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ARTICLE

Chemistry Education Research Trends: 2004-2013

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This paper presents findings from a content analysis of 650 empirical chemistry education research papers published in two top-tiered chemistry education journals *Chemistry Education Research and Practice* and *Journal of Chemical Education*, and four top-tiered science education *International Journal of Science Education*, *Journal of Research in Science Teaching*, *Research in Science Teaching* and *Science Education* from 2004-2013. We found that empirical chemistry education research (CER) papers accounted for 7.7 percent of the publications in the four science education journals. The most highly published area of research was in conceptions and conceptual change and most studies adopted mixed methods. The majority of the studies were conducted in higher education contexts and in the United States. Researchers who publish prolifically in the field included Vicente Talanquer, Michael Sanger, Keith Taber, Melanie Cooper and Marcy Towns. Current research trends and gaps are illuminated and possible future work in CER is discussed in the paper.

Introduction

More than a decade ago, Gilbert, De Jong, Justi, Treagust and van Driel (2003) argued that for chemistry education to prosper in future, a suitable range of types of research must be carried out. We understand "range" to mean research topics, methods, methodologies, research participants and so on. According to them, relatively few studies focused on interdisciplinary studies (e.g., math and chemistry), problems that learners confront when they transit across the grade levels (e.g., from high school to university), and the effectiveness of technology-based pedagogies and impact of technology-based environments on learning. In this paper, we reviewed recent publications in chemistry education research (CER) to illuminate some of the recent trends and gaps in this field.

This paper reviews empirical chemistry education research papers published in the years 2004-2013. This review is a continuation and expansion of previous reviews completed by Kornhauser (1979), Gilbert, De Jong, Justi, Treagust, and Van Driel (2003), Mahaffy (2004), and Towns and Kraft (2011), and Towns (2013) in five aspects. First, we extended the period under review to include papers published up to the end of 2013. The most recent paper (see Towns & Kraft, 2011) that systematically reviewed CER papers covered up to the year 2010. Second, we included in our review the journal *Research in Science Education*, which was not included in the abovementioned review, as it was one of the top four SER journals in terms of impact factor. Third, more research topics (e.g., cultural, social, and gender issues, and informal learning) and sub-topics were identified showing the diversity and richness of CER. Fourth, we included the analyses of the different groups of participants and locations of study to show which groups of people and contexts were more or less well represented and understood. Fifth, we included a systematic analysis of the key contributors to show recognition of their efforts in driving the field of CER. The findings of this most recent 10-year review will allow us to reflect on how the field has progressed and offer useful information for current and incoming chemistry education researchers who wish to join the CER fraternity, build on the existing work, or push new boundaries. Insights into the work done by colleagues in the field during this period may be gained. The information may also be valuable to researchers in charting their future research studies in CER.

What defines chemistry education research (CER)?

According to Kornhauser (1979),

> The scientific basis of the new [chemistry] discipline is this: the methods of chemical education are derived from the structure, logic and methods of chemistry itself. No other discipline can replace chemical science as the basis of the methodology of chemical education (p. 32).

The above view about CER was articulated in the late 1970s. Yet, to date, there exist different viewpoints on what constitutes CER. For example, it can be broadly defined as a "scholarship focused on understanding and improving chemistry learning" (Herron & Nurrenbern, 1999). Bunce and Robinson (1997) referred to CER as the "third branch of our profession" covering topics such as "how and why students learn", "why is chemistry difficult to learn", and "what facilitates effective chemistry teaching and learning". Bodner (2005) had said that, "Chemistry education research is like research in any domain of chemistry. It is the process, not the product that is important". Basically, these ideas underscore the point that CER should be honoured as a unique domain in its own right—it is a form of disciplinary-based research conducted based upon a rigorous research design that generates evidences and informs practice. This form of disciplinary-based research takes into consideration the unique history of chemistry concept developments, the way chemistry knowledge is constructed, and the specific skill sets and apparatuses used in the chemistry laboratory. As such, the empirical findings from CER may be more understandable, relevant, and applicable to those who practice chemistry in various settings. In this case, the "practice" refers to the practice of teaching, learning, curriculum design, and assessment, and the practice that chemistry education researchers would undertake in carrying out their investigations. Some of these practices can be discipline-specific or common across the three major science disciplines. For example, studies about students' misconceptions are conducted in chemistry, biology, and physics but the content (e.g., chemical equilibrium, microorganisms, friction) may be discussed more in one subject then the other. Figure 1 below shows a Venn diagram to summarise our viewpoint about CER, PER (physics education research), and BER (biology education research).

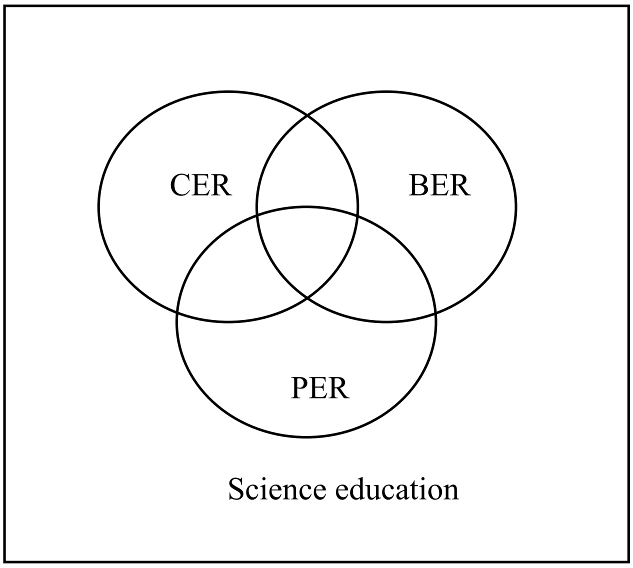


Fig. 1 The Venn diagram shows that chemistry education research (CER), biology education research (BER), and (physics education research (PER)—all disciplinary-based education research (DER)—are subsets of the broader science education research (SER). The overlapping areas refer to studies on interdisciplinary topics such as nanotechnology, biochemistry, environmental science, sustainability, and material science, which cut across two or more of the subject matters.

Goal of this review

This review, derived from a systematic content analysis of chemistry education empirical research articles, sought to address the following questions:

1. What was the representation of chemistry education empirical research in science education research journals?
2. What were the most and least researched on topics?
3. What research methods (qualitative, quantitative, or mixed) were being adopted?
4. Which groups of subjects were represented?
5. Where were the regions and specific locations that the research was carried out?
6. Who were the key contributors to the field?

We wanted to find out how well published were CER papers in SER journals. The acceptance of CER papers in SER journals would suggest that these papers cater to the wider readership of a broader science education audience and that DER had a place in SER journals. Additionally, we wanted to investigate the research topics that were most and least researched on to identify the strengths and research gaps in CER. The findings of the analysis on research methods would inform us about the research designs and the types of data generated. From this, we could also infer about the research capacity of CER researchers in doing qualitative and/or quantitative research. The profile of the subjects researched on and the locations at which the studies were carried out would allow us to know whose voices were represented, whose voices were left out, and which contexts were better studied than others. This context specific information is important to chemistry education policy making and curriculum change as not all findings are applicable across contexts and settings. Finally, we analysed the authorship to acknowledge the key contributors to CER.

