)[c]	32(14.1%)[b]	43(18.7%)[b]	47(22.7%)[b]
Learning-Conceptions	111(10.2%)[c]	18(8.7%)	30(13.9%)[b]	28(12.3%)[c]	21(9.1%)[c]	14(6.8%)
Learning-Context	399(36.7%)[a]	78(37.5%)[a]	78(36.1%)[a]	78(34.4%)[a]	91(39.6%)[a]	74(35.7%)[a]
Goals, Policy, and Curriculum	105(9.7%)	19(9.1%)[c]	21(9.7%)	28(12.3%)[c]	16(7.0%)	21(10.1%)[c]
Culture, Social and Gender	66(6.1%)	15(7.2%)	11(5.1%)	16(7.0%)	13(5.7%)	11(5.3%)
Philosophy, History, and NOS	74(6.8%)	11(5.3%)	24(11.1%)	10(4.4%)	17(7.4%)	12(5.8%)
Educational Technology	22(2.0%)	3(1.4%)	3(1.4%)	7(3.1%)	4(1.7%)	5(2.4%)
Informal Learning	48(4.4%)	7(3.4%)	12(5.6%)	10(4.4%)	13(5.7%)	6(2.9%)

[a]Top one topic, [b]Top two topic, [c]Top three topic.

In addition, the results of research topics by journal are revealed in Table 6. In general, the topics of Learning-Context and Teaching were consistently the two most published topics in *SE*, *JRST*, and *IJSE*. However, some variations appeared in the three journals regarding the third most-published topics. That is, Learning-Conceptions ranked third in *IJSE* and *JRST* published papers, while Goals, Policy, and Curriculum ranked third in *JRST* and *SE*. This implies that *JRST* and SE tended to publish the papers concerning the current status of science education curriculum reforms, standards, or policies. The explanation of this result may be due to the recent science curriculum reform in the United States. As Chang et al. (2010) indicated, curriculum guidelines seemingly play an influential role in affecting science education research and practices. Accordingly, the release of the Next Generation Science Standards (NGSS Lead States, 2013) may encourage researchers to carefully examine the new standards from various aspects and perspectives (e.g. Feinstein & Kirchgasler, 2015; Moore, Tank, Glancy, & Kersten, 2015) by way of the two main channels (i.e. *JRST* and *SE*) for energising in-depth discussions.

Besides, Table 6 also illustrates that *JRST* and *SE* tended to publish comparatively more papers aimed at Informal Learning (8.4% and 7.8%, respectively) than *IJSE* (1.7%). In other words, in *IJSE*, researchers showed less interest in publishing papers regarding science learning in informal contexts. The plausible explanation for this result may relate to the scope of this particular journal. In 2011, *IJSE* launched the other outlet (*IJSE*: Part B) for the specific emphasis of welcoming research in public science communication and informal learning (Stocklmayer & Gilbert, 2011). Thus, it is possible that science education researchers who are interested in informal learning may turn to other potential journals to publicise their research, thus resulting in this finding. Similar to this interpretation, researchers may target some other well-established journals with respect to Educational Technology (e.g. *Computers & Education*), also considered as a widely-recognized research field, to publish their research articles instead of *SE*, *JRST*, and *IJSE*.

Comparison of published papers in the 5-year period of 1998–2017

Within the last 2 decades, science education researchers published most articles regarding Learning-Context (1,112 papers), followed by Learning-Conceptions (592 papers), and Teaching (553 papers). In contrast, the two least researched topics were relevant to Informal Learning (158 papers) and Educational Technology (134 papers).

Figure 1 also displays the comparisons of the research topics for the four periods from 1998 to 2017. To be more specific, the topic of Learning-Context has continuously ranked

Table 6. Frequencies and percentages of research topics in individual journals from 2013 to 2017.

