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A Systematic Review of Remote Laboratory Work in Science Education with the Support of Visualizing its Structure through the *HistCite* and *CiteSpace* Software

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Abstract Laboratory work, particularly the latest remote laboratories (RLs), has been assumed to have a general positive effect on science education because practical work can provide diverse learning experiences and enhance thinking skills suitable for the 21st century. However, there has not been a synthesis of the science education research to support this assumption. The objective of this study is to systematically review the growth of educational research on laboratory work, particularly in RLs, utilizing a series of review processes with innovative software for visualizing structural relationships. The combined use and support of *HistCite* and *CiteSpace* software enabled the visualization of the citation structure and history of articles. The findings revealed that RLs were a state-of-the-art subset of laboratory work and a new way of conducting laboratory work that has gained fairly wide research attention in engineering education over the past two decades. Thus, this innovative literature review process has established a solid background for future research and development efforts on RLs in science education dealing with scientific and engineering practices.

Keywords *CiteSpace* analysis · *HistCite* analysis · Practical work · Remote laboratories · Systematic review

Practical work in a science laboratory is acknowledged as a fundamental part of science learning (Hofstein & Mamlok-Naaman, 2007). The effectiveness of laboratory

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exercises is crucial to students' understanding of scientific principles and developing insights into the scientific enterprise, practices, and abstract ideas (Abrahams & Reiss, 2012; Emden & Sumfleth, 2014; Hofstein & Lunetta, 2004). The new framework for science education in the USA stresses the importance of science and engineering practices that are an integral part of laboratory investigations and design activities (National Research Council, 2012). In addition, science practical work through the use of technology has flourished in the past two decades (Wang et al., 2014). With the fast growth of laboratory studies, real-time science experiments using the Internet — referred to as web-based laboratories or remote laboratories (RLs) — have been developed recently using cloud computing. Using these RLs, students can display, control, interact with, and download real-time data in the classroom, science laboratory, computer laboratory, or other places with Internet access. Therefore, RLs are a subset of laboratory work for employing the latest and most innovative technology. However, there has not been a synthesis of the science education research to support the claimed advantages of RLs. Thus, a systematic review of prior, relevant literature of RLs and science education is essential to the understanding of the current application and trend of RLs. This study explored the development of laboratory work and RLs by a series of review processes involving a systematic review in laboratory work and RLs and science education with innovative software (*HistCite* and *CiteSpace*) for visualizing their histories. We believe that the results of this systematic review will provide important insights in laboratory-based and computer-based practical work to inform classroom practices with the existing evidence base and identify areas for further research. Furthermore, this analysis could help the science education researchers, science teacher educators and teachers to identify the challenges and make use of these innovative RLs in their future science education research and development. In more simple word, the aim of this research review is to help the researchers to summarize the earlier literature in the field, point out the research trend, and provide the directions for future research. Based on the review results, we summarize some current status of the RLs field and then provide some directions for future research.

Background

RLs in Science Education

The way of conducting science practical work has experienced substantial changes from the cookbook or recipe experiments to computer-based laboratories through the use of simulation software to perform virtual experiments or a data logger to perform hands-on and real science experiments. The cookbook practical work normally requires students to follow specific procedures and solve specific questions provided in the laboratory manual (Gallet, 1998). These activities lack authenticity and do not reflect students' input and ownership. It is because the teachers normally have to set everything for students, and they actually know or expect the findings of most of the experiments. Then, "a lot of time is spent on the routine procedures of recording data, tabulating data and plotting graphs" (Tho, Chan, & Yeung, 2015, p. 2). However, it is an entirely different situation if students integrate their science learning via a computer-based laboratory, where they can display the data in graphical or tabular form and all routine jobs are computerized, thereby saving time for other activities such as creating and answering their own "what if" questions (Ng & Yeung, 2000; Tho & Hussain, 2011; Steinberg, 2003; Taylor, 1997). In other words, this new learning approach is made possible by the fact that the computer-based laboratory can efficiently reduce the time needed in conducting experiments, allowing more time for interpreting or evaluating data. Thus, students can engage in more higher-order thinking activities, such as in improving their experimental design skill or modifying existing experiments using their creativity and critical thinking skill.

The rapid advancement of technology and the prevalent use of the Internet in education have enabled science practical work in web-based or remote laboratories (RLs), which have recently adopted cloud computing. Torre et al. (2013) claimed that the RLs can be considered a constructivist method that allows students to be active participants and explore certain science questions and ideas. In addition, RLs can enable the social constructivism learning environment via conducting experiments remotely and sharing experimental data among users from different places (Abdulwahed & Nagy, 2011).

RLs offer an experiential, real-time, interactive, online learning environment where students can control, observe, and respond to selected science experiments (Tho & Yeung, 2015; Gröber, Vetter, Eckert, & Jodl, 2007). Using a flexible RL learning environment allows science students to easily manipulate the real-time experiment anywhere and anytime (Scanlon, Colwell, Cooper, & Di Paolo, 2004). Therefore, RLs can be exploited to overcome issues related to large class sizes, limited class time, weather, safety, distance and short experiment problems. With these fundamental merits of RLs, it may improve the laboratory work of science learning.