Methods

Scope of the literature search

While we recognise the value of different types of publications, the scope of this review includes only empirical papers that had adopted rigorous research designs and were peer-reviewed. Given the vast amount of papers to review, we decided to limit the number of journals. We selected two chemistry education and four science education research journals, namely, *Chemistry Education Research and Practice* (CERP), *Journal of Chemical Education* (JCE), *Journal of Research in Science Teaching* (JRST), *Science Education* (SE), *International Journal of Science Education* (IJSE) and *Research in Science Education* (RSE). Currently, CERP and JCE are the only two chemistry education-based journals that are indexed under the Thomson Reuters Science/Social Science Citation Index (SSCI). JRST, SE, IJSE and RSE are the four science education research journals with the highest impact factor indexed under the SSCI. Table 1 shows the three-year and five-year impact factor of these journals.

All papers published in the six journals had undergone a single or double-blind review process. All paper published between 2004-2013 were downloaded and underwent further selection. Basically, all papers based upon empirical studies with a focus on chemistry teaching, learning, and assessments were included in the review. Non-empirical papers such as theoretical papers, positional papers, editorials, book reviews, and commentaries were excluded as we wanted to narrow the scope of the review, and focus on studies that described the research methods and discussed findings based upon empirical data. When identifying relevant papers published in SER journals, we conducted a Boolean keyword search using "chemistry" in each journal webpage. We downloaded, read, and filtered out papers that did not have a focus on chemistry education and/or were non-empirical. The chemistry papers in SER journals may be categorised as having an intrinsic, extrinsic, or coincidental relationship to chemistry teaching and learning (Taber, 2013). In CERP, only papers that explore issues and topics: (1) specific to the nature of teaching and learning chemistry as a curriculum subject (i.e., inherent CER with intrinsic relationship), and (2) arising from general teaching and learning issues but clearly motivated by aspects of chemistry teaching and learning (i.e., embedded CER with extrinsic relationship) would be published. In our selection of CER papers in SER journals, we included papers that fall under one of these category and excluded collateral CER papers that are coincidentally related to but not motivated by a specific interest in chemistry teaching and learning. Additional notes on the inclusion and exclusion process can be found in Appendix A. Finally, a total of 650 papers were selected and analysed. Table 2 shows the number of papers being analysed from each journal.

Analysis

Each paper was analysed for the research topic, research method, level of study or group of participants, location of study and authors. Binary coding was used, meaning that all the papers were analysed quantitatively by assigning one or zero point per paper for "research topic" and "research method". For "level of study or group of participants" a paper may be coded under more than one category if the study involved several levels and groups. The frequency of occurrences was summed. For the "location of study" and "authors" we tabulated the location(s) of study and the names of the authors in order of authorship.

The papers were divided into three sets. We each manually and independently coded and tabulated information for one set of papers. To check for inter-rater reliability, each author coded the papers that was previously coded by another person and compared the coding results. Hence, each paper was coded at least twice. We achieved more than 90 percent inter-rater reliability and any disagreements were resolved by discussion until we completely agreed on all the coding.

Table 1 The impact factor and five-year impact factors of the six journals being reviewed in this paper based on the 2012 Journal Citation Report from Thomson Reuters. JCE was indexed as a science journal while the other journals were indexed as a social science journal

Journal* Name	Impact factor	5-year impact factor
Chemistry Education Research Journals		
Journal of Chemical Education (JCE)	0.817	0.831
Chemistry Education Research and Practice (CERP)+	1.075	1.200
Science Education Research Journals		
Journal of Research in Science Teaching (JRST)	2.552	3.227
Science Education (SE)	2.382	2.712
International Journal of Science Education (IJSE and IJSE(B)^)	1.340	1.795
Research in Science Education (RSE)	1.104	1.582

* Note that not all journals were indexed journals during the period 2004-2013. However, all of them were indexed under Thomson Reuters by 2013.

+ CERP merged with University Chemistry Education in 2005. In this paper, we refer to the journal as CERP.

^ IJSE(B) is not indexed in Thomson Reuters, but it focused on the informal leaning aspects of science education research. Hence, CER papers that discuss this topic could be published in IJSE(B) rather than IJSE. We included the papers in IJSE(B) to ensure that the literature search was inclusive. For simplicity, we use the term "IJSE" to refer to IJSE and IJSE(B) in this paper.

Table 2 The number of papers from each journal analysed in this paper

Journal	Number of papers	Percentage (%)
Chemistry Education Research and Practice	206	31.7
Journal of Chemical Education	240	36.9
International Journal of Science Education (IJSE)	91 (including one from IJSE (B))	14
Journal of Research in Science Teaching (JRST)	45	6.9
Research in Science Education (RSE)	46	7.1
Science Education (SE)	22	3.4
Total	**650**	**100**

Findings and Discussion

Representation of CER in SER

In the period 2004-2013, a total of 2642 articles (including empirical and non-empirical papers such as editorials, commentaries, book reviews, and so on) were published in JRST, RSE, SE, and IJSE (including IJSE(B) which started in 2011). The 204 papers selected for review in this paper accounted for approximately 7.7 percent of the total publications in these four journals. Figure 2 below shows the number of CER papers published in the respective four SER journals over the 10-year period. Although this number may seemed relatively low—possibly due to the availability of CER-focused journals—it was relatively higher than the 4.7 percent of empirical CER papers published in JCE alone as the scope of the journal was wide and published many articles on teaching tools and strategies for practitioners' use in the laboratories and classrooms. Hence, it was encouraging to learn from this analysis that CER papers could be accepted for publication in SER journals. CER academics could consider publishing more papers in SER journals so as to reach out to a wider SER audience. However, we did not have information about the representation of PER and BER in these journals, so it was not possible for us to compare the representation of CER to PER and BER.

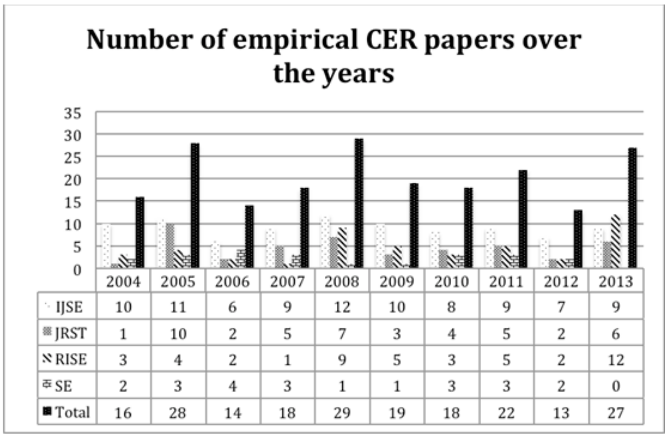


Fig. 2 A barchart showing the number of empirical CER papers published in IJSE, JRST, RSE and SE from 2004-2013.

As shown in Figure 2, IJSE published the most empirical CER papers from 2004 to 2012 with RSE surpassing IJSE in 2013. There was no obvious trend (refer to the darkest shaded bar) in the number of empirical CER papers published in the four journals over the 10-year period. On the average, 20 empirical CER papers were published in SER journals each year during this period.

Research topics

The papers were coded for only the most salient research topic. This topic was identified from reading the abstract, the goal or purpose statement, research questions, findings and conclusion. Each papers was coded under one of the nine categories—(a) teacher education, (b) teaching, (c) learning (students' conceptions and conceptual change); (d) learning (classroom contexts and learner characteristics); (e) goals and policy, curriculum, evaluation and assessment; (f) cultural, social, and gender issues; (g) history, philosophy, and nature of chemistry; (h) educational technology; and (i) informal learning (adapted from Tsai and Wen, 2005). The list of sub-categories (codes) within each category is listed in Appendix B. We used Tsai and Wen's categories and sub-categories as the initial codes and subsequently edited some to make it relevant to CER and the papers reviewed. We also deleted the sub-categories that were not relevant and added new sub-categories identified from reviewing the papers.

