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Probleme Dayalı Öğrenmenin Kimya Eğitiminde Kullanımına Yönelik Makalelerin Bibliyometrik ve Betimsel İçerik Analizleri

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Özet: Bu çalışmada, bibliyometrik ve betimsel içerik analizleri kullanılarak kimya eğitiminde probleme dayalı öğrenme (PDÖ) yaklaşımının kullanımına yönelik araştırmalardaki eğilimlerin ve bu araştırmaların karakteristik özelliklerinin ortaya konması amaçlanmıştır. Bu amaca ulaşmak için Web of Science (WoS) veri tabanından erişilen 119 makaleye bibliyometrik analiz ve WoS veri tabanında "Eğitim & Eğitim Araştırmaları" kategorisine giren 30 makaleye de betimsel içerik analizi uygulanmıştır. Bibliyometrik analizle, ilgili makalelerdeki anahtar kelimeler, özet bölümlerindeki kelimeler, atıflar ve ortak atıflar analiz edilmiştir. Betimsel içerik analizi ile ise makalelerdeki araştırma alanları, değişkenler, araştırma yöntemleri, örneklemler, veri toplama araçları, veri analiz yöntemleri ve araştırma sonuçları incelenmiştir. Bibliyometrik analiz sonuçları, makalelerde en sık kullanılan anahtar kelimelerin problem çözme/karar verme, PDÖ, lisans eğitimi, sorgulamaya dayalı/keşfederek öğrenme, laboratuvar eğitimi ve işbirlikçi/işbirliğine dayalı öğrenme olduğunu göstermiştir. Makalelerin özet bölümlerinde en sık kullanılan kelimelerin ise problem, öğrenciler, öğrenme, çalışma, ders, yaklaşım, beceri ve kimya olduğu anlaşılmıştır. En çok atıf alan yazarlar Leman Tarhan, Santiago Sandi-Urena, Melanie M. Cooper ve Todd A. Gatlin olmuştur. "Journal of Chemical Education" ve "Chemistry Education Research and Practice" en çok makalenin yayımlandığı ve en çok atıf alan dergilerdir. Betimsel içerik analizi sonuçları, kimya eğitiminde PDÖ uygulamaları için temel öğrenme ortamlarının üniversite kimya laboratuvarları ve kimya dersleri olduğunu göstermiştir. İlgili makalelerde, lisans öğrencileri en sık tercih edilen örneklem olurken akademik başarı,

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PDÖ üzerine görüşler ve tutum en sık incelenen değişkenler olmuştur. Makalelerde nicel ve nitel araştırma yöntemleri sıklıkla kullanılırken karma yöntemin sınırlı sayıda kullanıldığı tespit edilmiştir. Ayrıca veri toplama aracı olarak mülakatlar, başarı testleri ve alternatif ölçme araçlarının yaygın bir şekilde kullanıldığı anlaşılmıştır.

Anahtar kelimeler: Betimsel içerik analizi, bibliyometrik analiz, kimya eğitimi ve problem dayalı öğrenme

GENİŞ ÖZET

Giriş

Bu çalışmada, kimya eğitimi araştırmalarında probleme dayalı öğrenme (PDÖ) yaklaşımının kullanıldığı makaleler bibliyometrik ve betimsel içerik analizlerinden oluşan iki aşamalı bir analize tabi tutulmuştur. Araştırma bulgularının kimya eğitiminde PDÖ üzerine çalışan araştırmacılara katkı sağlaması beklenmektedir. Ayrıca çalışmanın gelecekte bu alanda çalışacak araştırmacılar için de yararlı bir kaynak olacağı düşünülmektedir. Çalışmanın araştırma soruları aşağıda listelenmiştir:

Bibliyometrik analiz ile cevaplanacak araştırma soruları;

- Makalelerde sıkça kullanılan anahtar kelimelerin dağılımı nedir?
- Makalelerin özetinde sıkça kullanılan kelimelerin dağılımı nedir?
- Kimya eğitiminde PDÖ ile ilgili makalelerde en çok alıntı yapılan (alıntı ve ortak alıntı) yazarlar kimlerdir?
- Makalelerde en aktif (alıntı ve ortak alıntı) dergiler hangileridir?

Betimsel içerik analizi ile cevaplanacak araştırma soruları;

- Makalelerin araştırma alanları nelerdir?
- Makalelerde sıkça incelenen değişkenler nelerdir?
- Makalelerde sıklıkla kullanılan araştırma yöntemleri nelerdir?
- Makalelerde sıklıkla tercih edilen örneklemler ve örneklem büyüklükleri nelerdir?
- Makalelerde sıklıkla kullanılan veri toplama araçları nelerdir?
- Makalelerde sıklıkla kullanılan veri analiz yöntemleri nelerdir?
- Makalelerde vurgulanan sonuçlar nelerdir?

Yöntem

Bu araştırmada veriler bibliyometrik haritalama ve betimsel içerik analiz teknikleri kullanılarak analiz edilmiştir. Araştırma, literatür taraması, ilgili makalelerin seçilmesi ve analizi olmak üzere üç ardışık adımı içermektedir.

Literatür taraması, ilgili makalelerin seçilmesi ve analizi

Çalışmada, 2020 yılına kadar hakemli dergilerde (İngilizce) yayımlanan kimya eğitiminde PDÖ ile ilgili makalelere WoS veri tabanı üzerinden erişilmiştir. WoS'da tarama yapılırken gelişmiş tarama seçeneği tercih edilmiştir. Anahtar kelime olarak konu alanı bölümüne "chemistry" ve "problem-based" veya "problem based" yazılmıştır. Şubat 2021'de yapılan arama ile toplam 169 makaleye erişilmiştir. Araştırmanın kapsamı PDÖ'nün kimya eğitimi alanındaki uygulamaları ile sınırlandırılmıştır. Bu nedenle WoS'da "Education & Educational Research" ve "Education & Scientific Disciplines" kategorileri seçilmiştir. Sonuç olarak araştırma parametrelerine uygun 119 makaleye erişilmiştir. Sonrasında en çok kullanılan anahtar kelimelerin, özetlerdeki kelimelerin, en çok atıf yapılan yazarların ve bu alandaki aktif dergilerin ağ görselleştirmesini ortaya çıkarmak için bu 119 makalenin VOSviewer programı aracığıyla bibliyometrik analizi yapılmıştır.

Bibliyometrik analizden sonra betimsel içerik analizi gerçekleştirmek amacıyla 119 makale arasından WoS veri tabanında "Education & Educational Research" kategorisindeki makaleler betimsel içerik analizi için ayırt edilmiştir. Bu aşamada, "Education & Educational Research" kategorisinde ve SSCI indekste taranan toplam 47 makaleye erişilmiştir. Tüm makalelerin tam metinleri indirilmiştir. Araştırmacılar tarafından makalelerin çalışmanın amacına uygunluğu kontrol edilmiştir. Kimya eğitiminde PDÖ uygulamalarına odaklanmayan bazı makaleler çalışmanın kapsamı dışında tutulmuştur. Dâhil edilmeyen makalelerden bazılarında doğrudan PDÖ uygulamalarına odaklanılmadığı tespit edilmiştir. Sonuç olarak 17 makalenin kapsam dışında bırakılması sonrası kimya eğitiminde PDÖ kullanımı ile doğrudan ilişkili olan 30 makale belirlenmiştir. Belirlenen makaleler betimsel içerik analize tabii tutulurken Sozbilir vd., (2012) tarafından geliştirilen "Makale Sınıflandırma Formu" kullanılmıştır. İlgili form; makale künyesi, araştırma alanı, değişkenler, araştırma yöntemleri, örneklem grupları, veri toplama araçları, veri analiz yöntemleri ve araştırmanın sonuçları bölümlerini içermektedir.

Sonuç ve Tartışma

Bu çalışma iki bölümden oluşmaktadır. Birinci bölümde 119 makale ile bibliyometrik analiz, ikinci bölümde ise 30 makale ile betimsel içerik analizi yapılmıştır. Bibliyometrik ve betimsel içerik analizlerinden önce ise makale sayısının yıllara göre dağılımı incelenmiştir. Kimya eğitiminde PDÖ ile ilgili ilk makalenin 1992 yılında yayımlandığı tespit edilmiştir. Sonraki 15 yıl içinde makale sayısında çok az değişiklik olmuştur. 2007-2016 yılları arasında kimya eğitiminde PDÖ kullanımına odaklanan makale sayısında önemli bir artış olmuştur. Bununla birlikte, 2016'dan sonra, araştırmacıların kimya eğitiminde PDÖ çalışmalarına olan ilgisi önemli ölçüde azalmıştır.

Bibliyometrik analiz bulgularına göre, *probleme dayalı öğrenme, problem çözme* ve *üniversite öğrencileri* makalelerde en sık kullanılan anahtar kelimeler olmuştur. Ayrıca makale özetlerinde en sık kullanılan kelimelerin *problem, öğrenci ve öğrenme* olduğu görülmüştür. Öğrenci ve problem, PDÖ'de merkezi iki bileşen olduğundan bu beklenen bir durumdur. Çalışmada ortaya çıkan diğer bir sonuç ise Leman Tarhan'ın (4 yayın, 71 atıf) kimya eğitiminde PDÖ uygulamaları alanında en üretken yazar olduğudur. Tarhan, çalışmalarında, PDÖ'nün lise öğrencilerinin kimya kavramlarını öğrenmesi üzerindeki etkilerine odaklanmıştır. Ayrıca incelenen makalelerin kaynakçalarında en çok atıf yapılan yazarların Barrows (30 atıf), Belt (25 atıf), Ram (22 atıf), Hmelo-Silver (21 atıf), Domin (21 atıf) ve Hofstein'ın (20 atıf) olduğu anlaşılmıştır. En çok alıntı yapılan dergiler ise "Journal of Chemical Education" *ve* "Chemistry Education Research and Practice" olmuştur.