A number of previous studies on RL system development and literature anticipated that remote-controlled technologies will play an important role in the science and engineering learning (Barrios et al., 2013; Hercog, Gergič, Uran, & Jezernik, 2007; Ma & Nickerson, 2006; Scanlon et al., 2004). Moreover, recent education reforms in laboratory work have identified the importance of technology-enhanced science learning, which can be achieved in science education through RL systems (Kong, Yeung, & Wu, 2009; Lowe, Newcombe, & Stumpers, 2013). In fact, there is a number of ways to study the educational review; for example, narrative review, content analysis, systematic review and meta-analysis. However, a systematic review of earlier and relevant literature of RLs and science education is important and appropriate to overview the current application and trend in this study. Such review can be done with the help of social network analysis method where it can be further applied for identifying research collaboration networks among researchers who have published articles related to prior literature (De Laat, Lally, Lipponen, & Simons, 2007; Yeung, Liu, & Ng, 2005). For instance, the network analysis can be conducted by using Bibexcel, *CiteSpace*, Gephi, *HistCite*, Pajek, Sci2 tool, and UCINET software. However, this study mentioned an innovative way to conduct the literature review through the systematic review with the support of *HistCite* and *CiteSpace* software.

Systematic Review with the Support of *HistCite* and *CiteSpace* Software

A systematic review can be defined as an orderly way of reviewing and summarizing a research study. Bennett, Lubben, Hogarth and Campbell (2005) stated that:

> Systematic reviews of educational research aim to answer specific review questions from published research reports by identifying relevant studies,

> characterizing such studies to form a systematic map of research in the area, extracting relevant data to establish the value of the findings, and synthesizing and reporting the outcomes (p. 387).

The Cochrane Collaboration (2014) stated that a "systematic review is a high-level overview of primary research on a particular research question that tries to identify, select, synthesize and appraise all high quality research evidence relevant to that question in order to answer it" (Systematic reviews, para. 1). Yoshii, Plaut, McGraw, Anderson and Wellik (2009) identified this approach "as a preeminent source of synthesized knowledge for evidence-based practitioners" (p. 21). Lin, Lin and Tsai (2014) pointed out that the purpose of a systematic review in science education was to get a "clearer view of the recent status" (p. 1347). Furthermore, systematic analysis procedures are important in identifying associations between instructional design and theoretical characteristics of research study and best practices (Lin, Hsu, Lin, Changlai, Yang, & Lai, 2012). However, there has been little attention paid to systematic reviews in science education (Bennett et al., 2005), which is likely due to the labor-intensive nature of such approaches and the demand placed on the researchers' judgments and understandings of the underlying values of the research quality and outcomes. Thus, this study aimed to use established procedures, identify any connected structure, and address research gaps or any incompleteness in this area suggestive of future studies.

Bennett, Lubben and Hogarth (2007) study was particularly useful for the current research because they focused on how to conduct and evaluate systematic review research through the use of the Evidence for Policy and Practice Information and Co-ordinating (EPPI) guide. However, we made no specific judgments on the quality of the articles selected for the current study because these RL studies focused more on development than evaluation and the assumed quality of these published studies in peer-reviewed sources. The EPPI data extraction or coding tool (Social Science Research Unit, n.d.) is a systematic review method for assembling all relevant research evidence, increasing the quality of the literature review and minimizing the research bias. Basically, the in-depth review process using the EPPI guide consists of a number of processes, namely:

> Data extraction, where information from the studies is extracted in a systematic way. Information extracted from the studies includes study aims and rationale; study research questions; study design methods, including selection of groups, sampling, and consent of subjects; data collection methods; data analysis methods; reliability and validity of methods of data collection and analysis; results and conclusions; quality of reporting; quality of the study in relation to methods and data (Bennett et al., 2007, p. 351).

Unfortunately, EPPI has not addressed some of the time, judgment, and understanding barriers to conducting systematic reviews using modern technologies.

HistCite (http://interest.science.thomsonreuters.com/forms/HistCite/) and *CiteSpace* (http://cluster.ischool.drexel.edu/~cchen/citespace/download.html) software recently received attention as they are able to link and visualize the citation history and citation structure of articles in a graphical form (Chen, 2006; Chen, Hu, Liu, & Tseng, 2012a; Garfield, 2009; Liang, 2010; Lucio-Arias & Leydesdorff, 2008). The combined use and support of this software can increase the time efficiency and supplement the judgment and understanding demands involved in systematic review analysis. *HistCite* is free software that focuses specifically on generating "chronological maps of bibliographic collections resulting from subject, author, institutional or source journal searches of the *ISI Web of Science*® [*WoS*]. *WoS* export files are created in which all cited references for each source document are captured." (Garfield, 2009, p. 173). This provides an evidence trace from listed journals that can guide and reinforce the researchers' decisions and interpretations.

CiteSpace software performs many functions to simplify the understanding and explanation of the chronology structure and linkages of past research patterns based on WoS data by "identifying the fast-growth topical areas, finding citation hotspots in the land of publications, decomposing a network into clusters, automatic labelling clusters with terms from citing articles, geospatial patterns of collaboration, and unique areas of international collaboration" (Chen, 2004, para. 1). This free software with Java application

> supports a unique type of co-citation network analysis – *progressive network analysis* – based on a time slicing strategy and then synthesizing a series of individual network snapshots defined on consecutive time slices [to identify] nodes that play critical roles in the evolution of a network [and] are candidates of intellectual turning points (Chen, Ibekwe-SanJuan, & Hou, 2010, p. 1393).