Table 3 shows the number and percentages of the 650 papers classified under each category in order of decreasing frequency of occurrences.

Table 3 The number of papers and percentages of papers classified under each category.

Categories	Number of papers	Percentage (%)
Learning—Students' and teachers' conception & conceptual change	170	26.2
Teaching	130	20.0
Learning—Classroom contexts & learner characteristics	126	19.4
Goals and Policy, Curriculum, Evaluation, and Assessment	106	16.3
Educational technology	71	10.9
Teacher education	31	4.8
Cultural, Social and Gender Issues	11	1.7
History, Philosophy, and Nature of Chemistry	4	0.6
Informal learning	1	0.1
Total	**650**	**100**

Most empirical studies focused on conception and conceptual change. There was only one study on informal learning outside the classroom. In what follows, we offer more detailed analysis of the top three categories by discussing the common topics of research within each of these categories.

Learning—Students' and teachers' conception & conceptual change. This was the most popular research topic in CER publications in 2004-2013. This area of work dated back to the 1980s and was initiated by Joseph Novak and Rosalind Driver (see Driver & Easley, 1978; Driver & Erickson, 1983) Novak, 1977; Helm & Novak, 1983) This trend observed in CER corresponded to the trend in SER where studies on conceptions and conceptual change topped the list from 1998 to 2002, accounting for 24.7 percent of the total research articles (Tsai & Wen, 2005). Figure 3 maps out the number of conceptions and conceptual change papers published over the 10-year period in the six journals reviewed here.

Although the number of papers published in conceptions and conceptual change decreased in some years, there was generally an upward trend in the publication frequency from 2004-2013.

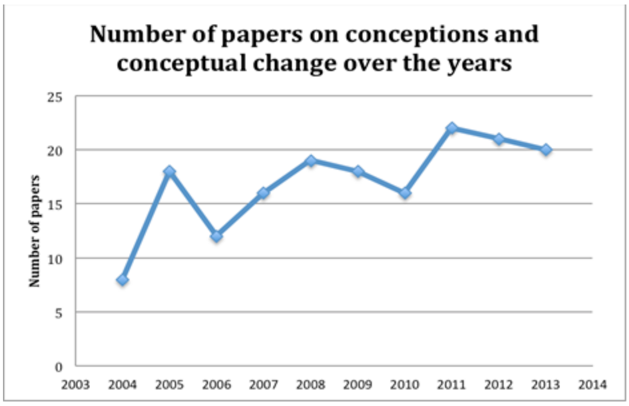


Fig. 3 Number of conceptions and conceptual change papers published over the 10-year period in CERP, JCE, IJSE, JRST, RSE and SE.

The variety of conceptions and conceptual change studies were broad. It included learners' alternative conceptions or misconception studies in specific chemistry topics; approaches used to solve chemistry questions; difficulties in learning specific topics; instruments used to diagnose, address, or change conceptions; and learning progression of in specific chemistry topics.

To elaborate, about 50 percent of the studies in this category examined learners' conceptions in specific chemistry topics. These topics include evaporation (see e.g., Gopal, Kleinsmidt, Case, & Musonge, 2004), atoms and molecules (see e.g., Cokelez & Dumon, 2005), matter (see e.g., Krnel, Watson, & Glazar, 2005; Nakhleh, Samarapungavan, & Saglam, 2005), particulate nature of matter (see e.g., Johnson, 2005; Löfgren & Helldén, 2009; Tsitsipis, Stamovlasis, & Papageorgiou, 2010; Adadan, Trundle, & Irving, 2010), organic chemistry (see e.g., Ferguson & Bodner, 2008; Rushton, Hardy, Gwaltney, & Lewis, 2008), chemical equilibrium (see e.g., Ozmen, 2008; Cheung, 2009a, 2009b), buffer (see e.g., Orgill & Sutherland, 2008), ionisation energy (Tan, Taber, Liu, Coll, Lorenzo, Li, Goh, & Chia, 2008; Tan & Taber, 2009), chemical kinetics (see e.g., Cakmakci, 2010), acids and bases (see e.g., Cartrette & Mayo, 2011), chemical bonding (see e.g., Othman, Treagust, & Chandrasegaran, 2008; Yayon, Mamiok-Naaman, & Fortus, 2012; Cheng & Gilbert, 2013; Luxford & Bretz, 2013), and others. The other more common area of research in this research area was on the use of instruments such as two-tier diagnostic (see e.g., Tan, Taber, Goh, & Chia, 2005; Chandrasegaran, Treagust, & Mocerino, 2007) and four-tier diagnostic tools (see e.g., Sreenivasulu & Subramaniam, 2013), assessments (see e.g., Vachliotis, Salta, Vasiliou, Tzougraki, 2011), survey (see e.g., Stains, Escriu-Sune, Santizo, & Sevian, 2011), and concept maps (see e.g., Kaya, 2008; Lopaz, Kim, Nandagopal, Cardin, Shavelson, & Penn, 2011; Kibar, Yaman, & Ayas, 2013) to study students' conceptions.

Studies that focused on strategies to address alternative conceptions were few and the methods varied. For example, there were studies that examined the use of the Dual Situated Learning Model (DSLM) (see e.g., She, 2004), analogies, conceptual change oriented instruction (Özkaya, Üce, Hakan Sarıçayır, and Sahin, 2006), concept mapping (see e.g., Chiu & Lin, 2005), and conceptual change text (see e.g., Sendur & Toprak, 2013).

Teaching. This was the second most researched category for CER during the period of 2004-2013. Figure 4 below shows the number of papers published on teaching in the journals reviewed here.

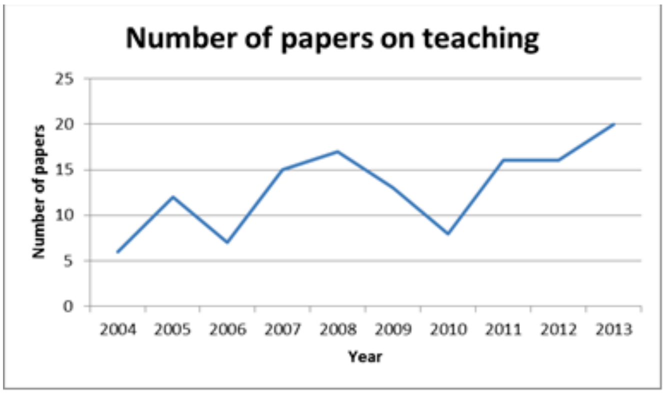


Fig. 4 Number of papers in the category of teaching published over the 10-year period in CERP, JCE, IJSE, JRST, RSE, and SE.

Figure 4 shows a general upward trend in the number of publications on teaching. The majority of the papers published on teaching examined the various pedagogies used in teaching. Other areas that were researched on included teacher thinking, pedagogical content knowledge, knowledge representation, and teaching materials.

Studies that examined teaching pedagogies made up about two-thirds of the papers classified in this category. A number of pedagogies were examined, including peer-led team learning (e.g. Lewis & Lewis, 2005; Hockings, DeAngelis, & Frey, 2008), peer mentoring (e.g. Amaral & Vala, 2009; Essex, 2011), cooperative learning (e.g. Barbosa, Jofili, & Watts, 2004; Sandi-Urena, Cooper, Gatlin, & Bhattacharyya, 2011), jigsaw classrooms (e.g. Doymus, 2007; Tarhan & Sesen, 2012), demonstrations (e.g. Ashkenazi & Weaver, 2007; Price & Brooks, 2012), Science Writing Heuristic (e.g. Hand & Choi, 2010; Kingir, Geban, & Gunel, 2012), inquiry-based (e.g. Yang & Li, 2009; Sampson & Walker, 2012), hands-on learning (e.g. Oliver-Hoyo, Allen, Hunt, Hutson, & Pitts, 2004; Bruck, Bruck, & Phelps, 2010), problem-based learning (e.g. Senocak, Taskesenligil, Sozbilir, 2007; Tosun & Taskesenligil, 2013), context-based learning (e.g. Vaino, Holbrook, & Rannikmae, 2012), and others.