Betimsel içerik analizi ile ise öncelikle makalelerdeki öğrenme ortamları incelenmiştir. Sonuçlar, hem kimya laboratuvarının hem de kimya dersinin PDÖ uygulamalarında sıklıkla kullanıldığını göstermiştir. PDÖ'nün 2007'den sonra kimya derslerinde daha sık kullanıldığı göze çarpmıştır. Ayrıca makalelerde, son yıllarda PDÖ'nün kimya öğretiminde, STEM, ters yüz sınıf modeli ve bağlam temelli öğrenme gibi diğer öğretim yaklaşımları ile entegre edildiği uygulamalarda rapor edilmiştir. Betimsel içerik analizi kapsamında makalelerdeki değişkenler de incelenmiştir. Buna göre, makalelerde, bağımlı değişken olarak katılımcıların akademik başarılarına, PDÖ uygulamaları hakkındaki görüşlerine, tutumlarına ve bazı becerilerine odaklanılmıştır. Makalelerde en çok kullanılan araştırma yöntemleri ise nicel ve nitel yöntemler olmuştur. Karma yöntem çok az kullanılmıştır. Araştırmacılar, PDÖ'nün etkilerini test ederken, PDÖ ile daha çok geleneksel yaklaşımları karşılaştırmışlardır. Makalelerde örneklem olarak çoğunlukla lisans öğrencileri tercih edilmiş, ölçme araçları olarak ise mülakatlar, başarı testleri, beceri testleri ve alternatif ölçme araçları sıklıkla kullanılmıştır.

Öneriler

Bu çalışma, kimya eğitiminde PDÖ ile ilgili alan yazın çalışmalarının mevcut durumuna genel bir bakış ve alanın gelişim süreci hakkında önemli bilgiler sunmaktadır. Çalışmanın sonuçlarının, PDÖ'nün kimya eğitimi araştırma alanındaki gelecekteki araştırmalar için yön gösterici olacağı düşünülmektedir. Bu nedenle, bu çalışmanın bulguları ışığında aşağıdaki önerilerde bulunulmuştur:

Kimya eğitiminde PDÖ uygulamalarında eğitimcilerin rolüne odaklanan sınırlı sayıda çalışma bulunmaktadır. PDÖ uygulamalarında eğitimci rolü ve etkilerini ortaya çıkaracak çalışmalara ihtiyaç olduğu düşünülmektedir.

Farklı akademik başarı düzeyine sahip öğrencilerin kimya kavramlarını öğrenmesine ve bazı becerileri (problem çözme, eleştirel düşünme, grupla çalışma gibi) geliştirmesinde PDÖ etkisine ilişkin çalışma bulunmamaktadır. PDÖ'nün farklı akademik başarı düzeyine sahip öğrenciler üzerindeki etkilerini ortaya koyacak çalışmalar gerçekleştirilebilir.

Bibliometric and Descriptive Content Analyses for the Articles Related to Problem-Based Learning in Chemistry Education

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Abstract: The study aimed to reveal the research trends of articles related to PBL in chemistry education and to provide insights into the characteristics of the research activities through bibliometric and descriptive content analyses. For bibliometric analysis, a total of 119 articles were accessed from the Web of Science (WoS), and for descriptive content analysis, a total of 30 articles were eliminated from the "Education & Educational Research" category of WoS. In bibliometric analysis, author keywords, words in the abstracts, citation analyses, and co-citation analyses in the articles were analyzed to reveal an overall picture in the related literature. Then, a descriptive content analysis was performed to examine in detail the fields of research, variables, methods, sample groups, data collection tools, data analysis methods, and the results highlighted in the articles. The bibliometric analysis results showed that the most-used keywords were problem-solving/decision making, problem-based learning, undergraduate, inquiry-based/discovery learning, laboratory instruction, and collaborative/cooperative learning. The most used words in the abstracts of the articles were a problem, students, learning, study, course, approach, skill, and chemistry. The most cited authors were Leman Tarhan, Santiago Sandi-Urena, Melanie M. Cooper, and Todd A. Gatlin. The top two journals in the terms of the total number of articles and the most cited were "Journal of Chemical Education" and "Chemistry Education Research and Practice". The descriptive content analysis results showed that undergraduate chemistry laboratories and chemistry courses were the main learning environments for PBL settings in chemistry education. Undergraduate students were the most frequently preferred sample. The most examined variables in the articles were academic achievement, views about PBL and attitude. Quantitative and qualitative studies were the main research focus, but there was a limited number of mixed studies. Also, interviews, achievement tests, and alternative assessment tools were widely used as data collection tools in the articles.

Keywords: Bibliometric analysis, chemistry education, descriptive content analysis, and problem-based learning.

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INTRODUCTION

Problem-based learning (PBL) is a method of learning and teaching in which students work collaboratively to find solutions to problems guided by a tutor. Students encounter real-world problems, interact with each other, identify the desired learning objectives, and test potential hypotheses. In PBL, ill-structured problems rooted in real-world situations are used to motivate students to discover important concepts and their interconnections. Within PBL, the instructor functions as a facilitator by guiding students rather than directing them (Hmelo-Silver, 2004). Proponents of PBL claim that it helps improve the quality of learning by developing students' reflective, critical and collaborative skills (Yew & Goh, 2016).

PBL was initially designed for health studies in the 1960s (Barrows & Tamblyn, 1980). As well, it has moved beyond health studies into engineering, business, law, science education, and other disciplines (Driessen & Van Der Vleuten, 2000; Polonco et al., 2004; Soderberg & Price, 2003). Although PBL originally was designed for adult education, it has then been implemented at all levels of education (Butler, 1999; Delisle, 1997). The reason for the interest in PBL is its success in promoting students' higher-order thinking and a wide range of practical skills such as communication, teamwork, problem-solving and self-directed learning (Hung & Loyens, 2012). The main components of a typical PBL setting are listed below (Solomon, 2005):

- Learning in small groups,
- Changing the teacher's role from expert to facilitator in learning,
- Taking responsibility for learning (self-directed learning),
- Activating prior knowledge,

Hung and Amida (2020) describe the characteristics of PBL as follows;

- Problem-Driven, Structured Learning: PBL organizes students' learning process through scientific problem-solving process stages.
- Self-Directed Learning: PBL aims to help students to become a self-directed learner who is proactive in managing and achieving their learning goals.
- Contextualized Learning with Real-Life, Complex Problems: PBL uses real-life and authentic problems to provide a contextualized learning environment for students. Problems used in PBL lack sufficient information to develop a solution or have multiple ways to be solved.
- Problem/Case-Structured Curriculum: In PBL, the content knowledge and skills to be gained are organized around the problems.
- Small-Group Learning: In PBL, learning occurs in a small group setting during the problem-solving process.

As mentioned above, the role of the instructor in PBL is different from that of a traditional teacher. Teachers encourage students to use questions and to take responsibility for their learning instead of trying to give much information. They act as expert consultants or a partner rather than a provider of information (Senocak, 2009; Ward & Lee, 2002). Dolmans et al. (2002) described an ideal PBL instructor as both an expert in the subject matter and an expert in facilitating student learning.

There are some efforts to review the published literature of PBL and its effects on education. These studies have a wide range of relevance. For example, some studies reviewed the PBL articles published at certain time intervals (Zakaria et al., 2019), in different databases such as ERIC, EBSCO, or MEDLINE (Alharbi, 2017), or in different disciplines such as medicine, maths, and educational leadership (Hallinger & Bridges, 2017). Also, a significant number of the literature review studies only focused on a brief history of PBL and on the definition of the characteristics of the method (Butler, 1999; Shankar, 2010; Ward & Lee, 2002). Although PBL is frequently used in various fields of science education such as physics, chemistry, and biology, there is no literature review using bibliometric mapping and descriptive content analysis techniques together to examine the articles in these fields. To fill this gap, we aimed to conduct a literature review related to the use of PBL in chemistry education. In this scope, first, the articles published on the use of PBL in chemistry education up to 2020 in Web of Science (WoS) were examined with bibliometric analysis that was conducted to map the research characteristics. Then, PBL articles were examined through descriptive content analysis in terms of some variables such as method trends, data collection tools, and data analysis techniques. The variables in the bibliometric mapping were limited to the analysis provided by the VOSviewer software.

Descriptive content analysis is considered one of the types of content analysis, and in this type of analysis, studies on a particular topic are examined and general trends in the studies are determined (Çalık & Sozbilir, 2014). Descriptive content and bibliometric analyses are combined to provide an overall picture of the related literature in the present study. Bibliometric analysis is a statistical technique used to reveal an overall picture of written documents. It has high utility and is convenient as the relevant data are both quantitative and readily available (Pesta et al., 2018). The bibliometric analysis provides an opportunity for researchers to reveal the history and current state of research and indicate which trends are likely to emerge in the future (Vogel & Masal, 2015). It has gained the attention of researchers from different areas (Bhatt et al., 2020), and it is frequently used to quantitatively analyze scientific publications (Chen et al., 2016). Bibliometric analysis has been applied in many disciplines to evaluate research trends (Mao et al., 2010).