Thus, the literature review suggested a systematic review of laboratory work, particularly RLs, in science education with the *HistCite* and *CiteSpace* software would be appropriate and worthwhile. We believe that there may be significant advantages linked with RL approaches in science education that might inform further research and development work on infusing technology in science classrooms. However, there are several essential questions to be explored:

- What is the growth of RLs in laboratory work?
- What is the design of RLs in laboratory work?
- Do learning and teaching via the use of RL technologies help students understand science better?
- Do learning and teaching via the use of RL technologies enhance students' attitudes toward this new mode of learning?
- Are there any gender differences in learning and teaching via the use of RL technologies?
- Does learning and teaching via the use of RL technologies develop students' practices and processes for this new mode of learning?

The following sections begin by considering the methods and design steps on how to review previous research in laboratory work and RLs. The evidence of the study are then reviewed and analyzed. Finally, we report on the findings and future work flowing from the study.

Methodology

This study focused on previous research studies on laboratory work, particularly RLs, found in the WoS Education and Educational Research categories and was divided into three main parts. First, *HistCite* analysis was conducted to identify the universe of articles and their citation links to central studies. Second, the RLs studies were identified and isolated through the *HistCite* and *CiteSpace* analysis. Third, a number of articles were selected based on criteria and the EPPI guide for in-depth document analysis to identify trends, design principles, and areas for further research.

Part 1—HistCite Analysis Procedures

We used the WoS database for our main source of journal exploration. A search for laboratory and RL research studies based on education and educational research studies was conducted. Once the journal lists were created, the *HistCite* software was applied to generate chronological historiographs (i.e., a time-based network diagram) based on the relationship of the cited works (i.e., the local citation score), which is the number of citations to a paper within the collection. Once the chronological historiographs of studies in the large pool were generated, they were screened and highlighted to identify the sub-pool of RL studies. This was followed by the *HistCite* analysis of RL studies through the topic of remote experiments or laboratories to identify the citation pattern and select the related studies for further in-depth document analysis.

We applied the *HistCite* software to analyze the structure of the studies and relationships among the 1,583 papers identified in the WoS (Fig. 1). The 62 RL research studies (Fig. 2) were found based on the education and educational research studies using the WoS database on the larger pool of laboratory or practical work studies.

Because of the number of articles in the *HistCite* file, the full findings cannot be completely described here. Hence, we include the first page of the *HistCite* file of laboratory work (Fig. 3) that provides general information about the results in the first line of the file. Due to the subscription history of our library, the coverage of WoS, the collection spans from 1992 to 2014. The timeline for the growth of laboratory work in educational research is exhibited by a *HistCite* presentation of the ranked citation index of 1,583 research articles within 230 journals by 3,700 authors and with 43,438 cited references. The meanings of the acronyms used in Fig. 3 and elsewhere in the text are:

- GCS: global citation score presents the total number of citations to a paper in WoS.
- LCR: local cited references presents the number of citations in a paper's reference list to other papers within the collection.
- LCS: local citation score presents the count of citations to a paper within the collection.
- CR: cited references presents the number of cited references in the paper's bibliography.

Date: Feb 2014
Results: 1,583
(from All Databases)
You searched for:
TOPIC: (laborator*)
Refined by: RESEARCH AREAS=(EDUCATION EDUCATIONAL RESEARCH)
Timespan=All years.
Search language=Auto

Fig. 1 WoS search result for the topic *laboratory*

Date: Feb 2014
Results: 62
(from All Databases)
You searched for:
TOPIC: (remot* laborator*) ORTOPIC: (remot* experiment*)
Refined by: RESEARCH AREAS=(EDUCATION EDUCATIONAL RESEARCH)
Timespan=All years.
Search language=Auto

Fig. 2 WoS search result for the topic *remote laboratory*

There are two types of historiographs can be generated from *Histcite*, GCS (within WoS) and LCS (within collection). In this case, the historiograph via LCS is generated because we studied the number of times a paper is cited by other papers in the local collection with same topic. The historiograph of laboratory studies is too large and complex to be shown here (see Electronic Supplemental Materials Website ESM A); but Fig. 4 shows the historiograph generated based on the LCS, which has been cropped partially to display and trace the historical pattern of the RL studies conducted by identifying the related papers using a circle to denote critical nodes of the evolutionary network of background citations. However, a number of papers were not being identified and highlighted due to the position and number combination where some combination of these numbers caused unclear value in the historiograph. Based on these historiographs, the RL was found to be a state-of-the-art subset of laboratory work as the circle in Fig. 4 denotes the growth of the RL studies which is closed to the year of 2014. Hence, it is a new way of conducting laboratory work, particularly in science education; this practice has gained fairly wide research attention over the past two decades in the engineering area.