The remaining one-third in this category mainly examined the areas, teacher thinking (e.g. Bennett, Grasel, Parchmann, & Waddington, 2005; Drechsler & van Driel, 2009), pedagogical content knowledge (e.g. Bond-Robinson, 2005; Drechsler & van Driel, 2008), knowledge representation (e.g. Sarantopoulos & Tsaparlis, 2004; Hilton & Nichols, 2011), and teaching materials (e.g. Drechsler & Schmidt, 2005; Ayyildiz & Tarhan, 2013), each in relatively equal numbers.

Learning—Classroom contexts & learner characteristics. This category was the third most researched on category for CER during the period of 2004-2013. Figure 5 shows the number of papers published on classroom contexts and learner characteristics over the period of 2004-2013 in the journals reviewed here.

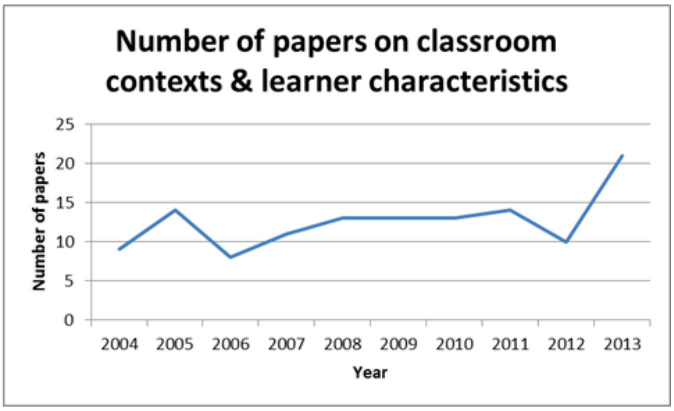


Fig. 5 Number of papers in the category of classroom contexts and learner characteristics published over the 10-year period in CERP, JCE, IJSE, JRST, RSE, and SE.

The number of papers published on classroom contexts and learner characteristics were quite constant but a spike was registered in 2013. The areas of research that were classified under this category included the attitudes and beliefs of participants, cognitive variables in participants, learning approaches, factors affecting learners' chemistry performance, classroom interaction and classroom environment.

Studies, which investigated the attitudes and beliefs of participants, made up about one-third of the papers in this category. This included studies that examined changes in attitude after an intervention (e.g. Jose & Williamson, 2005; Walczak & Walczak, 2009), evaluated and validated scales that measures attitudes and beliefs (e.g. Bauer, 2008; Heredia & Lewis, 2012), and studied attitudes and beliefs towards topics including chemistry teaching (e.g. Markic & Eilks, 2008) and dishonesty (e.g. Del Carlo & Bodner, 2004). Another area, which was commonly researched on among the studies reviewed were cognitive variables, making up about one-quarter of the papers in this category. This included studies that examined on participants' problem-solving abilities (e.g. Cartrette & Bodner, 2010; Overton, Potter, & Leng, 2013), reasoning skills (e.g. Stains & Talanquer, 2007; Stieff, 2011), difficulties in understanding (Grove & Bretz, 2010; Wood, Ebenezer, & Boone, 2013), and representation competency (Madden, Jones, & Rahm, 2011).

Other research areas were less commonly explored. For example, learning approaches were less researched on and more varied. The learning approaches examined included self-directed study (e.g. Leinhardt, Cuadros, & Yaron, 2007), rote learning and meaningful learning (e.g. Grove & Bretz, 2012) and the use of analogies (e.g. Haglund & Jeppsson, 2012). Classroom interactions were also less researched on and included teacher-student interactions (e.g. Hogstrom, Ottander, & Benckert, 2010) and peer interactions (e.g. Jeon, Huffman, & Noh, 2005).

Research topics of CER papers in SER journals. In order to find out the types of CER papers published in SER journals, we conducted a separate analysis on the SER papers selected for review. We found that 'learning – students' and teachers' conception and conceptual change' was the most researched on topic. The order of topics in terms of frequency was also relatively similar to that of the overall analysis of the 650 papers. This suggests that SER journals were also interested in publishing papers with similar types of topics favoured in CER.

Table 4 shows the number and percentages of the 204 papers in the four SER journals classified under each topic in order of decreasing frequency of occurrences.

Table 4 The number of papers and percentages of papers in SER journals classified under each category

Categories	**Number of papers**	**Percentage (%)**
Learning—Students' and teachers' conception & conceptual change	60	29.4
Learning—Classroom contexts & learner characteristics	46	22.5
Teaching	39	19.1
Goals and Policy, Curriculum, Evaluation, and Assessment	21	10.3
Educational technology	17	8.3
Teacher education	14	6.9
History, Philosophy, and Nature of Chemistry	4	2.0
Cultural, Social and Gender Issues	3	1.5
Informal learning	0	0.0
Total	**204**	**100**

In sum, empirical CER papers published in the year 2004-2013 focused mainly on conceptions, conceptual change, teaching, contexts, and learners' characteristics. However, there were relatively few studies that examined the nature of chemistry, and the cultural, social, gender, historical, philosophical, and informal learning aspects of chemistry education. While the philosophy of chemistry is gradually emerging as a distinctive epistemology for chemistry (Gilbert, De Jong, Justi, Treagust, & Van Driel, 2003), there were only four studies (see e.g., Aalsvoort, 2004; Brito, Rodríguez, & Niaz, 2005) in this area of research. This was in stark contrast to the "nature of science" work in SER. More work that investigates what constitutes the nature of chemistry—philosophically, epistemologically, and historically—and how it may become integrated into the curriculum is needed so that a better understanding of what chemistry education is all about may be obtained.

Research methods

We coded the studies as qualitative, quantitative, or mixed methods. The papers were coded as qualitative if only qualitative methods such as interviews and observations were used and the data were represented qualitatively (e.g., narratives and interview excerpts). The papers were coded as quantitative if only quantitative instruments such as surveys using Likert-scale and tests with prescribed options were used. Additionally, the data were analysed using statistical methods and represented quantitatively showing numbers, charts, tables, and so on. The papers were coded as mixed methods if a mixture of qualitative and quantitative instruments (e.g., questionnaires with Likert-scale items and open-ended response) and methods were adopted. Additionally, the data were analysed and/or represented qualitatively and quantitatively. For example, qualitative interview transcripts may be transformed into quantitative data by counting the frequency a word or phrase was mentioned. Subsequently, the data was presented in tables and bar charts.

Table 5 shows the number and percentage of papers that reported qualitative, quantitative, or mixed methods studies. There was relatively more quantitative than qualitative studies. Most studies adopted mixed methods and "mixing" typically occurred at the methods level with the use of qualitative and quantitative approaches such as interviews and Likert-scale surveys. Additionally, many mixed methods studies involved the transformation of qualitative data into quantitative data by coding and counting the frequency. However, the qualitative and quantitative data were presented separately. Hence, the mixing occurred at the methods and analysis levels. Other mixed methods studies that mix theories and methodologies or that present quantitative and qualitative data in an integrated manner, can be explored where appropriate to enhance the sophistication of the design. The epistemological thinking of researchers could be invoked in the process as they re-think more complex ways to analyse, represent, and understand the complex social, cultural, and political dimensions of chemistry education.