Research Topic	*SE*	*JRST*	*IJSE*
Teacher Education	11(5.7%)	15(5.7%)	44(7.0%)
Teaching	32(16.6%)[b]	42(16.0%)[b]	119(18.8%)[b]
Learning-Conceptions	15(7.8%)	24(9.1%)[c]	72(11.4%)[c]
Learning-Context	66(34.2%)[a]	95(36.1%)[a]	238(37.7%)[a]
Goals, Policy, and Curriculum	21(10.9%)[c]	24(9.1%)[c]	60(9.5%)
Culture, Social and Gender	11(5.7%)	22(8.4%)	33(5.2%)
Philosophy, History, and NOS	16(8.3%)	17(6.5%)	41(6.5%)
Educational Technology	6(3.1%)	2(0.8%)	14(2.2%)
Informal Learning	15(7.8%)	22(8.4%)	11(1.7%)

[a]Top one topic, [b]Top two topic, [c]Top three topic.

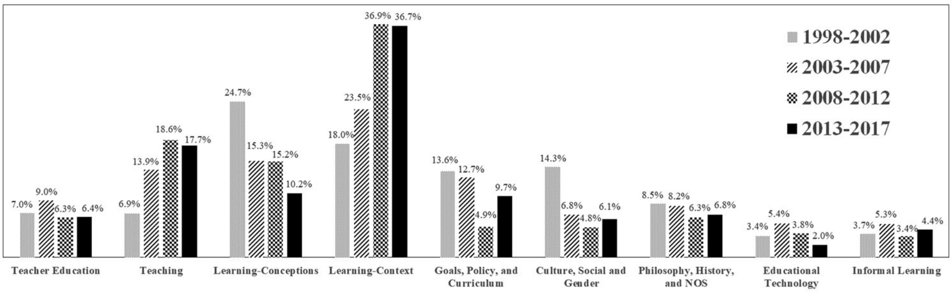

Figure 1. Comparisons of percentages of research topics among the different 5-year periods for the three journals (*SE*, *JRST*, and *IJSE*).

as the top since 2003 while the topic of Teaching has ranked second for a decade. It seems that there has been a gradually declining trend of papers on the research topic of Learning-Conceptions from 1998 to 2017, although this topic has still been ranked third since 2008. In particular, in the period of 2013–2017, papers regarding Learning-Conceptions obviously decreased (from 15.2% to 10.2%). The percentages of publications focused on the topic of Teacher Education in the 2008–2012 (6.3%) and 2013–2017 (6.4%) periods were relatively similar. However, the declining trend of Goals, Policy, and Curriculum reported in the study of Lin et al. (2014) was not observed in the 2013–2017 period, indicating that this research topic has drawn much attention from researchers in this latest 5-year period (from 4.9% to 9.7%). It also seems that there has been a growing trend of the topic Culture, Social and Gender in the recent 5 years (6.1%) compared with the result of the 2008–2012 period (4.8%). As for Educational Technology, a declining trend was evident in 2013–2017 (from 3.8% to 2.0%).

In sum, it is clear that researchers have changed their preferences for a handful of research topics in the three journals within these 20 years. First, the research relevant to learners' characteristics and learning contexts, such as learning environment, higher-order thinking, and affective dimensions of science learning remains the foremost priority and major concentration for researchers. Second, there is no doubt that the topic of Learning-Conceptions, such as the issues of specific science topics or conceptual change, has been unceasingly in decline in the last 15 years as highlighted in the literature (e.g. Chang et al., 2010; Lin et al., 2014), although this topic is still regarded as an important aspect of science learning (e.g. Eshach, Lin, & Tsai, 2018).