The RL studies were explored with a separate *HistCite* analysis that revealed the timeline for the growth of RL educational research based on the ranked citation index of 62 articles (see Electronic Supplemental Materials Website ESM B) within 21 journals by 217 authors with 1,581 cited references. Figure 5 shows the *HistCite* graphmaker display of the historiograph of RLs that was generated based on the LCS and the relationship of cited works with circle

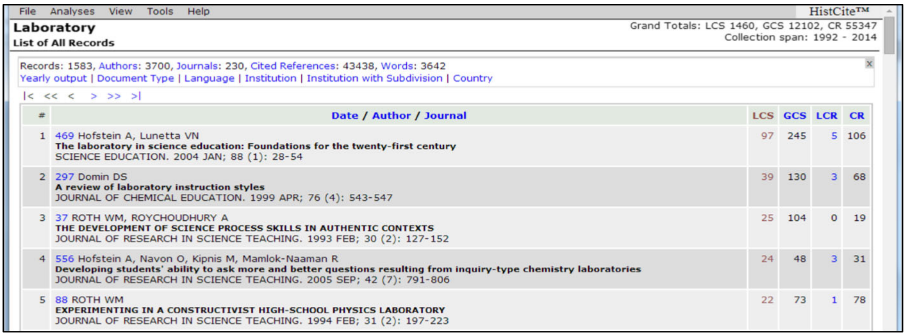


Fig. 3 The *HistCite* file of article publications linked to the field of laboratories

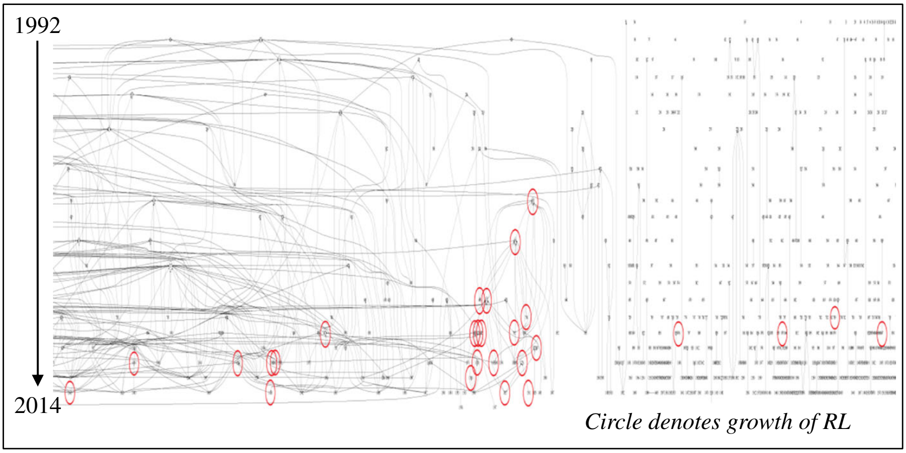


Fig. 4 The chronological historiographs of laboratory work from 1992 to early 2014

diameters proportional to the LCS and arrows exhibiting the citation direction. Even though the number of RL articles is much smaller than that of ordinary laboratory work, it is still a large enough to trace the related RL studies via the chronological historiograph.

The citation direction arrows show that 32 articles were either cited by others or cited other works within the WoS collection and illustrate the relationship of citations between papers. Therefore, the number of influential articles has been substantially reduced from 62 to 32 articles. These articles are important for tracking the related sources and giving credit to other research with similar ideas. Two articles were excluded from further review because one was written in a language other than English (Prezelj & Cudina, 2009 – written in Slovenian) and another was related to virtual laboratories rather than RLs (Wannous & Nakano, 2010), resulting in a total of 30 articles for further in-depth review using the EPPI criteria.

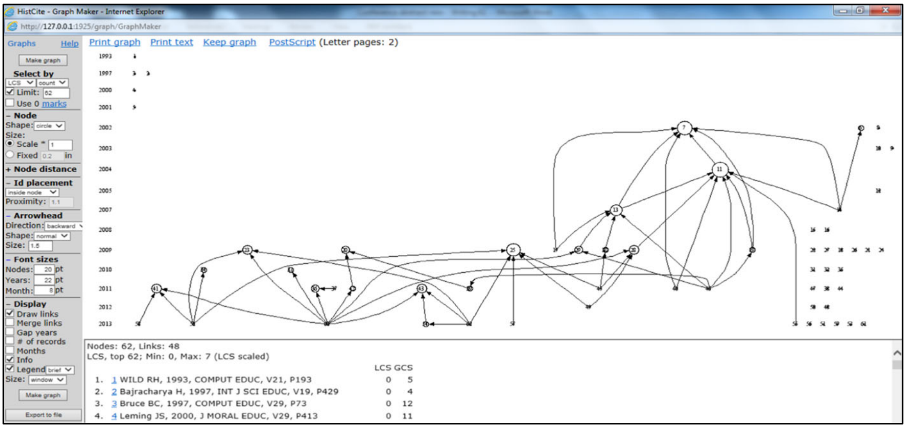


Fig. 5 The *HistCite* graphmaker display of the historiographs of RL from 1993 to 2013

Part 2—CiteSpace Analysis Procedures

The identified RL database was submitted to *CiteSpace* analysis for reporting the cluster terms and searching for other important articles through the cited references or bibliographic collections. The *CiteSpace* software identified cluster terms and ten other important highly cited articles that were not listed in the WoS database through the cited references or bibliographic collections.

The purpose of this study involving searching the important RL articles that are highly cited within the community required this step in the analysis to consider the original 62 articles selected for *CiteSpace* analysis instead of the restricted 30 RL articles. Thus, the data of the *CiteSpace* analysis originated from the 62 articles and from the 50 most-cited papers each year between 1993 and 2013. Figure 6 presents a timeline visualization of the clusters with automatically created labels (only highly cited papers in major clusters are shown). Thus, the 507 references and 1981 co-citation links were allocated into 32 clusters with major clusters identified, but the limitation of the software allowed only 29 major clusters to be listed in Fig. 6. The cluster labels shown were useful for understanding the research scope or direction of RLs because these terms were frequently used within the community. Furthermore, these terms are very useful for conducting research related to RL development, results, discussion, conclusions, and suggestions.