In the current study, through a two-tier analysis consisting of bibliometric and descriptive content analyses, our findings are expected to provide a valuable contribution to researchers studying PBL in chemistry education. In addition, the study is also thought to be a useful resource for researchers in this field in the future. The research questions set out in the present study are listed below:

Research questions to be answered by bibliometric analysis:

- What is the distribution of keywords frequently used in the articles?
- What is the distribution of the words frequently used in the abstract of articles?
- Who are the most cited (citation and co-citation) authors in the articles related to PBL in chemistry education?
- What are the most active (citation and co-citation) journals in the articles?

Research questions to be answered by descriptive content analysis:

- What are the fields of research in the articles?
- What are the variables of articles frequently used in the articles?
- What are the research methods frequently used in the articles?
- What are the sample groups and sample sizes frequently preferred in the articles?
- What are the data collection tools frequently used in the articles?
- What are the data analysis methods frequently used in the articles?
- What are the results highlighted in the articles?

METHOD

Model of the Study

This study included three sequential steps, namely scanning, selecting, and analysis of the articles.

Scanning, Selecting, and Analysis of Articles

The articles related to PBL in chemistry education published in the peer-reviewed journals in the English language up to 2020 were accessed from the WoS database. A combination of different strings of keywords ("Chemistry" and "problem-based" or "problem based") was used to search the relevant studies. The search, conducted in February 2021, resulted in 169 articles.

The scope of the study is limited to the practices of PBL in chemistry education. Therefore, we did an additional search to reach articles published in "Education & Educational Research" and "Education & Scientific Disciplines" categories in WoS. As a result, a total of 119 articles were accessed based on the research parameters. Then, a bibliometric analysis was performed for the articles with a VOSviewer program to reveal the network visualization of the most used keywords, words in the abstracts, highly cited authors and active journals in the field.

After the bibliometric analysis, we used another selection among the 119 articles for their applicability to the descriptive content analysis. Articles in "Education & Educational Research" category in WoS were distinguished for descriptive content analysis. A total of 47 articles were accessed in the "Education & Educational Research" category in the SSCI index journals. Then, the full texts of all the articles were downloaded. We reviewed the titles, abstracts, and the other sections of 47 articles to determine if they were related to the study. After a detailed review, we excluded 17 articles that were not directly linked to the scope of the study. Then, 30 articles were selected for the descriptive content analysis to determine the research tendencies in the articles. All of the selected articles for descriptive content analysis were summarized in the supplementary material (see Appendix 1).

'Article Classification Form' developed by Sozbilir et al., (2012) was used for the descriptive content analysis of the 30 articles. The form included the identity of the article, the field of research, variables, research methods, sample groups, data collection tools, data analysis methods, and the results highlighted in articles. Descriptive content analysis was performed by two researchers. The researchers examined the data separately during the analysis. The differences between the researchers' evaluations were discussed, and a consensus was reached. Then, the descriptive content analysis results were presented with descriptive statistics. As for the bibliometric analysis, the VOSviewer software was used for network analysis. It is a tool for analyzing bibliometric networks and forming maps based on network data (Van Eck & Waltman, 2010). It also has the capacity to work with large datasets and provides a range of visualization. This tool was used in the study to map the scope and structure of the research field. The bibliometric and descriptive content analysis processes are summarized in Figure 1.

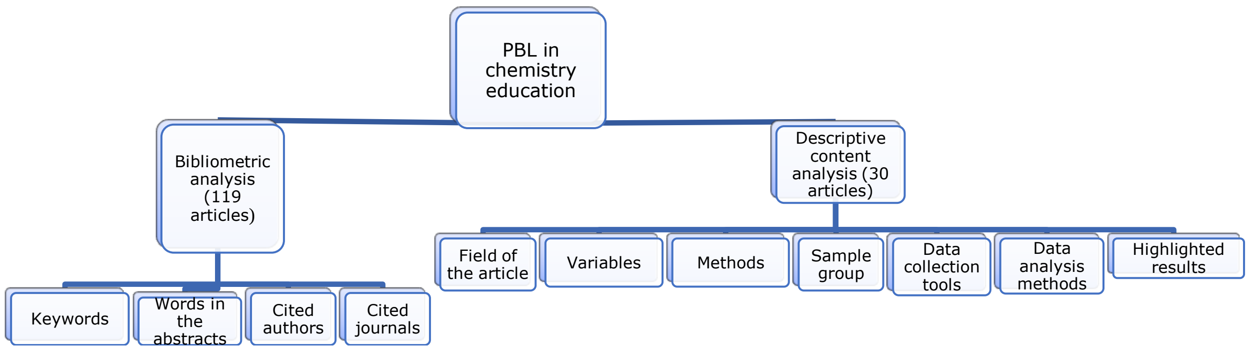

Figure 1

Data Analysis Process for the Study

FINDINGS

Bibliometric mapping findings

A total of 119 articles were analyzed to reveal the network between the author keywords, words in the abstracts, citations, and co-citations in articles through VOSviewer. Before presenting the bibliometric findings, the distribution of the number of articles by years is displayed in Figure 2, in which the first article was published in 1992, and there was no markedly increase in the number of articles until 2006. Since 2007, PBL research in chemistry education has turned into a rapid development ratio. The publication number in the field increased from 1 in 2006 to 12 in 2016. However, after 2016, the number of articles decreased dramatically to 4.

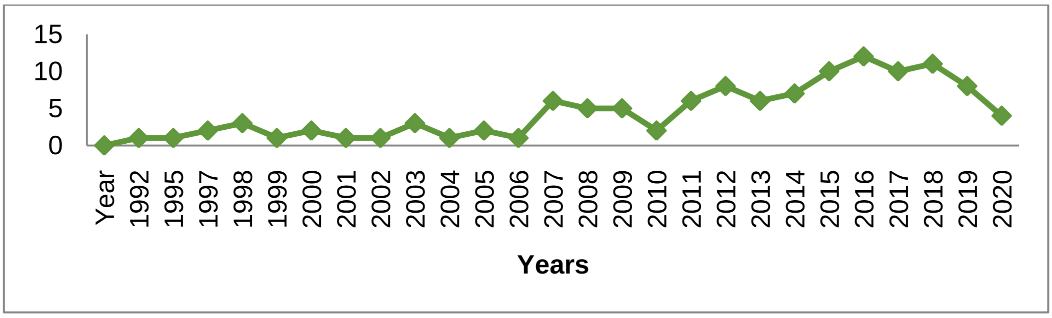

Figure 2

The Distribution of the Number of Articles with Bibliometric Analysis by Years

The Most Used Keywords in the Articles

"Co-occurrence" analysis was used and "author keywords" were selected for the keywords' mapping used in articles. The keywords' minimum repetition number was selected as 5. The number of keywords has turned out to be 19 automatically. The map formed is presented in Figure 3.

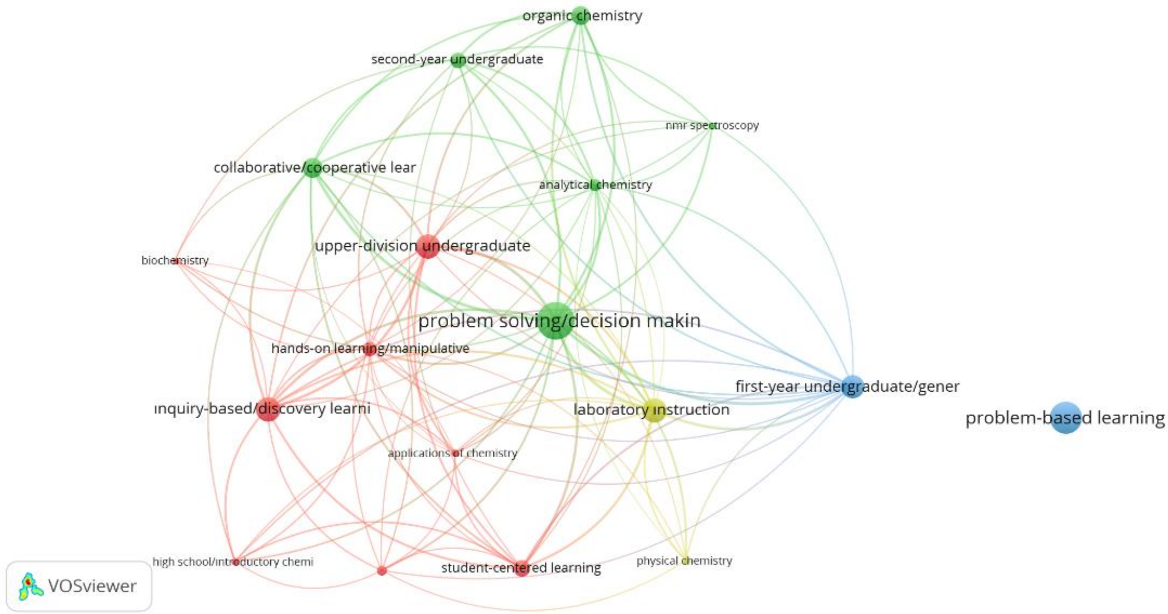

Figure 3

The Most Used Keywords in Articles

Four clusters appeared after the analysis. The most used keyword was "problem-solving/decision making" (f=26). In addition, other frequently used keywords were "problem-based learning" (f=22), "upper-division undergraduate" (f=17), "inquiry-based/discovery learning" (f=17), "laboratory instruction" (f=17), "first-year undergraduate" (f=16) and "collaborative/cooperative learning" (f=14). These findings show that the articles mostly focused on problem-solving, undergraduate education, inquiry-based learning, cooperative learning, and laboratory environment. Also, the distribution of the keywords used in the articles by years was determined. The distribution of the keywords by years is mapped and presented in Figure 4. Articles published in recent years (shown with yellow color), mainly focused on "organic chemistry" (f=13), "analytical chemistry" (f=9), "upper-division undergraduate" (f=17), "inquiry-based/discovery learning" (f=17), "collaborative/cooperative learning" (f=14), and "student-centered learning" (f=12). According to these findings, it could be stated that in recent years, the articles published on PBL in chemistry education have focused on chemistry course topics such as organic chemistry, analytical chemistry rather than laboratory instruction. These keywords can be indicators of fresh research interests of researchers in the field of PBL in chemistry education.