Moreover, the topic of Teaching attracted much attention from 2008 to 2017. This result also echoes the suggestion proposed by de Jong (2007), indicating that science education researchers should strive to bridge the gap between research outcomes and teaching practices. Previous studies (e.g. Lee et al., 2009; Lin et al., 2014) have also pointed out that the popularisation of investigations on the teaching practice of science may aim to resolve the relevant issues derived from the viewpoints of science learning. In addition, in the recent 5 years, researchers published more papers regarding various issues of culture, social, and gender than those of 2008–2012, suggesting that more efforts should be put into this area. For instance, *JRST* edited two special issues (Parsons & Carlone, 2013; Varelas, Settlage, & Mensah, 2015) to facilitate researchers' discussion of the issues of culture and equity. It is possible that, for the moment, researchers may have not only recognised the importance but also acknowledged the complexity of these relevant topics. Also, cross-cultural studies are also common in the field of science education for exploring the role of culture in science learning (e.g. Wang, Liang, & Tsai, 2018). This may necessitate more theoretical, methodological, and empirical endeavours to thoughtfully approach these issues in systematic ways.

Top 10 highly cited papers in each 5-year period from 1998 to 2017

This study takes a closer look at the top 10 most-cited articles in terms of citation number per year in the four 5-year periods as well as the 2 decades as a whole. In 2013–2017 (Appendix Table A1), it is interesting that half of the papers (numbered 2, 6, 7, 8, 10) were concerned with cultural, social, and gender issues such as capital, identity, race, etc. Other most-cited articles were quite diverse in terms of the research issues. That is, these articles were related to conceptual learning and understanding (numbered 1), argumentation (numbered 3), scientific inquiry (numbered 4), practical epistemology (numbered 5), and nature of science (numbered 9). Furthermore, Appendix Table A2 displays the results of the top 10 most-cited papers in 2008–2012 of this study and the study of Lin et al. (2014). Consistent with the findings of the last review, the papers related to a handful of research issues such as inquiry (numbered 1, 3), scientific modelling (numbered 2), and argumentation (numbered 6, 10) continued to be the main research foci. Some research issues, including STEM education (numbered 4, 5), learners' interest in science (numbered 7), and science identity (numbered 8) also emerged in the recent 5 years.

In addition, Appendix Table A3 presents a comparison of the top 10 most-cited articles in 2003–2007 of the current study and the study of Lin et al. (2014). As shown, although the issues of argumentation as well as informal reasoning (numbered 3, 5, 9) were still highlighted, the research issues concerning undergraduate research experiences (numbered 4, 6) and science identity (numbered 7) emerged in the period of 2003–2007. It can also be seen in Appendix Table A4, most of the top 10 most-cited papers in 1998–2002 were still concerned with the research issue of argumentation (numbered 1, 5, 8) and the topic of NOS (numbered 2, 7). It should be noted that the article regarding science teachers' pedagogical content knowledge (numbered 9) did not appear in the review of Lin et al. (2014). This highly-cited paper may serve as the foundation for researchers to conduct relevant studies in the Teaching category. In other words, equipping science teachers with adequate professional knowledge could be a viable approach to resolve the issues related to those learning studies such as Learning-Conceptions or Learning-Context. As for the top 10 most-cited papers in the cumulative 20 years (Appendix Table A5), it is quite similar to the findings of the four divided periods. It should be noted that some long-lasting research foci related to learners' affective characteristics such as attitudes or motivation (numbered 1, 7), laboratory learning environment (numbered 2), and scientific modelling (numbered 8) have constantly drawn the attention of researchers throughout the 2 decades.

By and large, several enduring research issues, including argumentation, scientific inquiry, scientific modelling, and NOS in particular periods still play influential roles in leading researchers to conduct relevant research in the field of science education. In addition, it should be noted that some prospective research issues have received much attention from researchers. First, it seems that researchers have turned to investigate science learning and learners' characteristics in terms of gender, ethnicity, social, and cultural capital (e.g. Archer, Dawson, DeWitt, Seakins, & Wong, 2015; DeWitt et al., 2013). These various forms of 'science capital,' which originated from the sociologist Bourdieu's notions of capital, allow researchers to take a fine-grained view on and provide alternative insights into the long-standing and persistent inequality issues such as learners' low engagement in science or uneven patterns of science-related career participation.