Next, the narrative was generated for analysis of the largest cluster (see Electronic Supplemental Materials Website ESM C). The automatically chosen cluster labels of the 10 largest clusters along with their size, identity number and silhouette value in brackets, are presented. The silhouette value is used for estimating the uncertainty involved in identifying the nature of a cluster with the value of 1, meaning a perfect separation from other clusters where no single article is clustered in two or more clusters. Chen et al. (2010) stated that "cluster labeling or other aggregation tasks will become more straightforward for clusters with the silhouette value in the range of 0.7~0.9 or higher." (p. 1391). The top-ranked title terms by log-likelihood ratio (LLR) were chosen as cluster labels. The largest cluster *remote engineering laboratories* (#0,

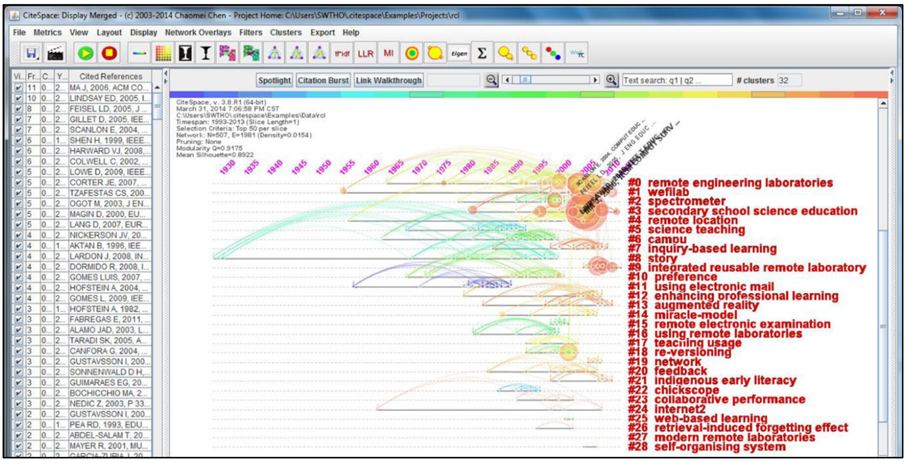


Fig. 6 Cluster labels and terms generated from 1993 to 2013

0.838) had 60 papers. The second largest cluster (#1, 0.888), with 34 papers, was labelled as *wefilab* (web-based wifi laboratory). The third and fourth largest clusters were *spectrometer* and *novel ict* (#2, 0.997; #3, 0.896) and had 32 papers each. Then, the fifth to tenth largest clusters were *remote location* (#4, 1), *science teaching* (#5, 1), *campus* (#6, 1), *inquiry-based learning* (#7, 1), *story* (#8, 1), and *integrated reusable remote laboratory* (#9, 0.963); all had fewer than 30 papers.

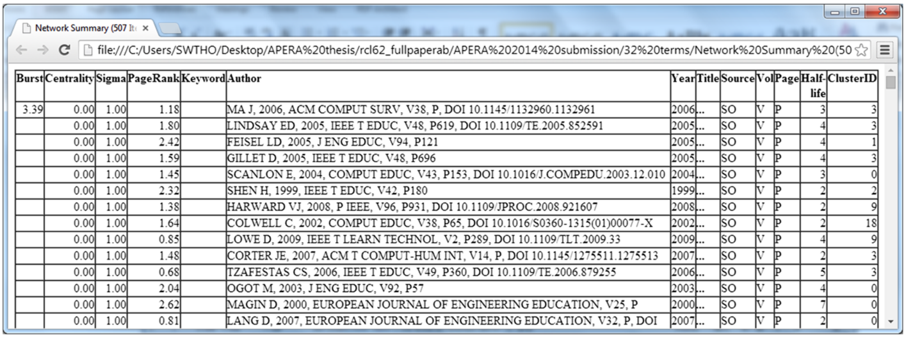
The network summary table (Fig. 7) was generated for choosing another ten most-cited papers that were not listed in the WoS database. These articles were added to the 30 articles identified earlier for in-depth review using the EPPI criteria.

Part 3—In-depth Analysis of Selected Articles

This part of the study concentrated on 40 RL research articles aforementioned for an in-depth analysis that was conducted using two elements of the EPPI guide, namely, reporting and quality of study. Each article was subjected to a double screening by two researchers involving decisions of further selection and classification based on the established criteria flowing from the essential questions for this study. As a result, this process can be claimed as valid, consistent, and unbiased; it can be further replicated and updated. The overall goal of the systematic review for the RL research and development was to ascertain what evidence exists that RL teaching and learning approaches that highlight development and evaluation to improve the understanding of science and the attitudes toward this new learning mode for all level students. Studies included in the review met the following criteria:

- Their principal focus is on the effects of RL approaches on design, understanding, attitudes, gender, and practices.
- They report evaluations of RL materials.
- They have been published in English-language journals or reported in conference proceedings during the period 1992–2013.