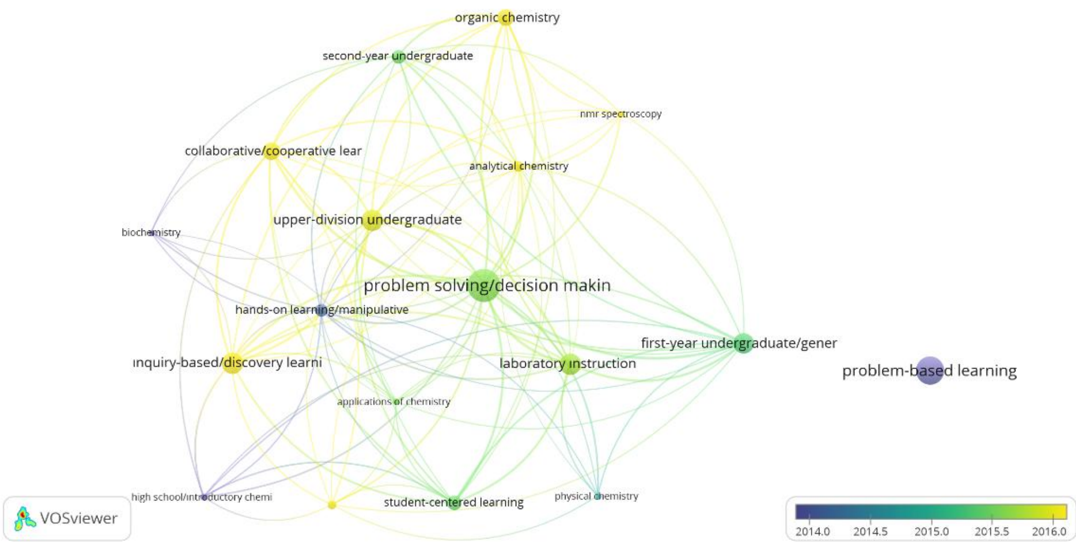

Figure 4

Distribution of the Most Used Keywords in Articles by Year

The Most Used Words in Abstracts

The WoS bibliographic database file has been uploaded to the VOSviewer for words' mapping frequently used in article abstracts. Then "abstract field" and "binary counting" were selected. The words' minimum repetition number was selected as 10. The number of words has turned out to be 41 automatically. The map formed is presented in Figure 5.

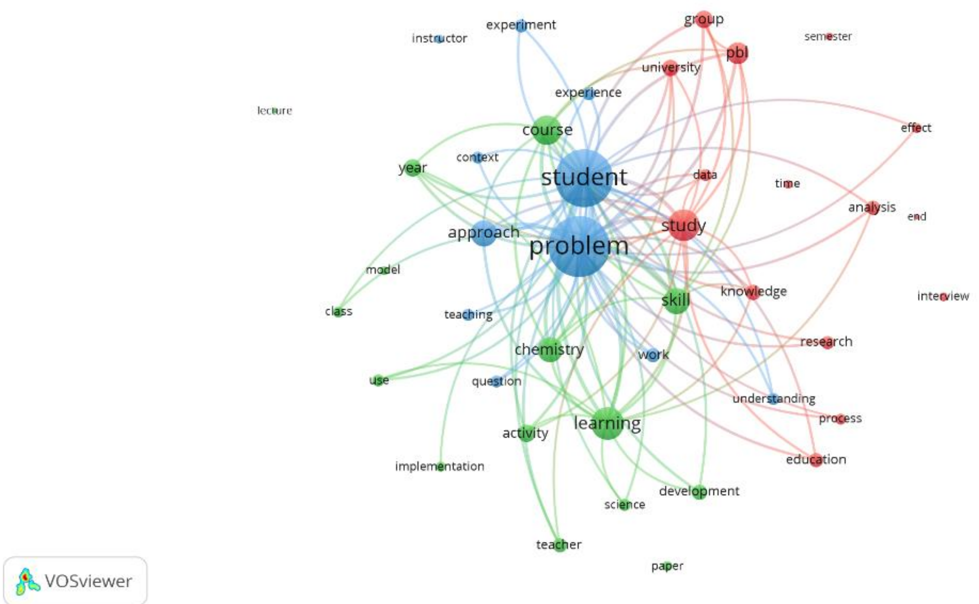

Figure 5

The Most Used Words in Abstracts

Three clusters appeared on the map after the analysis. Not surprisingly, the most employed words in the abstracts were "problem" (f=105) and "student" (f=98) because "problem" and "student" are central to the PBL method. In addition, other frequently employed words in the abstracts were "learning" (f=56), "study" (f=54), "course" (f=51), "approach" (f=45), "skill" (f=45), "chemistry" (f=43), "pbl" (f=37), "year" (f=31), "group" (f=30) and "activity" (f=30). The distribution of the words used in the abstract sections of the articles by years is given in Figure 6. As seen in Figure 6, the articles published in recent years focused on *interviews* as data collection tools and shown with yellow color.

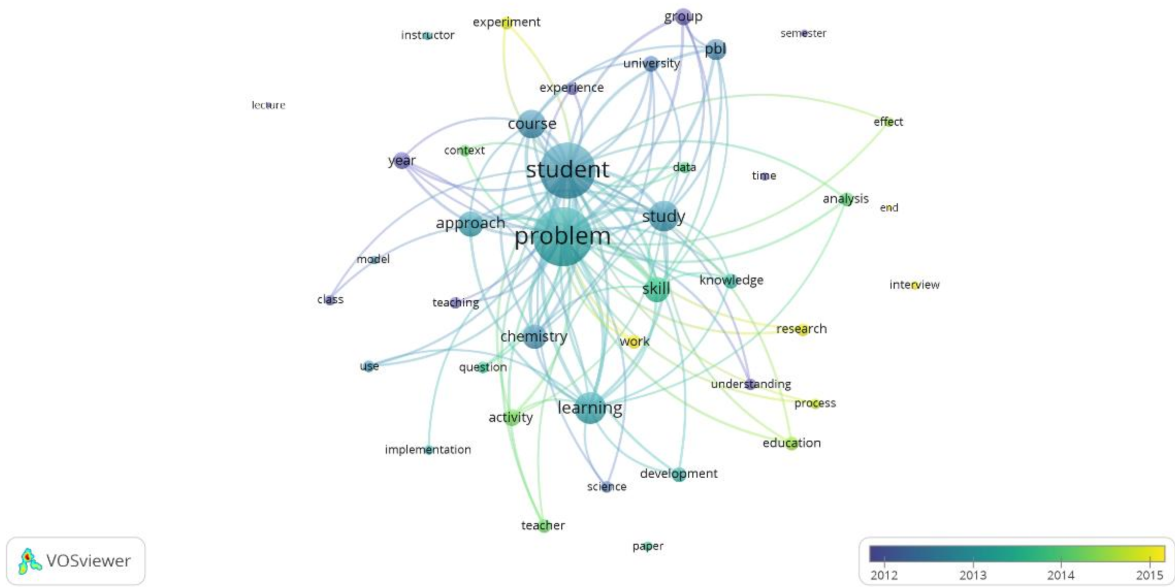

Figure 6

Distribution of the Most Used Words in Abstracts by Year

The Most Cited Authors

Determining the most cited authors in the articles was the third research question of bibliometric analysis. Therefore, firstly, a map was formed for the most-cited authors by selecting "citation analysis" and "authors" in the VOSviewer. The authors' minimum article number was selected as 2. The authors' minimum citation number was selected as 20. The number of authors turned out to be 12. The map formed is presented in Figure 7. The analysis revealed that Leman Tarhan (71 citations, 4 articles) Santiago Sandi-Urena (70 citations, 3 articles), Melanie M. Cooper (70 citations, 2 articles), Todd A. Gatlin (70 citations, 2 articles), and Y. Taskesenligil (58 citations, 2 articles) were the most-cited authors in the articles. The map in Figure 7 shows only authors who have strong connection with each other. Therefore other most-cited authors such as Tarhan and Taskesenligil are not displayed on the map.