Second, another emerging research trend in the 2013–2017 period is regarding STEM education. In recent years, the rapid proliferation of STEM education has warranted new areas of research (Li, 2014). The study of teaching and learning at the crossroads of science, technology, engineering, and mathematics allows researchers to examine various dimensions such as curriculum/pedagogy, teaching and teacher education, and policy, and facilitates conversations among researchers from different areas of expertise (Henderson, Beach, & Finkelstein, 2011). Bybee (2010) also contended that STEM education potentially provides learners with the opportunities of developing essential 21st century skills and promotes a STEM-literate citizenry in this rapidly changing global society.

Last but not least, derived from STEM education, the research of undergraduate research experiences (UREs) has been appreciated since the last decade. As synthesised in a recent review (see Linn, Palmer, Baranger, Gerard, & Stone, 2015), such valuable experiences may provide a number of affordances such as the promotion of awareness of professional identity in science, the persistence in pursuing STEM-related careers or higher degrees, and the increase in the understanding of domain knowledge and epistemic practices of science. Nevertheless, given the dynamic nature and complexity of UREs, the empirical evidence with respect to the influence of such experiences on student development is still insufficient and in need of ongoing investigations in this regard.

It is interesting to point out that, as proposed by Fensham (2004), the notion of 'seminal publications' could serve as an indicator of the maturation of the field. These seminal publications, regularly cited by researchers, go beyond merely a good review or exemplary study in terms of methodology. Some of them contain an idea that enables other researchers to conduct follow-up studies. Others may offer a unique theoretical perspective to interpret past relevant studies. To be more fundamental, a handful of publications may entail philosophical and epistemological frameworks that enable researchers to conduct subsequent empirical studies. The results of this study may, to a certain extent, provide documented evidence with respect to the proliferation of the field. Future research could adopt different methods such as co-citation network analysis (e.g. Tang et al., 2016) to better unravel the intellectual structure of the field.

Concluding remarks

The current study aimed to adopt the content analysis method to systematically analyse the publications in *SE*, *JRST*, and *IJSE* in the period of 2013–2017. The gained findings derived from this study were further compared with our previous reviews (Lee et al., 2009; Lin et al., 2014; Tsai & Wen, 2005) to unravel the research trends in science education within the last 2 decades. The results of this study suggest that the main contributing countries have become increasingly diverse in addition to a handful of English-speaking countries in the three journals. With the active participation of the international research community, the entire science education community could also benefit from the global perspectives to further advance science education research (Zeidler & Abd-El-Khalick, 2017). Furthermore, those identified research topics and issues not only reflect the past and current research practices in this community but also serve as an opportunity to contemplate the future direction in this field. As identified in this study, the prevalent research topics and issues oftentimes cannot be separated from the context of school science, indicating that the research and the practices of science education are closely aligned. Thus, for those who are novice or early-career researchers, the results of this study may be crucial and beneficial to grasp an initial understanding of this progressive research field. Thus, for practitioners such as science educators and policy-makers, being equipped with a proper understanding of the present research concentrations in this field may guide them to make informed educational judgements and decisions in their instructional practices or policy-making processes.

Last but not least, some limitations of this study could also shed light on future endeavours. First, the framework for analysing the retrieved papers of this study in terms of research topic could be refined. For instance, the popularity of the 'Learning-Context' category may be attributed to some potential sub-topics (e.g. interest/motivation/attitudes), as mentioned above. This issue may encourage researchers to make a closer examination of certain categories to yield meaningful results and insights into science education research, especially those popular categories. Moreover, although each article was assigned to the best-fit research topic category in this study, it seems that an increasing number of articles were related to several categories. Although this phenomenon may be an indicator of maturation of a research field, it also urges the development of a distributive technique or formula, similar to the one for scoring multiple authors' nationality, to carefully scrutinise this effect in the future. Another limitation is related to journal choice. Although there are some other significant journals such as *Science & Education* or *Cultural Studies in Science Education* in the field, these journals may be relatively limited in terms of aims and scope. This study mainly selected the three prominent journals that characterise broad interests of research topics and each of them is with a long-lasting publication history. Since this study is part of a long running sequence of systematic review, the analyses and results of this study allow us to make periodical scrutiny with previous ones to establish an overview of the research field. Researchers with distinctive interests on specific topics could also adopt the methodology of this study to enlighten the future research direction of this field from a more refined perspective.