However, on deeper investigation, only 26 articles (out of 40 RL research articles) met both of these criteria; the other 14 studies just reported on the development of the RL system (5), discussed the RL literature review (3), or focused more on describing the architecture of RLs with incomplete data collection and analysis (6). The detailed



Burst	Centrality	Sigma	PageRank	Keyword	Author	Year	Title	Source	Vol	Page	Half-life	ClusterID
3.39	0.00	1.00	1.18		MA J, 2006, ACM COMPUT SURV, V38, P, DOI 10.1145/1132960.1132961	2006	...	SO	V	P	3	3
	0.00	1.00	1.80		LINDSAY ED, 2005, IEEE T EDUC, V48, P619, DOI 10.1109/TE.2005.852591	2005	...	SO	V	P	4	3
	0.00	1.00	2.42		FEISEL LD, 2005, J ENG EDUC, V94, P121	2005	...	SO	V	P	4	1
	0.00	1.00	1.59		GILLET D, 2005, IEEE T EDUC, V48, P696	2005	...	SO	V	P	4	3
	0.00	1.00	1.45		SCANLON E, 2004, COMPUT EDUC, V43, P153, DOI 10.1016/J.COMPEDU.2003.12.010	2004	...	SO	V	P	3	0
	0.00	1.00	2.32		SHEN H, 1999, IEEE T EDUC, V42, P180	1999	...	SO	V	P	2	2
	0.00	1.00	1.38		HARWARD VJ, 2008, P IEEE, V96, P931, DOI 10.1109/JPROC.2008.921607	2008	...	SO	V	P	2	9
	0.00	1.00	1.64		COLWELL C, 2002, COMPUT EDUC, V38, P65, DOI 10.1016/S0360-1315(01)00077-X	2002	...	SO	V	P	2	18
	0.00	1.00	0.85		LOWE D, 2009, IEEE T LEARN TECHNOL, V2, P289, DOI 10.1109/TLT.2009.33	2009	...	SO	V	P	4	9
	0.00	1.00	1.48		CORTER JE, 2007, ACM T COMPUT-HUM INT, V14, P, DOI 10.1145/1275511.1275513	2007	...	SO	V	P	2	3
	0.00	1.00	0.68		TZAFESTAS CS, 2006, IEEE T EDUC, V49, P360, DOI 10.1109/TE.2006.879255	2006	...	SO	V	P	5	3
	0.00	1.00	2.04		OGOT M, 2003, J ENG EDUC, V92, P57	2003	...	SO	V	P	4	0
	0.00	1.00	2.62		MAGIN D, 2000, EUROPEAN JOURNAL OF ENGINEERING EDUCATION, V25, P	2000	...	SO	V	P	7	0
	0.00	1.00	0.81		LANG D, 2007, EUROPEAN JOURNAL OF ENGINEERING EDUCATION, V32, P, DOI	2007	...	SO	V	P	2	0

Fig. 7 *CiteSpace* network summary table

data extractions of those selected articles (Table 1) show the evaluation of the 26 selected studies (see Appendix for complete reference information). Based on the findings, 19 studies reported on the design of the RLs, 23 on understanding, and 12 on attitude. It was noted that 12 studies reported on a combination of these three aspects; two aspects were of relatively low concern from the previous researchers. Five studies reported on related skills and only one study reported on gender aspect. Thus, an overview and the evidence of these articles are discussed in the following section.

Thus, we completed three important phases to analyze the structure of laboratory or practical work studies that focused on RL studies and how to review the selected articles. Figure 8 summarizes the related procedures and initial findings.

Findings and Discussion

An Overview of Related Studies

Four geographic regions contributed most of the studies, and most of these studies were funded small-scale research. The countries of origin of the data for the articles are grouped into four subsets (the number in brackets refers to the number of articles): Europe (13), the United States (6), Australia (4), and Asia (3). Almost 70% of the research and development received funding, which is an important element to develop and sustain RLs. Generally, RL research was applied to small-scale samples, with nearly 85% of the studies having fewer than 200 participants. Therefore, more advanced data analysis could not be performed due to sample sizes; most studies did not report effect sizes, which meant that a meta-analysis could not be done. This problem may be due to the limitation of the RL systems explored that cannot be used, controlled, and monitored by many participants at the same time.

Evaluation of education level and content focus showed that most of the studies were conducted at the university level and involved physics. Almost all studies involved university students as participants; 23 studies were undertaken by undergraduate students and one by undergraduate and postgraduate students. Only one study each was found at the primary (Kong et al., 2009) and secondary levels (Lowe et al., 2013). Regarding remote experiments, all were related to physics topics except for one relating to biology (Fiore & Ratti, 2007) that involved observing mouse behavior.

The methodology used in these studies varied. Ten studies used an experimental design, and 16 studies used nonexperimental designs. However, 7 of the 10 experimental studies did not clearly state the number of participants in the experimental and control groups. Seven of the studies used mixed methods, 18 used quantitative methods, and only one used qualitative methods for collecting and analyzing their data. Almost 80% of the research studies did not mention a pilot study, one study explicitly identified a pilot test (Lang et al., 2007), and five claimed that the study itself was a pilot study (Barrios et al., 2013; Gillet, Ngoc, & Rekik, 2005; Lowe et al., 2013; Nickerson, Corter, Esche, & Chassapis, 2007; Tzafestas, Palaiologou, & Alifragis,