Table 5 Number of papers that reported qualitative, quantitative, or mixed methods studies

Type of methods	Number of papers	Percentage (%)
Qualitative	141	21.7
Quantitative	171	26.3
Mixed	338	52.0

Figure 6 shows the number of papers examined in our review over the 10-year period that used qualitative, quantitative, and mixed methods. There is a general increasing trend for all three methods over the 10 years, although for each of the three methods, a decrease in the number of papers can be observed in some years.

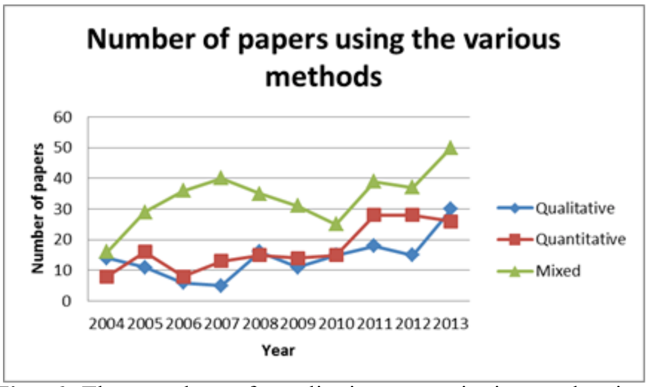


Fig. 6 The number of qualitative, quantitative and mixed methods studies over the ten-year period.

Level of study or group of participants. We coded the papers for the level of study (e.g., grade level for which the curriculum material was designed) or group of research participants (e.g., Grades 1-6, Grade 7-9, Grade 10-13, university, preservice teachers, and/or inservice teachers). Note that different countries have different age groups at the various school grade levels and what was considered "secondary" or "middle school" could be different between and within countries. For consistency, we used the age to classify the participants under the various grade levels. Grade 1 begins from the age of 7 and continues up to Grade 13 (participants aged 19). In most countries, university education begins after grade 12.

Table 6 shows the number and percentages of papers that reported studies conducted with various groups of participants or participants at various grade levels. More than half of the studies were examined at the higher education level, which includes university faculty, undergraduates, postgraduates, as well as textbooks used at the university level. On the other hand, papers published with pre-school participants only made up 0.5 percent of the total number of papers. This suggests a need to increase the number of studies conducted with this group of participants so that we may understand how young children learn, talk chemistry, and participate in chemistry lessons before they reach the upper levels.

Out of the 650 papers examined, 93 papers included participants from more than one level. Specifically, 67 papers included participants across two levels of study, 22 papers included participants across three levels of study, three papers included participants across four levels of study, and one paper included participants across seven levels of study. This suggests the lack of vertical integration in terms of studies that cut across grade levels. In fact, there were only four studies on learning progression (see e.g., Liu & Lesniak, 2005, 2006; Stevens, Delgado, & Krajcik, 2010; Johnson & Tymms, 2011) and they were limited to topics such as matter and substance. The little understanding we have about learners' developmental understanding of chemistry across grade levels may subsequently limit curriculum writers, policy makers, and educators' ability to make informed decisions about the sequencing and planning of chemistry topics and content over the whole trajectory of schooling.

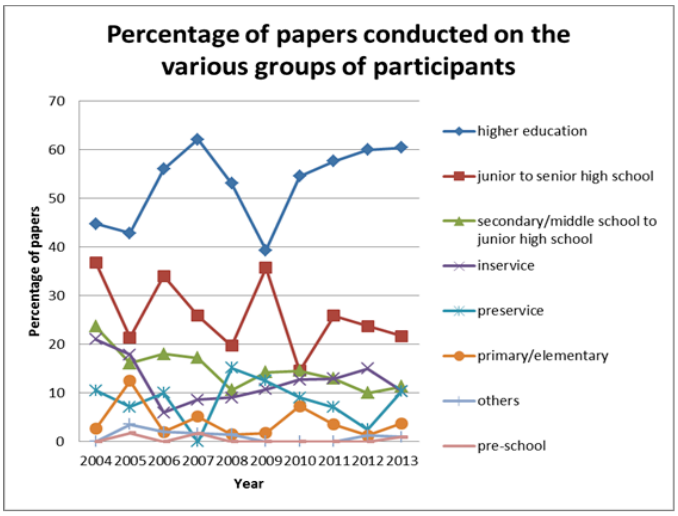
Table 6 Number of papers that reported studies conducted with various groups of participants or participants at various levels of study. Note that the total percentage exceeds 100 percent as the studies involved more than one group of participants.

Level of study or group of participants	Number of papers	Percentage (%)
Preschool	3	0.5
Primary/Elementary (Grades 1 to 6)	26	4.0
Secondary/Middle School to Junior High School (Grades 7 to 9)	91	14.0
Junior to Senior High School (Grades 10 to 12/13)/ Pre-university	163	25.1
Higher Education	353	54.3
Preservice Teachers	54	8.3
Inservice Teachers	79	12.2
Others	7	1.1

Figure 7 shows the percentage of participants at each level of study across the period of 2004-2013. The majority of the studies were conducted at higher education. This trend was not observed 30 years ago when there was resistance from editors to published work on advanced level courses premised on the argument that the readership would not be wide. As such, CER studies were then, rare at science education based conference such as National Association Research in Science Teaching (Bodner, 2011). However, with the emergence of new appointments of chemistry education faculty within chemistry departments, CER had built up over the years.

As seen in Figure 7, the percentage of papers with participants from higher education has a generally increasing trend in this period, whereas the other categories have either a generally decreasing trend or remained relatively stable. When viewed with the results from Table 6, this suggests that there was an increasing number of studies conducted on the participants who were already the most researched on. It also suggests that more emphasis may need to be placed on participants that were less researched on currently.

Fig. 7 Percentage of papers conducted on participants from each level across the 10-year period.



Note. Percentages were calculated using the number of papers conducted on each group of participants in a particular year over the total number of papers reviewed in that year.

Location of study. We coded the papers for the location at which the study was conducted. We think that it was more useful to code for the location of study instead of the nationality of the authors or the location of their universities. This was because researchers could conduct collaboration studies in another location or move to another university after the research was completed. We noted that many papers in the earlier part of the decade did not provide contextual information about the study even though it may be important for the audience to make sense of the findings based upon the situational factors and conditions or see how they could apply the practice to their own contexts. In such cases, we made inferences about the location of study from the acknowledgements to the grant source because most grants were location specific. We also inferred from the writings such as the way the grade levels were stated (e.g., commonwealth countries generally use the word "primary" rather than "elementary" and "secondary" rather than "middle school"), the description of the school semesters (e.g., the spring and fall semesters were applicable to North American contexts), the nature of the curriculum (e.g., GCE A-levels are taken in UK and Singapore), and the authors' affiliation.

In Table 7, we listed the world regions and specific locations of study.

Table 7 World regions and specific locations of study

World regions	Specific locations
Africa	Algeria; Nigeria; South Africa; Zimbabwe
Asia	China; Hong Kong; Indonesia; Iran; Israel; Jordan; Korea; Lebanon; Malaysia; Philippines; Saudi Arabia; Singapore; Taiwan
Europe	Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Norway; Poland; Portugal; Slovakia; Slovenia; Spain; Sweden; The Netherlands; Turkey; United Kingdom
North/Central America	Canada; Puerto Rico; United States of America
Oceania	Australia; New Zealand
South America	Argentina; Brazil; Venezuela
Others	Unknown (not stated and cannot be inferred from the paper)

Table 8 shows the number of papers that reported studies conducted in the various regions. Studies that were conducted in North/Central America and Europe made up more than 80 percent of the total number of papers examined. This could be in part, due to the location (CERP and IJSE are UK-based, JCE, JRST and SE are US-based, and RSE is Australian-based) of the journals selected for review.