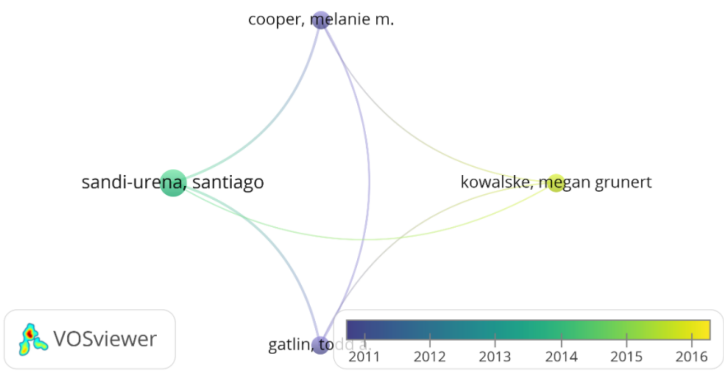

Figure 7

The Most Cited Authors (Citation Analysis)

Secondly, "co-citation" and "cited authors" were selected to determine the authors who were most cited in the references of 119 articles. The authors' minimum citation number was selected as 15. The number of authors turned out to be 13. The map formed is presented in Figure 8. Barrows (30 co-citations), Belt (25 co-citations), Ram (22 co-citations), Hmelo-Silver (21 co-citations), Domin (21 co-citations), and Hofstein (20 co-citations) were the most-cited authors in the articles related to PBL in chemistry education. They are among the leading authors of PBL literature, and they produce highly cited articles in the field.

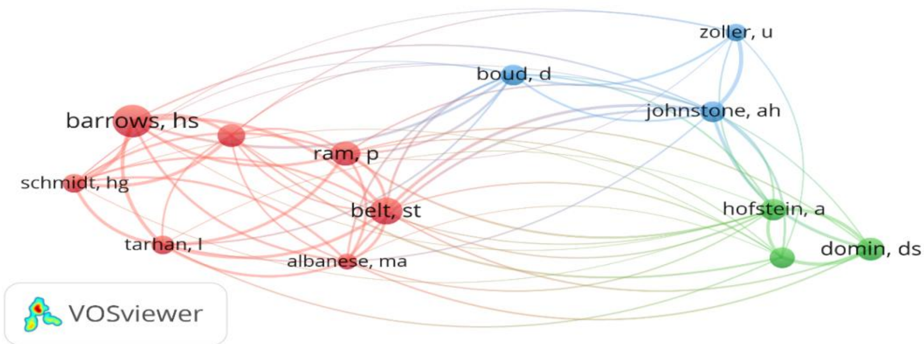

Figure 8

The Most Cited Authors (Co-Citation Analysis)

The Most Cited Journals (Citation and Co-Citation)

The fourth research question of bibliometric analysis was about determining the most cited journals in articles related to PBL in chemistry education. In order to form a map for these journals, "citation analysis" and "sources" were selected. The journals' minimum article number was selected as 1. The journals' minimum citation number was selected as 20, and the number of journals turned out to be 9. The map formed is presented in Figure 9.

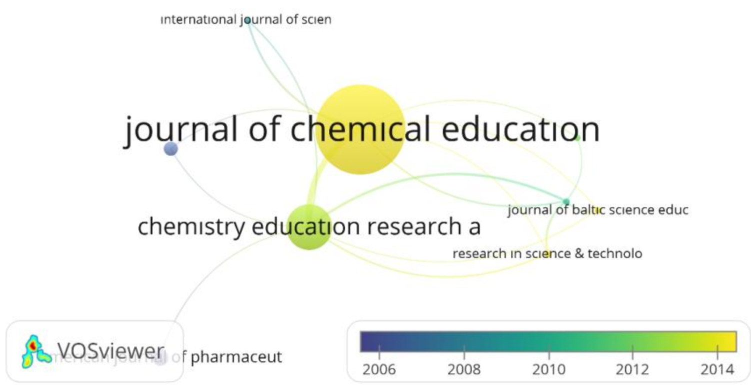

Figure 9

The Most Cited Journals (Citation Analysis)

Journal of Chemical Education-JCE (590 citations, 49 articles), Chemistry Education Research and Practice-CERP (475 citations, 25 articles), International Journal of Science Education (201 citations, 2 articles), American Journal of Pharmaceutical Education (174 citations, 9 articles) and Research in Science Education (104 citations, 4 articles) were the most cited journals in articles. In addition, "co-citation analysis" and "cited sources" were selected with the VOSviewer. The journals' minimum citation number was selected as 30. The number of journals has turned out to be 12. The map formed is presented in Figure 10. JCE (657 co-citations), CERP (129 co-citations), Journal of Research in Science Teaching (109 co-citations), American Journal of Pharmaceutical Education (94 co-citations), International Journal of Science Education (77 co-citations) and Science Education (55 co-citations) were the most cited journals in the references of 119 articles. As seen from Figures 9 and 10, JCE and CERP were the most productive and influential journals in terms of both the number of citations and articles.

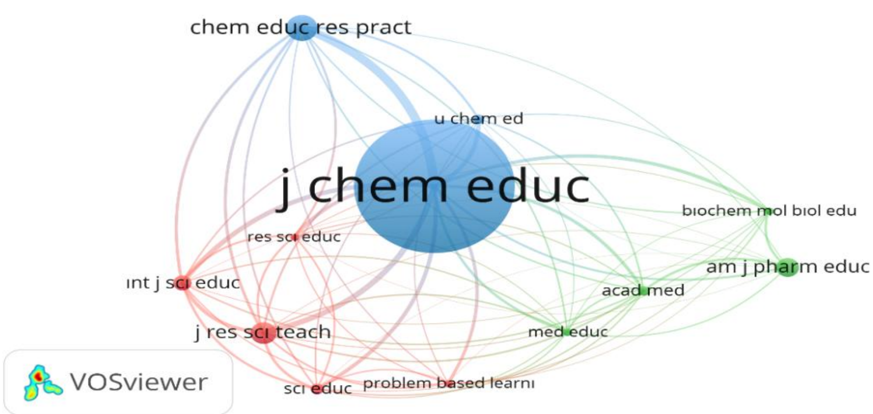

Figure 10

The Most Cited Journals (Co-Citation Analysis)

Descriptive Content Analysis Findings

In this section, 30 articles that were obtained from the "Education & Educational Research" category in the SSCI index and directly related to the use of PBL in chemistry education were examined with descriptive content analysis in terms of some variables to determine the research trends.

The Field of Research in Articles

The distribution of the fields of research in the articles by years is presented in Table 1. As seen in Table 1, the articles focused on PBL settings in chemistry laboratories and chemistry courses. Table 1 also shows that PBL settings were initially implemented in the chemistry laboratory, later, the researchers started to use chemistry courses for PBL applications.

Table 1

Research Fields of the Articles Related to PBL in Chemistry Education by Years

Research fields of the articles	2007-2013	2014-2020	Total	
	f	f	f	%
Chemistry course	9	7	16	53.3
Chemistry laboratory	9	5	14	46.7

Variables in Articles

The dependent variables used in the articles are presented in Table 2. As seen in Table 2, 43.3% of the articles focused on academic achievement, and 40.0% of the articles focused on the participants' views of PBL. In addition, the attitudes of the samples were determined in 26.6% of the articles. These findings revealed that the articles mostly focused on participants' academic achievement and views about PBL settings rather than problem-solving and critical thinking skills.

Table 2

Dependent Variables in Articles

Dependent variables					
	f	%		f	%
Learning/academic achievement	13	43.3	Professional development	1	3.3
Views of PBL	12	40.0	Self-efficacy	1	3.3
Attitude	8	26.6	Misconceptions	1	3.3
Experience	3	10.0	Motivation	1	3.3
Scientific process skills	2	6.6	Interest	1	3.3
Perception	2	6.6	Higher level cognitive skills	1	3.3
Analytical thinking skills	1	3.3	Class discourse	1	3.3
Creative thinking skills	1	3.3	Persistence of knowledge	1	3.3
Self-regulated learning skills	1	3.3	Content knowledge	1	3.3
Self-evaluation proficiency	1	3.3	Transferable skills	1	3.3
Metacognitive development	1	3.3	Scientific understanding	1	3.3
Epistemological development	1	3.3	Anxiety	1	3.3
Technological pedagogical science knowledge	1	3.3			

Research Methods in Articles

As seen in Figure 11, the quantitative research method was preferred in 40.0% of the articles. The qualitative research method was preferred in 40.0%, and the mixed research method was preferred in 20.0%. Also, Table 3 shows in detail the frequency and percentages of the research methods used in the articles.

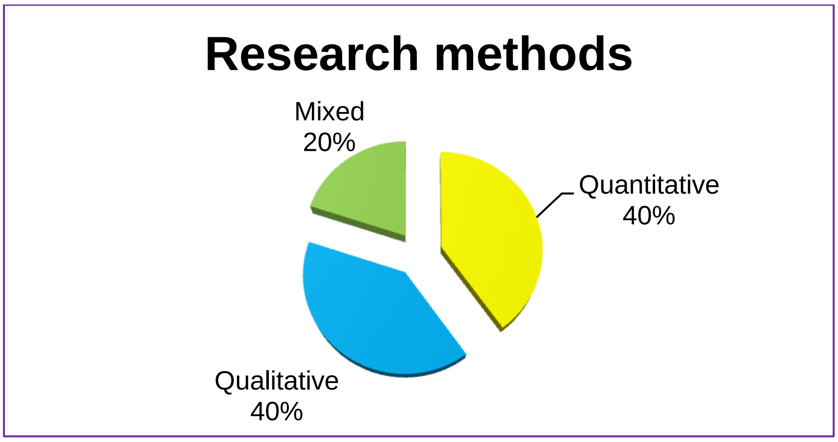

Figure 11

Percentage Use of Research Designs in Articles

According to Table 3, the quasi-experimental design (33.3%) was the most frequently preferred quantitative method in the articles. As for qualitative research methods, case study (16.6%) and phenomenology (13.4%) were the most preferred designs. Among mixed research methods, triangulation research was the most preferred.