Table 1 Reporting Details on Evaluation of the 26 Studies

Author(s)	Sample (n)	Partici-pants	Discipline	Methods	Outcomes				
					D	U	A	G	P
Abdulwahed & Nagy (2009)	70 (E:n/a; C:n/a)	U	Physics	E, Quan	√	√			
Abdulwahed & Nagy (2011)	65 (E:n/a; C:n/a)	U, G	Physics	E, Quan		√	√		
Barrios et al. (2013)	43	U	Physics	NE, Quan	√				
Cooper & Ferreira (2009)	153	U	Physics	NE, M		√	√		√
Corter et al. (2007)	306	U	Physics	NE, M	√	√	√		√
Corter et al. (2011)	457 (E:169; C_H: 121, C_S: 167)	U	Physics	E, Quan	√	√	√		
Cui et al. (2012)	315	U	Physics	NE, Quan	√	√	√		
Fabregas et al. (2011)	60	U	Physics	NE, Quan		√	√		
Fiore & Ratti (2007)	27	U	Biology	NE, M	√	√			
Gillet et al. (2005)	96	U	Physics	NE, M	√	√			
Gustavsson et al. (2009)	78	U	Physics	NE, Quan	√				
Kong et al. (2009)	23	P	Physics	NE, Quan		√	√		
Lang et al. (2007)	52 (E:31; C:21)	U	Physics	E, Quan	√	√		-	√
Lindsay & Good (2005)	146 (E:n/a; C:n/a)	U	Physics	E, Quan		√			
Lowe et al. (2013)	112	S	Physics	NE, Quan	√	√	√	-	√
Nickerson et al. (2007)	29	U	Physics	NE, Quan	√	√	√		
Ogot et al. (2003)	n/a (E:n/a; C:n/a)	U	Physics	E, Quan	√	√	√		
Sauter et al. (2013)	123 (E:n/a; C:n/a)	U	Physics	E, M	√	√	√		
Scanlon et al. (2004)	12	U	Physics	NE, Qua	√	√	√		
Shyr (2011)	110 (E:55; C:55)	U	Physics	NE, M	√	√	√		
Stefanovic (2013)	1595 (E:n/a; C:n/a)	U	Physics	E, Quan	√	√	√	√	√
Tawfik et al. (2013)	64	U	Physics	NE, Quan	√	√	√		
Tiwari & Singh (2011)	54	U	Physics	NE, Quan	√	√	√		
Torre et al. (2013)	115 (E:62; C:53)	U	Physics	E, Quan		√			
Tzafestas et al. (2006)	60 (E:n/a; C:n/a)	U	Physics	E, M		√			
Vargas et al. (2011)	120	U	Physics	NE, Quan	√				
Total					19	23	16	1	5

Notes. Sample: E = experimental group, C = control group, C_H = hands-on control group, C_S = simulation control group; Participants: G = postgraduate, U = undergraduate, S = secondary, P = primary; Methods: E = experimental, NE = nonexperimental, M = mixed, Qua = qualitative, Quan = quantitative; Outcomes: D = design, U = understanding, A = attitude, G = gender, P = practices

2006). Unexpectedly, none of the studies reported the effect size and none discussed the ethical consent for conducting the research.

Evidence of Design of the RL Systems

Generally, the data for the design of the RLs were collected via questionnaire items, open-ended questions, and interviews. Evidence for the design of the RL systems comes from the findings of 19 articles (Table 1) that discussed the RL design itself (i.e., format, content, quality, and manual guide), sense of reality, acceptance, usability, usefulness, and technical problems faced. Based on these data, there appeared to be educational merits for the RL system with the design, sense of reality, acceptance, usability, and usefulness aspects. However, some general limitations were found such as guidance; since RLs were a new laboratory approach, some participants had difficulty performing tasks. Another limitation related to access; there were system crashes due too many users wanting to use the same remote experiment as well as Internet concerns (e.g., problems with Internet connection and hacking problem etc.). In addition, RL system is imperfect solution, currently for conducting the remote experiments are unable to support "high degree of openness" (Chen et al., 2012b, p.8) due to remote apparatus used.