Table 8 Number of papers that reported studies conducted in different regions

Regions of study	Number of papers	Percentage (%)
North/Central America	316	48.6
Europe	229	35.2
Asia	74	11.4
Oceania	26	4.0
Africa	14	2.2
South America	7	1.1
Others*	5	0.8

Note. Total percentage exceeds 100% as the studies might have been conducted in more than one location or region.
* Location of study was not stated or cannot be inferred from the paper.

Figure 8 shows the percentage of papers conducted in the various regions from the period of 2004-2013. Studies conducted in North/Central America show a general increasing trend, although there was a major decrease in the year 2009. On the other hand, the number of studies conducted in regions that were underrepresented remained relatively stagnant, or showed a decreasing trend (e.g., Asia) during the period of 2004-2013. This suggests that more research was being conducted in the regions that were already overrepresented. Researchers may consider working on more collaborative studies in other contexts (e.g., comparative and cross-cultural studies) and learn from other scholars who may offer alternative perspectives to chemistry teaching and learning.

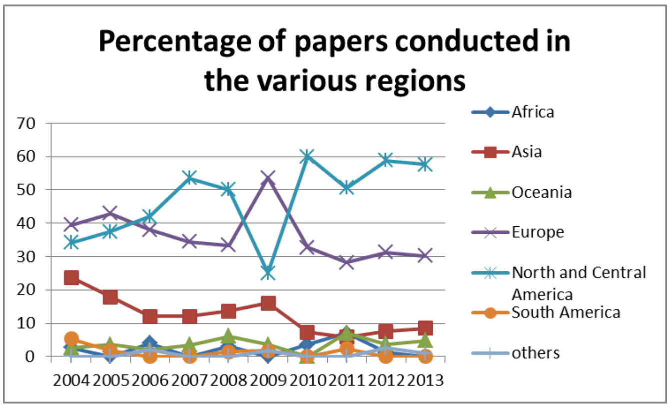


Fig. 8 Percentage of papers conducted in the various regions across the 10-year period.
Note. Percentages were calculated using the number of papers conducted in each region in a particular year over the total number of papers reviewed in that year.

Within each region, more papers were published in certain locations compared to others. Table 9 shows the number of papers that reported studies done in the 15 most common locations. About half of the studies were conducted in the USA.

Table 9 Number of papers that reported studies conducted in different locations of study

Location of study	Number of papers	Percentage (%)
USA	308	47.4
Turkey	60	9.2
Greece	29	4.5
UK	27	4.2
Israel	26	4.0
Germany	24	3.7
Australia	23	3.5
The Netherlands	19	2.9
Sweden	17	2.6
Singapore	12	1.8
Taiwan	12	1.8
Spain	11	1.7
France	10	1.5
South Africa	9	1.4
Hong Kong	7	1.1

Level/Groups by Location of Study. It is important to examine which level or groups of participants were overrepresented or underrepresented for each region or location as the results of studies conducted in one context may not be generalisable to other contexts. Table 10 shows the number of studies in each region that were conducted on the various groups of participants. It can be seen from Table 10 that papers which examined participants in Asia, Europe, and South America most often studied participants in grades 10-13, although the higher education level was most studied across all the regions. On the other hand, the participants in the higher education level were most studied in Africa, Oceania, and North/Central America. In particular, the vast majority of papers conducted in North/Central America examined participants at the higher education level. Participants in higher education were overrepresented in the research conducted in North/Central America, and conversely, other groups were underrepresented. Table 10 provides more information regarding which groups of participants were underrepresented in the various regions, and suggests that more research may want to focus on such groups of participants. Out of the 650 papers reviewed here, only 17 papers conducted their studies in more than one location, and only 5 papers conducted their studies in more than one region. As a result, their conclusions can often only be understood and applied in their individual contexts.

Contributing authors. The lists of authors were tabulated in order of their authorship. We noted that in JCE, the authors' names were grouped according to their affiliation in the printed copy of the journal paper. Hence, we referred to the order of authorship on online. For "authors", we tabulated the names of all the authors in the order it was reported in the papers. However, for this area of analysis, we did not simply count the frequency of occurrence. Rather, the order of the authorship was considered and the authors were scored differently. We used a formula developed by Howard et al. (1987) to score an author in a multi-authored paper:

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

where n is the total number of authors in the paper and i is the order of the specific author.

Using the above formula, we computed the scores and listed the names of the top ten published scholars in CER in Table 11. We also listed their areas of interest as indicated from the scholars' webpages and/or curricula vitae, their current affiliation, and editorial positions (if any). Note that eight of the ten authors were based in USA, one in UK, and one in Hong Kong.

Table 12 shows the breakdown of the topics of papers published by the 10 authors. Similar to the overall trend on research topics, conception change was the most prevalent area of research but there was less focus on the topic of teaching. We found stronger emphasis on the topic "Goals, Policy, Curriculum, Evaluation, and Assessment", although this could be explained by Towns' area of interest, which contributed to 30.4 percent of papers in the category.

Table 13 provides a more detailed breakdown of the frequency of papers published by the respective scholars according to the research topics.

We conducted a further analysis of the levels of study by the location of study by the above scholars (see Table 14). We found most studies conducted by them were predominately at higher education. This was coherent with the earlier discussion that studies conducted in North/Central America had a strong focus on higher education. As eight of the 10 authors are based in USA, overall results reflected this tendency.

Table 10 Number of studies conducted on the various levels in different continent

Continent Level	Africa	Asia	North/Central America	South America	Europe	Oceania	Others*
Preschool	0	0	0	0	2	1	0
Primary/Elementary (Grades 1 to 6)	0	2	9	0	13	1	1
Secondary/Middle School to Junior High School (Grades 7 to 9)	0	18	20	1	46	3	3
Junior to Senior High School (Grades 10 to 12/13)/Pre-university	4	28	39	3	75	10	4
Higher Education	7	14	254	2	56	12	8
Preservice Teachers	3	6	6	0	35	2	2
Inservice Teachers	1	21	24	1	29	2	1
Other groups	0	1	3	0	2	0	1

Note. Total count of papers exceeds 650 as some papers conducted their studies on participants from different levels.
* 'Others' include papers where the region of study was unknown and could not be inferred, as well as papers which were conducted in two or more regions.

Table 11 Top ten most published authors of empirical chemistry education research papers from 2004-2013.