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Appendices

Table A1. The top 10 most-cited papers in 2013–2017.

Rank	Title	Journal (year)
1	Towards a learning progression of energy	*JRST* (2013)
2	Science capital: A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts	*JRST* (2015)
3	Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students	*JRST* (2013)
4	Meaningful assessment of learners' understandings about scientific inquiry-the views about scientific inquiry (VASI) questionnaire	*JRST* (2014)
5	Epistemologies in practice: Making scientific practices meaningful for students	*JRST* (2016)
6	Becoming (less) scientific: A longitudinal study of students' identity work from elementary to middle school science	*JRST* (2014)
7	What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups	*JRST* (2014)
8	Adolescent boys' science aspirations: Masculinity, capital, and power	*JRST* (2014)
9	The 'general aspects' conceptualisation as a pragmatic and effective means to introducing students to nature of science	*JRST* (2016)
10	Young children's aspirations in science: The unequivocal, the uncertain and the unthinkable	*IJSE* (2013)

Table A2. A comparison of the top 10 most-cited papers in 2008–2012 in this study and Lin et al. (2014).

Rank	Title[#]	Journal (year)	Title*	Journal (year)
1	↑Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984–2002 **(2nd to 1st)**	*JRST* (2010)	Making Sense of Argumentation and Explanation	*SE* (2009)
2	↑Developing a learning progression for scientific modelling: Making scientific modelling accessible and meaningful for learners **(4th to 2nd)**	*JRST* (2009)	Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984–2002	*JRST* (2010)
3	↑Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations **(6th to 3rd)**	*SE* (2008)	Advancing reflective judgment through socioscientific Issues	*JRST* (2009)
4	Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature	*JRST* (2011)	Developing a learning progression for scientific modelling: Making scientific modelling accessible and meaningful for learners	*JRST* (2008)
5	Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students	*SE* (2011)	Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge	*JRST* (2008)
6	↓Making sense of argumentation and explanation **(1st to 6th)**	*SE* (2009)	Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations	*SE* (2008)
7	Research on interest in science: Theories, methods, and findings	*IJSE* (2011)	Funds of knowledge and discourses and hybrid space	*JRST* (2009)
8	Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine	*JRST* (2010)	Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy	*SE* (2008)
9	Proposing a core set of instructional practices and tools for teachers of science	*SE* (2012)	Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform	*JRST* (2008)
10	↔Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions	*SE* (2008)	Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions	*SE* (2008)

Note1: [#]the current study; *the study of Lin et al. (2014).
Note2: ↑: rank up, ↓: rank down, ↔: the same rank.

Table A3. A comparison of the top 10 most-cited papers in 2003–2007 in this study and Lin et al. (2014).