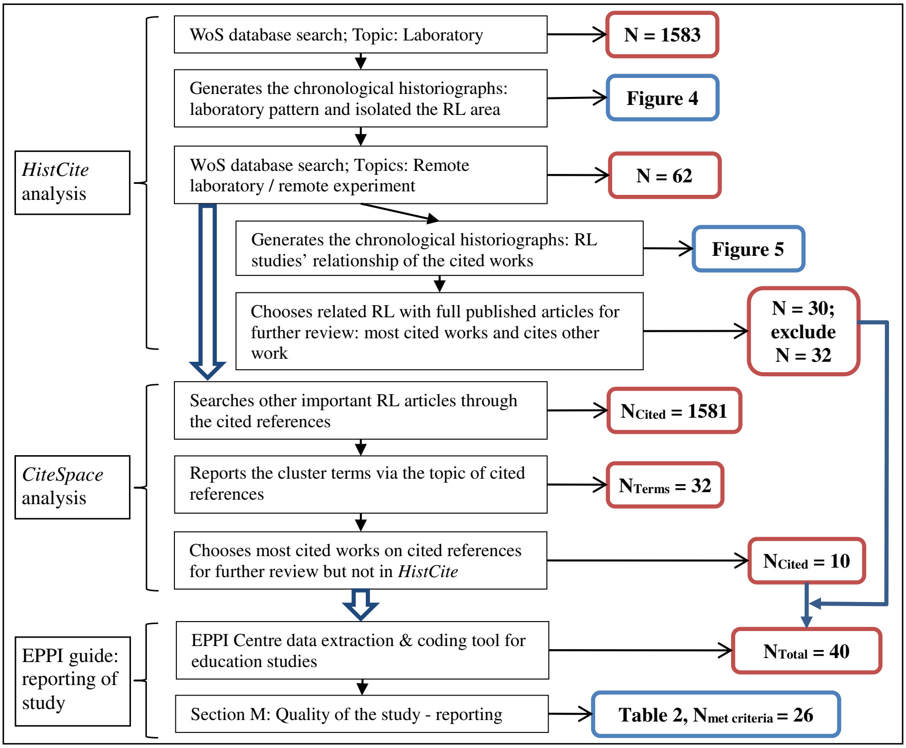


Fig. 8 The summary of findings in the literature review

Evidence of Understanding through the Use of the RL Systems

Normally, the data on understanding of certain concepts were collected via conceptual tests, laboratory tests, and laboratory reports. The evidence of understanding through the use of the RL systems comes from the findings of 23 articles (Table 1), in which 17 articles reported data on understanding using conceptual tests, four articles (Fabregas, Farias, Dormido-Canto, Dormido, & Esquembre, 2011; Fiore & Ratti, 2007; Nickerson et al., 2007; Torre et al., 2013) reported the data using student examination grades, and five studies reported laboratory reports as proof of understanding. Several studies used more than one method to collect data on understanding, with laboratory reports produced considered as essential data for evaluating the newly developed RLs. Interestingly, there were four articles (Corter et al., 2007; Lang et al., 2007; Nickerson et al., 2007; Tzafestas et al., 2006) that reported equally good performance of the remote experiments and hands-on or simulation experiments. Thus, RLs appear to be an alternative laboratory learning experience or supplement to hands-on practical work.

Evidence of Attitude through the Use of the RL Systems

Most of the studies used questionnaire items and open-ended questions for their data collection about attitudes. The evidence about attitudes as an outcome through the use of the RL systems comes from the findings of 16 articles (Table 1). Most of these studies discussed enjoyment, satisfaction, motivation, collaboration, and confidence. The data analysis of several studies used descriptive statistics (e.g., mean, standard deviation, percentage) for summarizing their data on attitude and narrative comments from open-ended questions. However, they did not fully compare the participants' outcomes. Thus, more inferential statistical analysis should be performed for testing the statistical hypotheses.

Evidence of Gender and Practices through the Use of the RL Systems

Few studies involved consideration of gender and practices. Unpredictably, only one study stated that no significant gender difference was found (Stefanovic, 2013); and two studies (Lang et al., 2007; Lowe et al., 2013) reported that statistical analysis could not be performed due to the limited number of female participants. Another important aspect that received little attention was students' practices; only five studies reported on practices (Table 1). The data on practices for RLs were collected via RL tasks/assignments (Cooper & Ferreira, 2009; Stefanovic, 2013), standardized test items (Corter et al., 2007), questionnaire items (Lang et al., 2007), and open-ended questions (Lowe et al., 2013). Several different RL practices were considered: ICT (Cooper & Ferreira, 2009; Lowe et al., 2013), experimentation (Lowe et al., 2013; Stefanovic, 2013), visualization (Corter et al., 2007), and English language (Lang et al., 2007).

Conclusion and Future Work

Using this three-part procedure facilitated the analysis process, which could include identifying research gaps and combining ideas of different research topics. Furthermore, this procedure reduced research bias; for instance, the review procedure is not overly influenced by the results in the study abstracts. Where the nature of the review process involves a clear or detailed review of the methodology and results, researchers can use this review format to summarize different constructs of evaluation; this should be very useful in research discussions, conclusions, and suggestions.

Thus, this study set out to identify the importance and innovation of advanced procedures for document analysis and systematic reviews. We observed the relationship of the cited works in the historiographs of laboratory work and RL research studies through *HistCite* analysis. Then, we obtained more information about RLs with *CiteSpace* analysis, which identified a manageable number of studies for further consideration. The in-depth analysis identified and deleted some studies that passed the software screens but did not fully meet the EPPI criteria. The in-depth consideration of the remaining studies showed that (a) RLs in the engineering area are quite well-established (in Table 1, most of RL studies from engineering area and in Fig. 6, the largest cluster based on *CiteSpace* analysis is remote engineering laboratories), (b) this technology has begun to attract attention from secondary and primary school science education (Kong et al., 2009; Lowe et al., 2013), and (c) lack of RL system development matching the secondary science education curriculum has been done (Lowe et al., 2013). Moreover, the other issues that need to be considered when conducting development and evaluation of RLs in science education are pilot tests, research ethics approval and informed consent, and gender issues. As a whole, this study has contributed to the literature on laboratory work in science education and, more particularly, sheds light on the growth of RLs. It may also have implications for the teaching of diverse science discipline areas.

Future studies of practical work in science, where RLs are a subset employing the latest and most innovative technology, need more work and to be applied to K–12 and new science education reforms. Further development of RLs at the K–12 school level will need to consider the underlying scientific concepts and practices and cross-cutting principles to closely match contemporary science education reforms and curricula and to maximize the important features of RLs (i.e., long-time observation, dangerous experiments, real-time interactivity, anytime and anywhere access, and engagement). The use of the RL system can potentially be integrated with existing e-learning methods (i.e., massive open online courses and mobile learning), which are important in distance education. Additionally, the development of feasible remote experiments across the science disciplines (e.g., biology and chemistry) should be considered in future work.

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Appendix

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