Score	Papers	Name	Institute, Location	Area of Interest	Notes
7.800	15	Vicente A. Talanquer	University of Arizona, USA	• Students' explanation and reasoning	Editorial board member: IJSE & CERP
5.900	10	Michael Sanger	Middle Tennessee State University, USA	• Identifying student misconceptions in chemistry • Designing and evaluating instructional methods to confront student misconceptions • Using computer-based visualization strategies (computer animations, electron density plots) to improve students' conceptual knowledge of chemistry at the molecular level	
5.592	11	Keith S. Taber	University of Cambridge, UK	• Learners' ideas, misconceptions, alternative conceptions and alternative frameworks • Conceptual understanding, conceptual integration and conceptual change and development • Constructivism in science education • Learner thinking and metacognition • Explanations in science • Teaching about the nature of science • Challenging high attainers	Editor: CERP Editorial board member: IJSE
5.376	13	Melanie Cooper	Michigan State University, USA	• Curricula development and assessment • The Effect of Interventions and Educational Environments on Problem Solving and Metacognition • Investigation of Representational Competence • BeSocratic: A free-form interactive system	Editorial board member: JRST Advisory Panel: CERP
5.180	14	Marcy H. Towns	Purdue University, USA	• Small-group learning, • Computer supported collaborative learning	Associate Editor: JCE
5.000	5	Derek Cheung	The Chinese University of Hong Kong, Hong Kong	• Chemistry education • Curriculum development • School-based assessment • Assessment of affective learning outcomes	
4.623	9	Scott E. Lewis	University of South Florida, USA	• Peer-led team learning	
4.260	13	Stacey Lowery Bretz	Miami University, USA	• Development of assessment measures to diagnose chemistry misconceptions and to stimulate metacognition and reflection in both the teaching and learning of chemistry. • Application of cognitive science theories to the teaching and learning of chemistry. • Experiments, taxonomies and rubrics for inquiry learning in the chemistry laboratory. • Children's learning of chemistry. • Project evaluation, with an emphasis on qualitative measures.	
4.175	9	Nathaniel Grove	University of North Carolina Wilmington, USA	• Factors influencing meaningful/rote learning in chemistry • Students' epistemological development in chemistry. • The development of representational competence in chemistry. • The role of metacognition in developing representation competence. • The use of technology in the chemistry classroom.	
4.078	13	Jennifer E. Lewis	University of South Florida, USA	• Diagnostic, assessment inventory • Student attitude, attitude change	

Table 12 The breakdown of the number of papers published by the top ten scholars in CER.

Categories	Number of papers	Percentage (%)
Learning—Students' and teachers' conception & conceptual change	35	31.8
Learning—Classroom contexts & learner characteristics	29	26.4
Goals and Policy, Curriculum, Evaluation, and Assessment	23	20.9
Teaching	17	15.5
Educational technology	4	3.6
Teacher education	1	0.9
Cultural, Social and Gender Issues	1	0.9
Total	**110**	**100**

Table 13 The frequency (and percentages) of publications by the top ten scholars according to research topics. The percentages under each category were computed based on the total number of papers within the category. The percentages under the "total" column were computed based on the total number of papers (110).

Author	Category (Frequency/ Percentage (%))							Total
	Conception	Context	Policy	Teaching	Technology	Teacher Ed	Social	
Talanquer	4 (11.4%)	6 (20.7%)	1 (4.3%)	4 (23.5%)	-	-	-	15 (13.6%)
Sanger	4 (11.4%)	-	1 (4.3%)	3 (17.6%)	2 (50.0%)	-	-	10 (9.1%)
Taber	11 (31.4%)	-	-	-	-	-	-	11 (10.0%)
Cooper	4 (11.4%)	4 (13.8%)	2 (8.7%)	2 (11.8%)	-	1 (100%)	-	13 (11.8%)
Towns	1 (2.9%)	1 (3.4%)	7 (30.4%)	2 (11.8%)	2 (50.0%)	-	1 (100%)	14 (12.7%)
Cheung	2 (5.7%)	2 (6.9%)	-	1 (5.9%)	-	-	-	5 (4.5%)
S. Lewis	2 (5.7%)	1 (3.4%)	3 (13.0%)	3 (17.6%)	-	-	-	9 (8.2%)
Bretz	4 (11.4%)	4 (13.8%)	4 (17.4%)	1 (5.9%)	-	-	-	13 (11.8%)
Grove	2 (5.7%)	5 (17.2%)	2 (8.7%)	-	-	-	-	9 (8.2%)
J. Lewis	1 (2.9%)	6 (20.7%)	3 (13.0%)	1 (5.9%)	-	-	-	11 (10.0%)
Total	35 (100%)	29 (100%)	23 (100%)	17 (100%)	4 (100%)	1 (100%)	1 (100%)	110 (100%)

Table 14 The frequency (and percentages) of studies conducted by the top ten scholars on the various groups of research participants in the various locations.

Level	Location (Frequency/ Percentage (%))									Total
	USA	Hong Kong	UK	Singapore	Australia	France	Puerto Rico	Sweden	Multiple	
University	84 (92.3%)	-	-	-	1 (100%)	-	1 (100%)	-	1 (33.3%)	87 (79.1%)
Pre-service	1 (1.1%)	-	-	1 (33.3%)	-	-	-	-	-	2 (1.8%)
In-service	1 (1.1%)	2 (40%)	-	-	-	-	-	-	-	3 (2.7%)
Grades 10-13	1 (1.1%)	2 (40%)	2 (50%)	2 (66.7%)	-	1 (100%)	-	1 (100%)	1 (33.3%)	10 (9.1%)
Grades 7-9	-	-	1 (25%)	-	-	-	-	-	-	1 (0.9%)
Others	2 (2.2%)	-	-	-	-	-	-	-	-	2 (1.8%)
Multiple	2 (2.2%)	1 (20%)	1 (25%)	-	-	-	-	-	1 (33.3%)	5 (4.5%)
Total	91 (100%)	5 (100%)	4 (100%)	3 (100%)	1 (100%)	1 (100%)	1 (100%)	1 (100%)	3 (100%)	110 (100%)

Concluding remarks and recommendations

In summary, our 10-year review of 650 empirical papers published in two CER and four SER journals during 2004-2013 revealed that empirical CER papers accounted for 7.7 percent of the publications in the four science education journals. Although relatively few, this showed that CER papers were accepted in SER journals. Analysis of the papers showed that the top three research topics in the CER and SER journals were similar and they were: (a) conceptions and conceptual change, (b) teaching, and (c) learning—classroom contexts and learner characteristics. Similarly, there were relatively fewer studies that reported on: (a) goals and policy, curriculum, evaluation, and assessment; (b) educational technology; (c) teacher education; (d) culture, social, and gender issues; (e) history, philosophy, and nature of chemistry; and (f) informal leaning in the CER and SER journals. These are the topics that can be researched on more. Most studies adopted mixed methods using a variety of quantitative and qualitative research methods. The majority of the studies were conducted in higher education contexts and in North/Central America and Europe. Few studies were carried out in more than one location. Hence, more studies in non-Western contexts and more cross-contextual studies may be done to add to the diversity of perspectives and knowledge about chemistry teaching and learning. More studies on other groups of participants, other than university students, should be focused on to obtain a better representation of voices. The top ten highly published CER scholars included Vicente Talanquer, Michael Sanger, Keith Taber, Melanie Cooper, Marcy Towns, Derek Cheung, Scott Lewis, Stacey Bretz, Nathaniel Grove and Jennifer Lewis. They contributed largely to conceptions and conceptual change studies conducted in higher education contexts in USA.

The findings of our 10-year review of empirical CER journals in the six journals for the period 2004-2013 were consistent with the DBER (Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering) report and associated committee documents (Singer, Nielsen, Schweingruber, 2012; Towns, 2013; Towns & Kraft, 2011).

First, we noted that the majority of the studies were conducted in higher education contexts, most of them focused on general chemistry or courses at the introductory level. Few studies were reported about upper-level undergraduates who majored in chemistry or postgraduates in chemistry.

Second, few studies examined how misconceptions and alternative conceptions can be effectively addressed. We noted that the strategies that were studied were varied and conducted by one or only a few studies, on one group of learners, for one topic, and over a limited period of time. Perhaps, the same strategy could be implemented in a few other learning contexts, with different types of learners, and evaluated for its effectiveness over a longer period of time. In that way, pedagogical knowledge about a sustainable and effective conceptual change strategy may be developed to inform practice.