Table 3

Research Methods in Articles

Research methods		f	%
Quantitative	Quasi-experimental	10	33.3
	Pre-experimental	2	6.7
	Total	**12**	**40.0**
Qualitative	Case study	5	16.6
	Phenomenology	4	13.4
	Action research	3	10.0
	Total	**12**	**40.0**
Mixed	Triangulation	4	13.4
	Embedded	1	3.3
	Convergent (concurrent)	1	3.3
	Total	**6**	**20.0**
Total		**30**	**100**

Sample Groups in Articles

The distribution of the sample groups in articles is detailed in Table 4. Undergraduate students (76.6%) and high school students (13.4%) were most preferred as sample groups in the articles. Middle school students (3.3%) and research assistants (6.7%) were the least preferred groups. However, Table 4 shows that primary school students or graduate students were not preferred in articles as sample groups.

Table 4

Frequency of Use of Sample Groups

Sample groups	f	%
Middle school (5-8th grade) students	1	3.3
High school (9-12th grade) students	4	13.4
Undergraduate students	23	76.6
Research assistants	2	6.7
Total	**30**	**100**

Data Collection Tools in Articles

According to Figure 12, interviews and achievement tests were mostly used as data collection tools in articles. Skill/ability tests, scales, and observations were among the least used data collection tools in the articles. Interviews were mostly held to determine the participants' views of PBL settings in articles.

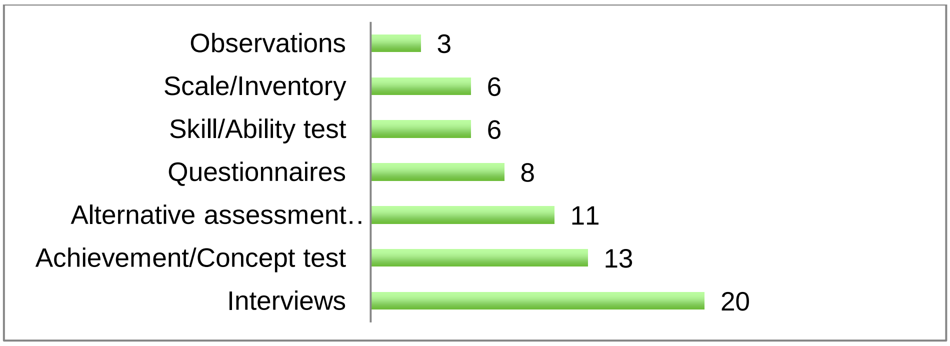

Figure 12

Frequency Use of Data Collection Tools

Data Analysis Methods in Articles

The distribution of the data analysis methods in articles is detailed in Table 5. Frequencies-percentages tables and means, standard deviations were widely used as quantitative descriptive data analysis methods in articles. T-test and ANOVA/ANCOVA were widely used as quantitative inferential data analysis methods in articles. The most used qualitative data analysis methods were qualitative descriptive analysis and content analysis.

Table 5

Trends of Data Analysis of Articles by Years

Data analysis methods	Data analysis techniques	f	%
Quantitative descriptive analysis	Frequencies and percentages-tables	17	56.6
	Means, standard deviations	14	46.6
	Graphs/figures	8	26.6
Quantitative inferential analysis	T-test	9	30.0
	ANOVA/ANCOVA	8	26.6
	Non-parametric tests	5	16.6
	Correlations	1	3.3
Qualitative analysis	Content analysis	10	33.3
	Descriptive analysis	11	36.6

DISCUSSION

This study consisted of two parts. Bibliometric analysis with 119 articles in the first part and descriptive content analysis with 30 articles in the second part were conducted. Articles with bibliometric analysis were published in "Education & Educational Research" and "Education & Scientific Disciplines" categories in WoS. The articles analyzed for descriptive content were gathered from the "Education & Educational Research" category in WoS. Because PBL is a teaching approach, "Education & Educational Research" was used as primary sources for the articles examined with descriptive content analysis.

Before bibliometric and descriptive content analyses, the distribution of the number of articles by years was examined. It was found that the first article on PBL in chemistry education was published in 1992. In the article, the author described a problem-based pharmacy course that organized information about physical chemistry around real problems at the University of Toronto (Duncanhewitt, 1992). There were few changes in terms of the number of articles in the next 15 years. On the other hand, there was a significant increase in the number of articles focusing on the use of PBL in chemistry education between the years 2007 and 2016. However, after 2016, the interest of researchers in PBL studies in chemistry education dramatically decreased.

In bibliometric analysis, firstly, our focus was on which keywords were most often employed by the authors of articles. The results showed that “problem-based learning”, “problem-solving”, “university students” were the three most frequently used keywords. The distribution of the keywords by years was also examined. It was seen that keywords such as “problem-based learning”, “group”, and “practice” were used frequently in the first years, but then the keywords such as “experimental design”, “interview”, “control group” and “effect” were used more frequently. This result indicated that recent articles mainly focused on testing the effectiveness of PBL on students' learning. Most of the experimental studies (12 articles) were carried out in Turkey. Secondly, we examined the most frequently used words in the abstracts of the articles. The findings showed that "problem", "student" and "learning" were the most frequently used words in the abstracts. This was not a surprise because student and problem were two central concepts in PBL (Hmelo-Silver & Barrows, 2006). When the distribution of the words in the abstracts was examined by years, it was revealed that “interview”, “effect”, “context” and “activity” were used highly in recent articles. This finding showed that researchers focused on the opinions of the participants along with testing the effectiveness of PBL in recent years (*e.g.:* Günter & Kılınç-Alpat, 2017; Mataka & Kowalske, 2015). Thirdly, the most productive and highly cited authors were examined. Leman Tarhan (4 publications, 71 citations) was found as the most productive author in the field. She focused especially on the effects of PBL on high school students' chemistry learning. Meanwhile, Santiago Sandi-Urena (3 publications, 70 citations), Melanie M. Cooper (2 publications, 70 citations), and Todd A. Gatlin (2 publications, 70 citations) were the most cited authors. In addition, a co-citation analysis was performed. The results showed that Barrows (30 co-citations), Belt (25 co-citations), Ram (22 co-citations), Hmelo-Silver (21 co-citations), Domin (21 co-citations), and Hofstein (20 co-citations) were the most cited authors in these articles (119 articles). Lastly, the most cited journals were examined. JCE and CERP were determined as both the most productive and the most cited journals. These results showed that these journals are the most active and preferred journals in the field.

Regarding descriptive content analysis, firstly, the learning environments in the articles were examined. The results showed that both chemistry laboratory and chemistry courses were used as learning environments in PBL settings. Researchers found those PBL laboratory settings, improved students' engagements, chemistry laboratory practices, skills such as communication and research (Donnel, et al., 2007; Laredo, 2013; Smith, 2012). Students also expressed their satisfaction with PBL laboratory practices (Zoller & Puskin, 2007). PBL settings were used more frequently in chemistry courses after 2007. In addition, in recent years, some attempts appeared, combining PBL and other teaching approaches in chemistry teaching such as STEM, flipped classroom, and context-based learning (*e.g:* Baran & Sozbilir, 2018; Chonkaew et al., 2016; Eichler & Peeples, 2016). Secondly, the variables in the articles were examined. The articles focused on participants' academic achievements, views of PBL, attitudes, and some skills as dependent variables. The results showed that researchers aimed to investigate the effects of PBL on students' academic achievements, their views about PBL, attitudes, and some skills (such as scientific process skills, analytical thinking skills, and creative thinking skills). Furthermore, some researchers tested the effects of PBL on several dependent variables with experimental studies. Thirdly, the research methods used in the articles were examined under three headings: quantitative, qualitative, and mixed. The results showed that the most used research methods in the articles were quantitative and qualitative. It was also revealed that the quasi-experimental design was the most frequently used in articles. This result showed that the researchers in the field investigated the effects of PBL on the participants while comparing PBL and the traditional approach. Fourthly, the samples in the articles were examined. The findings showed that undergraduate students were mostly preferred (76.6%) as a sample of PBL research on chemistry education. Similar findings emerged in the bibliometric analysis. Undergraduates were one of the most frequently repeated words in the keywords of the articles. Researchers revealed that PBL had very positive effects on undergraduate students (Baran & Sozbilir, 2018; Overton & Randles, 2015; Tatar & Oktay, 2011). However, high school students were used as samples in four articles, research assistants in two articles, and middle school students in only one article. Finally, the data collection tools and data analysis techniques used in the articles were examined. Interviews, achievement tests, skill tests, and alternative assessment tools emerged as the most frequently used tools. Also, quantitative descriptive analysis and qualitative descriptive analysis were frequently preferred as data analysis techniques in articles.

IMPLICATIONS

This study provides an overview of and an effective understanding of the current status of the literature on PBL in chemistry education and offers interesting insights into the development of the field. We believe that the results of this study are important for the future developments of PBL in the chemistry education research field. Therefore, the following suggestions in the light of the results of this study have been put forward:

Limited studies were focusing on the role of teachers on PBL in chemistry education. New studies may be conducted to gain better insights into the role of the teacher and student learning in PBL settings. In addition, there were a few studies on K-12 students' chemistry learnings in PBL. Therefore, new studies are needed in this field.