Rank	Title[#]	Journal (year)	Title*	Journal (year)
1	↔Attitudes towards science: a review of the literature and its implications	*IJSE* (2003)	Attitudes towards science: a review of the literature and its implications	*IJSE* (2003)
2	↔The laboratory in science education: Foundations for the twenty-first century	*SE* (2004)	The laboratory in science education: Foundations for the twenty-first century	*SE* (2004)
3	↔Enhancing the quality of argumentation in school science	*JRST* (2004)	Enhancing the quality of argumentation in school science	*JRST* (2004)
4	Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development	*SE* (2007)	TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse	*SE* (2004)
5	↓TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse **(4th to 5th)**	*SE* (2004)	Informal reasoning regarding socioscientific issues: A critical review of research	*JRST* (2004)
6	↑Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study **(8th to 6th)**	*SE* (2004)	How literacy in its fundamental sense is central to scientific literacy	*SE* (2003)
7	Understanding the science experiences of successful women of colour: Science identity as an analytic lens	*JRST* (2007)	Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry	*SE* (2004)
8	↓How literacy in its fundamental sense is central to scientific literacy **(6th to 8th)**	*SE* (2003)	Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study	*SE* (2004)
9	↓Informal reasoning regarding socioscientific issues: A critical review of research **(5th to 9th)**	*JRST* (2004)	What 'ideas-about-science' should be taught in school science? – A Delphi study of the expert community	*JRST* (2003)
10	↔Conceptual change: A powerful framework for improving science teaching and learning	*IJSE* (2003)	Conceptual change: A powerful framework for improving science teaching and learning	*IJSE* (2003)

Note1: [#]the current study; *the study of Lin et al. (2014).
Note2: ↑: rank up, ↓: rank down, ↔: the same rank.

Table A4. A comparison of the top 10 most-cited papers in 1998–2002 in this study and Lin et al. (2014).

Rank	Title[#]	Journal (year)	Title*	Journal (year)
1	↔Establishing the norms of scientific argumentation in classrooms	*SE* (2000)	Establishing the norms of scientific argumentation in classrooms	*SE* (2000)
2	↔Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science	JRST (2002)	Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science	*JRST* (2002)
3	↑The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective **(5th to 3rd)**	*SE* (2000)	Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks	*SE* (2002)
4	↓Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks **(3rd to 4th)**	*SE* (2002)	Fostering students' knowledge and argumentation skills through dilemmas in human genetics	*JRST* (2002)
5	↓Fostering students' knowledge and argumentation skills through dilemmas in human genetics **(4th to 5th)**	*JRST* (2002)	The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self – determination theory perspective	*SE* (2000)

(*Continued*)

Table A4. Continued.

Rank	Title[#]	Journal (year)	Title*	Journal (year)
6	↔Improving science teachers' conceptions of nature of science: a critical review of the literature	*IJSE* (2000)	Improving science teachers' conceptions of nature of science: a critical review of the literature	*IJSE* (2000)
7	Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas	*SE* (2002)	Scientific arguments as learning artifacts: designing for learning from the web with KIE	*IJSE* (2000)
8	↔Doing the lesson or 'doing science': Argument in high school genetics	*SE* (2000)	Doing the lesson or 'doing science': Argument in high school genetics	*SE* (2000)
9	Developing science teachers' pedagogical content knowledge	*JRST* (1998)	The nature of science and instructional practice: Making the unnatural natural	*SE* (1998)
10	↔Articulating communities: Sociocultural perspectives on science education	*JRST* (2001)	Articulating communities: Sociocultural perspectives on science education	*JRST* (2001)

Note1: [#]the current study; *the study of Lin et al. (2014).
Note2: ↑: rank up, ↓: rank down, ↔: the same rank.

Table A5. The top 10 most-cited papers in 1998–2017.

Rank	Title	Journal (year)
1	Attitudes towards science: a review of the literature and its implications	*IJSE* (2003)
2	The laboratory in science education: Foundations for the twenty-first century	*SE* (2004)
3	Establishing the norms of scientific argumentation in classrooms	*SE* (2000)
4	Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science	*JRST* (2002)
5	Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984–2002	*JRST* (2010)
6	Enhancing the quality of argumentation in school science	*JRST* (2004)
7	The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective	*SE* (2000)
8	Developing a learning progression for scientific modelling: making scientific modelling accessible and meaningful for learners	*JRST* (2009)
9	Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development	*SE* (2007)
10	Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks	*SE* (2002)