Third, few studies examined how factors such as age, race, gender, culture, and ethnicity affect teaching and learning. Often times, the sampled participants were perceived and analysed as a homogenous group hence, limiting our understanding about how these factors could interplay with the learning environment, intervention, or curriculum to bring out the results observed. This could be a step towards achieving the broader vision of a “science for all” (Lee & Fradd, 2008) or “science for everyone” (Fensham, 1985) through understanding the learners’ experiences *in process* (Bodner, 2005). Mahaffy (2004) used the metaphor of a tetrahedron to describe chemistry education as “tetrahedral chemistry education” (p. 229). The three dimensions of the tetrahedron underscore the human element emphasising on two new dimensions of learning chemistry: (1) “the rich web of economic, political, environmental, social, historical, and philosophical considerations, woven into our understanding of the chemical concepts, reactions, and processes that we teach to our students and the general public” and; (2) pedagogical strategies that cater to the learning styles of the learners and that introduces the chemical world at the symbolic, macroscopic, and molecular levels while acknowledging the existing conceptions and misconceptions that these learners already have.

According to Towns (2013), there is a need for CER to tap into the advantages of qualitative and quantitative methods and consider having more mixed methods studies. Our coding revealed that most studies were mixed in that a mix of qualitative and quantitative methods was adopted. In most cases, qualitative data was transformed into quantitative data by coding the qualitative texts and counting the frequencies. Nonetheless, mixing could also be done purposefully in other ways to enhance the sophistication of the research design and offer more comprehensive insights about the phenomena under study (Greene, 2007; Creswell, 2014). Theories, theoretical frameworks from different domains (e.g., psychology, learning theories, curriculum, and sociology), and research methodologies (e.g., ethnography, case study, narrative, and survey methodology) could be mixed. For example, researchers studying students’ alternative conceptions could integrate the constructivist and sociological lens to examine how students exercise their agency within the structures of the science classroom as they interact with their peers and co-construct understandings of the science concepts. The power relationships between the teacher and students in the classroom can also help us understand why students harbour certain conceptions and perhaps, a more dialectical relationship between the student and teacher could promote more effective teaching and learning. Additionally, researchers can explore ways to represent quantitative and qualitative findings in an integrated way rather than separate tables and excerpts. In sum, purposeful and carefully designed research studies could offer broader and deeper insights so that they may be generalised for policy-making purposes and provide contextualised knowledge to teachers.

Limitations and future work

This review remains limited in several aspects and further analysis can be carried out to identify other trends. One analysis, which we did not do and that may be useful, was the number of studies that were done with teachers as researchers. Borrowing Patton’s (2008) idea of utilization-focused evaluation that is done with the goal that the evaluation findings has intended use for the intended user to optimise the use of the findings, we argue that research findings will bring about improvement in teaching and learning if the practitioners were involved in the research process. By practitioners, we mean teachers, policy makers, and curriculum writers. In the process of doing the research, they take on the insider-outsider position—they provide the contextual information and research questions, understand the strengths and limitations of the research design, engage in the process of data analysis and writing, and learn to use the findings that will inform their professional practice.

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Appendix A

The inclusion and exclusion criteria for the journal papers reviewed.

Journal	Criteria for Inclusion	Criteria for Exclusion
CERP*	• Year 2004: papers labelled under the category "empirical study" • Year 2005-2007: papers labelled under the category "educational research" • Year 2008: papers labelled under the category "research"	• Year 2004: papers labelled under the categories e.g., "paper", "research report: concepts", "report on research methodology", "contributions of educational research to practice of chemistry education" • Year 2005-2007: papers labelled under the categories "practice" and "perspectives" • Year 2008: papers labelled under the categories "practice", "proceedings", "introduction", and "review"
JCE	• Issue 1, 2004 - Issue 4, 2011: papers labelled under the category "research: science and education" • Issue 5, 2011 – Issue 12, 2013: papers labelled "chemical education research" under the category "articles"	• Issue 1, 2004 - Issue 4, 2011: papers labelled under the categories "chemical education today", "viewpoints: chemists on chemistry", "chemistry for everyone", "in the class/ in the classroom", "in the laboratory", "information, textbooks, media, resources", and "on the web" • Issue 5, 2011 – Issue 12, 2013: papers labelled under the categories "editorial", "commentary", "reports", "news and announcements", "letters", "additions and corrections", "books and media reviews", "activities", "demonstrations", "laboratory experiments", "technology reports", and "communications" • Issue 5, 2011 – Issue 12, 2013: papers labelled under the category "articles" • Papers that focus on chemistry content, as opposed to chemistry education
JRST, SE, IJSE, & RSE	Papers identified using the Boolean search "chemistry" in the respective journal webpage.	Papers whose focus topic is not about chemistry education *per se* such as studies that • reported chemistry teachers as participants but the topic was not specifically about their chemistry teaching, education, etc. • focused on the tools of teaching/learning that is not specific to chemistry but applicable to other science subjects e.g., data loggers • discussed general science education-related viewpoints using chemistry examples • examined laboratory or practical curriculum/work/learning/teaching but not chemistry lab in particular • focused on how a theoretical construct adopted from other domains (e.g., sociology, anthropology) was used to examine a chemistry context/setting • examined scientific representations using chemistry examples but chemistry teaching and learning was not the main focus • focused on models and modelling in general and using some chemistry examples but chemistry teaching and learning was not the main focus • examined molecular level thinking using chemistry examples but chemistry teaching and learning was not the main focus

Appendix B

The following categories and sub-categories were extracted and adapted from Tsai and Wen (2005) in their review of science education journal papers. We have reclassified some sub-categories, revised them to make it more relevant to CER, and added new ones to the list. The sub-categories were used as codes to code each paper.

Category	**Sub-categories (or codes)**
Chemistry teacher education	• preservice and continuing professional development of chemistry teachers • chemistry teacher education programs and policy • field experience • issues related to chemistry teacher education reform • chemistry teacher as researcher/action research
Teaching	• pedagogical knowledge and pedagogical content knowledge • teaching strategies e.g., metaphors, images, analogies, demonstration, peer-led learning, cooperative learning, heuristics, inquiry, models, jig-saw, etc. • teachers' goals and thinking (e.g., curriculum decisions) • inservice teacher beliefs and perceptions
Learning—Students' and teachers' conception & conceptual change	• methods for investigating student understanding • students' alternative conceptions • instructional approaches for conceptual change • conceptual change in learners • conceptual development.
Learning—Classroom contexts & learner (students and teachers) characteristics	• students' motivation, beliefs, attitudes, perceptions and anxiety (affective dimensions of chemistry learning) teachers' views, beliefs, understanding, content knowledge and readiness to teach • instruments to measure the affective dimensions • learners' experiences • learning environment (e.g., laboratory environment) • individual differences (e.g., chemistry literacy, abilities) • reasoning, mental capacities, competencies, difficulties • learning approaches and styles • teacher–student interactions and peer interactions • language, writing and discourse in learning
Goals and Policy, Curriculum, Evaluation, and Assessment	• curriculum development, change, implementation, dissemination and evaluation • curriculum materials (content and structure) • assessment and grading (e.g., format, types and rubrics) • affective dimensions of assessment construction and performance • factors affecting performance • educational measurement (e.g., validation of instrument) • role of science in public policy • goals and policies (e.g., chemistry-related career choices) • chemistry curriculum reform
Cultural, Social and Gender Issues	• cultural, ethnic, social and gender issues related to chemistry education • english language learners (non-native english learners) learning chemistry
History, Philosophy, and Nature of Chemistry	• historical of chemistry • philosophy and chemistry • nature of science in chemistry curriculum materials
Educational technology	• interactive multimedia (e.g., videos, animations) • integration of technology into teaching and teacher training • learning and assessment involving the use of technology
Informal learning	• out-of-school learning