In PBL literature, studies are showing that PBL is an effective teaching and learning approach, particularly when it is evaluated for long-term retention of knowledge (Dolder & Alston, 2012; Li & Tsai, 2017; Yew & Goh, 2016). However, there are limited studies on the long-term effects of PBL on participants' chemistry learnings. We believe that new studies are needed in this field.

There is no study in the literature on the PBL effect on learning the chemistry concepts and developing the skills (such as problem-solving, critical thinking, working with a group) of students with different achievement levels. Therefore, there is a need for more related studies.

Many studies are comparing the effects of PBL with those of traditional teaching methods, but limited studies are comparing the effects of PBL with those of other student-centered teaching methods. In future studies, PBL and other student-centered approaches could be applied to compare their effects on students' chemistry learning or skills.

In most of the articles analyzed in this study, the research samples were made up of undergraduate students, and in future studies, researchers could include other groups of samples in their samples.

Conflict of Interest Declaration

The author(s) have not declared a potential conflict of interest during the research, authorship, and publishing of this article.

Support / Financing Information

The author(s) have not received any financial support during research, authorship, and publishing of this article.

Ethical Approval

No data were collected from human participants during the research. The document was examined in the research. All ethical standards were taken into consideration and followed during the research.

REFERENCES

Alharbi, H.A. (2017). The effectiveness of problem based learning: literature review. *International Journal of Current Research*, *9(4),* 49559-49565.

Aydoğdu, C. (2012). The effect of problem based learning strategy in electrolysis and battery subject teaching. *Hacettepe University, Journal of Education, 42*, 48-59.

Ayyıldız, Y. & Tarhan, L. (2018). Problem-based learning in teaching chemistry: enthalpy changes in systems. *Research in science & Technological Education, 36*(1), 35-54.

Baran, M. & Sozbilir, M. (2018). An Application of context- and problem-based learning (C-PBL) into teaching thermodynamics. *Research in Science Education, 48,* 663-689.

Barrows, H. S., & Tamblyn, R. S. (1980). Problem-based learning and approach to medical education. Berlin, Hiedelberg, New York: Springer.

Bhatt, Y., Ghuman, K. & Dhir, A. (2020). Sustainable manufacturing. Bibliometrics and content analysis. *Journal of Cleaner Production*, *260*(2020), 120988.

Butler, S. M. (1999). The process of problem-based learning: a literature review. *Journal of Health Occupations Education*, *13*(1), 133-167.

Chen, D., Liu, Z., Luo, Z., Webber, M. & Chen, J. (2016). Bibliometric and visualized analysis of emergy research. *Ecological Engineering, 90*, 285–293.

Chonkaew, P., Sukhummek, B. & Faikhamta, C. (2016). Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry. *Chemistry Education Research and Practice, 17,* 842-861.

Chopra, I., O'Connor, J., Pancho, R., Chrzanowski, M. & Sandi-Urena, S. (2017). Reform in a general chemistry laboratory: how do students experience change in the instructional approach? *Chemistry Education Research and Practice, 18,* 113-126.

Current, K. & Kowalske, M. G. (2016). The effect of instructional method on teaching assistants' classroom discourse. *Chemistry Education Research and Practice, 17,* 590-603.

Çalık, M. & Sozbilir, M. (2014). İçerik analizinin parametreleri. *Eğitim ve Bilim, 39* (174), 33-38.

Delisle, R. (1997). How to use problem-based learning in the classroom. Alexandria, VI: Association for Supervision and Curriculum Development.

Dolder, C., Olin, J. & Alston, G. (2012). Prospective measurement of a problem based learning course sequence. *American Journal of Pharmaceutical Education, 76*(9), 179.

Dolmans, Diana H. J. M., Gijselaers, Wim H., Moust, Jos H. C., de Grave, Willem S., Wolfhagen, Ineke H. A. P. & Van Der Vleuten, Cees P. M. (2002). Trends in research on the tutor in problem-based learning: Conclusions and implications for educational practice and research. *Medical Teacher*, *24*(2), 173-180.

Domin, D. S. (2007). Students' perceptions of when conceptual development occurs during laboratory instruction. *Chemistry Education Research and Practice, 8*(2), 140-152.

Donnel, C. Mc., O'Connor, C. & Seery, M. K. (2007). Developing practical chemistry skills by means of student-driven problem based learning mini-projects. *Chemistry Education Research and Practice, 8*(2), 130-139.

Driessen, E. & Van Der Vleuten, C. (2000). Matching student assessment to problem-based learning: Lessons from experience in a law faculty. *Studies in Continuing Education*, *22*(2), 235–248.

Duncanhewitt, W. C. (1992). Formulation problem-solving as alternative to traditional pharmaceutics. *American Journal of Pharmaceutical Education, 56*(3), 242-251.

Eichler, J. F. & Peeples, J. (2016). Flipped classroom modules for large enrollment general chemistry courses: A low barrier approach to increase active learning and improve student grades. *Chemistry Education Research and Practice, 17,* 197-208.

Günter, T., Akkuzu, N. & Alpat, S. (2017). Understanding 'green chemistry' and 'sustainability': an example of problem-based learning (PBL). *Research in Science & Technological Education, 35*(4), 500-520.

Günter, T. & Kılınç-Alpat, S. (2017). The effects of problem-based learning (PBL) on the academic achievement of students studying 'Electrochemistry". *Chemistry Education Research and Practice, 18,* 78-98.

Hallinger, P. & Bridges, E. M. (2017). A systematic review of research on the use of problem-based learning in the preparation and development of school leaders. *Educational Administration Quarterly*, *53*(2), 255–288.

Hmelo-Silver C. E. (2004). Problem-based learning: what and how do students learn? *Educational Psychology Review*, *16*(3), 235–266.

Hmelo-Silver, C. E. & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *The Interdisciplinary Journal of Problem-based Learning, 1*(1), 21–39.

Hung, W. & Loyens, S. M. M. (2012). Global development of problem-based learning: Adaption, adaptation, and advancement. *Interdisciplinary Journal of Problem-based Learning*, *6*(1), 4-9.

Hung W. & Amida A. (2020) *Problem-based learning in college science*. In: Mintzes J., Walter E. (Eds) Active Learning in College Science. Springer, Cham.

Li, H. C. & Tsai, T. L. (2017). The implementation of problem-based learning in a Taiwanese primary mathematics classroom: Lessons learned from the students' side of the story. *Educational Studies, 43,* 354-369.

Kelly, O. & Finlayson, O. (2009). A hurdle too high? Students' experience of a PBL laboratory module. *Chemistry Education Research and Practice, 10,* 42-52.

Kelly, O. C. & Finlayson, O. E. (2007). Providing solutions through problem based learning for the undurgraduate 1st year chemistry laboratory. *Chemistry Education Research and Practice, 8*(3), 347-361.

Laredo, T. (2013). Changing the first-year chemistry laboratory manual to implement a problem-based approach that improves student engagement. *Journal of Chemical Education, 90*(9), 1151-1154.

Mao , N., Wang, M. & Ho, Y. (2010). A bibliometric study of the trend in articles related to risk assessment published in science citation index. *Human and Ecological Risk Assessment*, *16*(4), 801-824.

Mataka, L. M. & Kowalske, M. G. (2015). The influence of PBL on students' self-efficacy beliefs in chemistry. *Chemistry Education Research and Practice, 16,* 929-938.

Overton, T. L. & Bradley, J. S. (2010). Internationalisation of the chemistry curriculum: two problem-based learning activities for undergraduate chemists. *Chemistry Education Research and Practice, 11,* 124-128.

Overton, T. L. & Randles, C. A. (2015). Beyond problem-based learning: using dynamic PBL in chemistry. *Chemistry Education Research and Practice, 16,* 251-259.

Pesta, B., Fuerst, J. & Kirkegaard, E. O. W. (2018). Bibliometric keyword analysis across seventeen years (2000–2016) of intelligence articles. *Journal of Intelligence*, *6*(4), 1-12.

Polonco, R., Calderon, P. & Delgado, F. (2004). Effects of a problem-based learning program on engineering students' academic achievements in a Mexican university. *Innovation in Education and Teaching International, 41*(2), 145–155.

Rodriguez-Becerra, J., Caceres-Jensen, L., Diaz, T., Druker, S., Padilla, V. B., Pernaa, J. & Aksela, M. (2020). Developing technological pedagogical science knowledge through educational computational chemistry: a case study of pre-service chemistry teachers' perceptions. *Chemistry Education Research and Practice, 21,* 638-654.

Sağır, S. U., Yalçın-Çelik, A. & Öner-Armağan, F. (2009). The effect of problem based learning strategy in metalic activity subject teaching. *Hacettepe University, Journal of Education, 36,* 283-293.

Sandi-Urena, S, Cooper, M. M. & Gatlin, T. A. (2011a). Graduate teaching assistants' epistemological and metacognitive development. *Chemistry Education Research and Practice, 12,* 92-100.

Sandi-Urena, S, Cooper, M. M., Gatlin, T. A. & Bhattacharyya, G. (2011b). Students' experience in a general chemistry cooperative problem based laboratory. *Chemistry Education Research and Practice, 12,* 434-442.

Senocak, E., Taskesenligil, Y. & Sozbilir, M. (2007). A study on teaching gases to prospective primary science teachers through problem-based learning. *Research in Science Education, 37,* 279-290.

Senocak, E. (2009). Development of an instrument for assessing undergraduate science students' perceptions: The problem-based learning environment inventory. *Journal of Science Education and Technology*, *18*(6), 560-569.

Shankar, P. R. (2010). Problem-based Learning: A review. *Journal of Clinical and Diagnostic Research*, *4,* 3249-3254.

Smith, C. J. (2012). Improving the school-to-university transition: using a problem-based approach to teach practical skills whilst simultaneously developing students' independent study skills. *Chemistry Education Research and Practice, 13,* 490-499.

Soderberg, P. & Price, F. (2003). An examination of problem-based teaching and learning in population genetics and evolution using EVOLVE, a computer simulation. *International Journal of Science Education*, *25*(1), 35–55.

Solomon, P. (2005). Problem-based Learning: A review of current issues relevant to physiotherapy education. *Physiotherapy Theory and Practice*, *21*(1), 37-49.

Sozbilir, M., Kutu, H. & Yasar, M. D. (2012). Science education research in Turkey: A content analysis of selected features of papers published. In D. Jorde & J. Dillon (Eds). Science Education Research and Practice in Europe: Retrospective and Prospective (p. 341-374). Rotterdam: Sense Publishers.

Tarhan, L., & Ayyıldız, Y. (2015). The views of undergraduates about problem-based learning applications in a biochemistry course. *Journal of Biological Education 49*(2), 116–126.

Tarhan, L., Ayar-Kayali, H., Ozturk-Urek, R. & Acar B. (2008). Problem-based learning in 9th grade chemistry class: Intermolecular forces. *Research in Science Education, 38*(3), 285-300.

Tarhan, L. & Acar-Sesen, B. (2013). Problem based learning in acids and bases: learning achievements and students' beliefs. *Journal of Baltic Science Education, 12*(5), 565-578.

Tatar, E. & Oktay, M. (2011). The effectiveness of problem-based learning on teaching the first law of thermodynamics. *Research in Science & Technological Education, 29*(3), 315-332.

Tosun, C. & Taskesenligil, Y. (2013). The effect of problem-based learning on undergraduate students' learning about solutions and their physical properties and scientific processing skills. *Chemistry Education Research and Practice, 14,* 36-50.

Van Eck, N. J. & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, *84,* 523–538.

Vogel, R., & Masal, D. (2015). Public leadership: A review of the literature and framework for future research. *Public Management Review*, *17*(8), 1165–1189.

Ward, J. D. & Lee, C. L. (2002). A review of Problem-based learning*. Journal of Family and Consumer Sciences Education*, *20*(1), 16-26.

Williams, D. P., Woodward, J. R., Symons, S. L. & Davies, D. L. (2010). A Tiny Adventure: the introduction of problem based learning in an undergraduate chemistry course. *Chemistry Education Research and Practice, 11,* 33-42.

Wong, K. K. H. & Day, J. R. (2009). A comparative study of problem-based and lecture-based learning in junior secondary school science. *Research in Science Education, 39,* 625-642.

Yew, E. H. J. & Goh, K. (2016). Problem-based learning: An overview of its process and impact on learning. *Health Professions Education*, *2*(2), 75-79.

Yoon, H., Woo, A. J., Treagust, D. & Chandrasegaran, A. L. (2014). The efficacy of problem-based learning in an analytical laboratory course for pre-service chemistry teachers. *International Journal of Science Education, 36*(1), 79-102.

Zakaria, M. K., Maat, S. M. & Khalid, F. (2019). A systematic review of problem based learning in education. *Creative Education*, *10,* 2671-2688.

Zoller, U. & Puskin, D. (2007). Matching higher-order cognitive skills (HOCS) promotion goals with problem-based laboratory practice in a freshman organic chemistry course. *Chemistry Education Research and Practice, 8*(2), 153-171.

Appendix 1 Brief points of the articles examined by descriptive content analysis

Authors & Year	Highlights
Rodriguez-Becerra et al., (2020)	Chemistry teacher candidates gained technological scientific knowledge through practice. Learning with real-world problems using educational calculation methods supported chemistry and pedagogy training of pre-service teachers
Ayyıldız & Tarhan (2018)	PBL significantly improved high school students' academic achievement of a chemistry unit, enthalpy changes in systems, and their decision-making skills.
Baran & Sozbilir (2018)	Context-PBL led a statistically significant increase in the undergraduate students' achievement in thermodynamics and their interest in chemistry. It also had an effect on the retention of knowledge.
Günter & Kılınç-Alpat (2017)	Implementation of PBL significantly developed undergraduate students' academic knowledge of electrochemistry concepts. Interviews revealed that participants had positive images about PBL settings.
Chopra, et al., (2017)	The experience of undergraduate students exposed consecutively to two different environments (verification-based and problem-based) in a General Chemistry Laboratory program was investigated.
Günter et al., (2017)	A PBL centered chemistry laboratory course for undergraduate students developed participants' level of understanding of green chemistry and sustainability concepts. Further, students expressed positive statements about taking an active role in their learning.
Chonkaew et al., (2016)	The effect of STEM activities based on PBL on the analytical thinking abilities and attitudes towards science learning of grade-11 students were investigated in the study of stoichiometry. The activities developed analytical thinking abilities and attitudes towards science learning.
Current & Kowalske (2016)	The effect of instructional method on chemistry teaching assistants' laboratory discourse was investigated.
Mataka & Kowalske (2015)	The influence of PBL on students' self-efficacy beliefs in chemistry was investigated in a PBL chemistry laboratory at a university. PBL significantly increased students' self-efficacy beliefs and allowed them to take more responsibility for their own learning.
Overton & Randles (2015)	A dynamic problem-based learning approach was used to teach sustainable development to chemistry undergraduates. It motivated students to learn about sustainability and developed a series of transferable skills such as problem solving, communication and group working.
Tarhan & Ayyıldız (2015)	Undergraduate students expressed that PBL motivated them to learn, take an active role in their learning, and improve their social skills such as working collaboratively.
Yoon et al., (2014)	The efficacy of PBL in an analytical chemistry laboratory was examined. PBL was found to be an effective teaching and learning method for enhancing chemistry students' creative thinking ability, self-regulated learning skills and self-evaluation.
Tosun & Taskesenligil (2013)	PBL is found effective in improving undergraduate students' learning of solution concepts in General Chemistry Course and scientific process skills. In addition,

	PBL had positive impacts on students' various skills such as group working, self-directed learning and problem solving.
Tarhan & Acar-Sesen (2013)	PBL significantly improved high school students' understanding of the ionization of water and acid and base strength concepts. Students had positive beliefs about PBL.
Smith (2012)	PBL integrated a laboratory instruction to deepen the undergraduate students' understanding of the laboratory techniques. The students found the PBL activities more interesting and better for making them think. Furthermore, they were found favorably in developing the students' skills such as communication and research.
Aydoğdu (2012)	PBL improved undergraduate students' academic achievement in electrolysis and battery subjects of chemistry laboratory. Also, students' attitudes towards chemistry are developed.
Sandi-Urena et al., (2011a)	Students' experience in a general chemistry PBL laboratory was examined. They increased metacognitive strategies and problem solving skills through challenging with ill-structured chemistry problems.
Sandi-Urena, et al., (2011b)	The effect of PBL chemistry laboratory on the teaching assistants' epistemological and metacognitive development was investigated. The laboratory context promoted their metacognitive and epistemological development.
Tatar & Oktay (2011)	PBL method had a positive effect on undergraduate students' academic achievement of the first law of thermodynamics and science process skills.
Williams et al., (2010)	PBL integrated into the introductory inorganic/physical chemistry module by giving to the students the responsibility of planning, researching and constructing solutions to a series of problems. Students improved their transferable skills such as communication, interpersonal and organizational skills.
Overton & Bradley (2010)	Problem-based learning activities were developed to raise chemistry graduates who are equipped to cope with the challenges of the global economy. The activities contributed to the language and cultural awareness of students with a chemistry context.
Wong & Day (2009)	The effects of PBL and lecture-based learning (LBL) on secondary students' science achievement were examined. PBL was at least as effective as LBL in gaining the knowledge required to achieve the learning objectives. Also the PBL students showed a significant improvement in comprehension and application of knowledge over an extended time.
Sağır et al., (2009)	PBL improved undergraduate students' academic achievement in the metallic activity subject of chemistry laboratory.
Kelly & Finlayson (2009)	A PBL laboratory-based module was developed and implemented for first year undergraduate chemistry. PBL developed the students' practical and transferable skills, as well as their content knowledge and scientific understanding.
Tarhan et al., (2008)	PBL is found as an effective teaching method for high school students' achievement related to the subject of

	intermolecular forces and social skills
Senocak et al., (2007)	PBL had a significant effect on undergraduate students' academic achievements of gases concepts in the chemistry course and slightly improved students' attitudes towards chemistry.
Domin (2007)	The effects of PBL chemistry laboratory were compared with the traditional manner laboratory at a two year college. Half of participants expressed that the PBL environment helped them better understand course concepts. Meanwhile the same number found them to be equally effective.
Donnel et al., (2007)	PBL was used as an alternative to the traditional recipe-style laboratory in order to enhance undergraduates' chemistry laboratory practices. PBL increased students' engagements and improved their morale. Researchers also observed that the students were better prepared for their individual research project in next year's courses.
Kelly & Finlayson (2007)	The experience of a group of students enrolled in a PBL chemistry laboratory module was examined. Most of the students expressed that learning and enjoyment in the PBL laboratory were better than in the traditional laboratory.
Zoller & Puskin (2007)	A PBL oriented laboratory activity was designed for a freshman organic chemistry course. The activity contributed to the students' higher-order cognitive skills. Students also expressed their gratifying for laboratory practices.