Chapter 2
How e-Learning Can Support PBL Groups: A Literature Review

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2.1 Introduction

Problem-based learning (PBL) is a powerful student-centred educational approach, where learning is based on authentic problems (e.g., Barrows, 2002; Barrows & Tamblyn, 1980; Moust, Bouhuijs, & Schmidt, 2014). E-learning can be defined as "learning facilitated and supported through the use of information and communications technology" (JISC, 2014). E-learning includes a range of technological tools and facilities employed to support or improve the learning process of students, for example to support the learning of specific knowledge and skills, to support communication and group work, and to support assessment and reflection (Donkers, Verstegen, de Leng, & de Jong, 2010). E-learning is widely used to support distance learning and face-to-face learning, but can e-learning also support the learning principles of PBL? Or do some e-learning implementations weaken the PBL principles?

This chapter focuses on how e-learning has been described to support PBL in groups working either face-to-face or online, based on a literature review. After the introduction to important concepts and the research questions in Sect. 2.1, our methods for literature search and data collection are explained in Sect. 2.2. The description of characteristics of the included studies, common ways to support PBL groups, and examples of innovative support are given in Sect. 2.3. The last section of the chapter discusses the limitations of our approach, the conclusions and lessons learnt, including opportunities and challenges of implementing e-learning in PBL settings. The chapter concludes with directions for future research.

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2.1.1 Problem-Based Learning

PBL is based on the assumptions that learning is a constructive, collaborative, contextual, and self-directed process (e.g., Dolmans, De Grave, Wolfhagen, & van der Vleuten, 2005; Mok, 2009). Realistic, complex, and ill-structured problems are used to stimulate learners to actively construct knowledge. Discussions in small groups are an essential part of PBL (e.g., Hmelo-Silver & Barrows, 2008; Ng, Bridges, Law, & Whitehill, 2014). From a cognitive viewpoint these discussions foster learning by helping individual students to activate prior knowledge, to elaborate, and to stimulate the (re)structuring of knowledge (Moust et al., 2014; Moust & De Grave, 2000). From a sociocultural perspective these discussions foster joint negotiation of meaning and collaborative knowledge construction through social interaction (Hmelo-Silver, 2004). Often the PBL process is explicitly structured in steps, for example, the seven steps at Maastricht University (MU 2014) or the problem cycle in dental education in Hong Kong (Bridges, Botelho, Green, & Chau, 2012). In a broader definition also some forms of project-based learning or inquiry learning could be seen as PBL as long as learning is centred around authentic problems and involves learning in small groups.

Positive effects of PBL have been reported on graduation rates and study duration, and on the students' diagnostic reasoning, interpersonal and professional competencies (Schmidt, 2010; Schmidt, van der Molen, te Winkel, & Wijnen, 2009) and on the students' long-term retention of knowledge, problem-solving skills, higher-order thinking skills, self-directed/lifelong learning skills, self-perception, and confidence (Hung, Jonassen, & Liu, 2008).

2.1.2 e-Learning

Meta-studies into e-learning in general found positive, though small effects on student learning (e.g., Bernard, Borokhovski, Schmid, Tamim, & Abrami, 2014; Cook et al., 2010; Cook, Garside, Levinson, Dupras, & Montori, 2010; Schmid et al., 2014; Spanjers et al., 2014). There was a large variability, meaning that some implementations of technology were better than others and that some actually affected student achievement deleteriously. According to Schmid et al. (2014) learning with cognitive support tools involving strategies that include student-centred, dynamic, interactive techniques, appeared to produce larger effect sizes than learning with presentation-type tools.

In the context of PBL the use of multimedia in PBL problems is supposed to provide implicit contextual information, such as visual, auditory, or other nonverbal cues that are absent in paper or oral presentations (Hung et al., 2008). E-learning tools and facilities have also been used to enable distance-based PBL (e.g., De Jong, 2012; Ng et al., 2014; Savin-Baden, 2007). Not all forms of e-learning fit the learning principles of PBL, though. Many e-learning modules, for example, are

based on information delivery and lead all students through the same materials in the same way, which is in contrast with the PBL principles of constructive and self-directed learning. Barrows (2002) also claims that many early online environments seemed to fail to deliver the promise of fostering collaborative learning (Barrows, 2002). To genuinely support PBL, e-learning tools and facilities should support or at least not hinder the PBL principles and processes identified above: activation of prior knowledge, elaboration, structuring, and restructuring of information, collaborative learning, learning in context, and self-directed learning.

2.1.3 Aim and Research Questions

The purpose of the research reported in this chapter is not to prove that e-learning works for PBL, but to get more insight in how e-learning can support PBL groups. More specifically, the aim of this literature review is to inspire teachers who are looking for ways to stimulate and support the PBL process and to provide a framework for future research on e-learning for PBL groups. The research questions are:

1. In which setting is e-learning used to support PBL groups (domain, place in the curriculum, number of students, etc.)?
2. Which reasons are given for the use of e-learning to support PBL groups and how is this evaluated?
3. In which ways is e-learning used to support the PBL principles and processes (i.e., activation of prior knowledge, cognitive elaboration, structuring and restructuring of information, collaborative learning, contextual learning, and self-directed learning)?

2.2 Method

A narrative literature review study has been conducted by a research team consisting of the seven authors of this chapter. Below we first describe the search strategy, selection of search terms, and the procedures for including studies in the review (Sect. 2.1). Then, in Sect. 2.2 we explain how the selected studies were analysed.

2.2.1 Search Strategy

A systematic search has been executed using EBSCO in the databases ERIC, PSYCHINFO/PSYCHARTICLES, CINAHL and MEDLINE.[1] Based on the definitions of PBL and e-learning given above, keywords were searched in the thesauri of the databases, in relevant articles from our own collection, and in a scoping search. For the final search the following search terms were used:

(problem-based learning OR problem based learning)

AND

(e-learning OR elearning OR electronic learning OR web-based OR online OR web-enabled OR blended OR interactive learning environments OR educational game OR serious gaming OR computer-mediated discussion OR computer-mediated communication OR technology-mediated OR technology-enhanced OR computer-supported collaborative learning OR CSCL OR interactive multimedia OR interactive multimedia OR electronic portfolio OR social media OR web 2.0 OR simulation OR simulator)

AND

Peer reviewed

The search period was set between 2005 and 2012. Eight secondary references, encountered when reading selected articles or from our own collection were added.

The first author inspected the abstracts and, when in doubt, full articles taking into account inclusion and exclusion criteria (see Fig. 2.1). Doubtful cases were discussed within the research team and if no clear conclusion could be reached, the articles were included. Included articles were subsequently read fully by at least one of the team members, checking them against the same criteria. If necessary a second opinion was given by a second reader (i.e., the first author, except when she had been the first reader in which case the last author). When articles described the same implementation in the same setting they were regarded as one study. One article was split up because it described two different studies. This resulted in a set of 151 separate studies. These were divided over the seven members of the research team.

2.2.2 Data Collection and Analysis

In order to collect rich descriptive data about the studies, a data collection form was designed, discussed in the team, and tried out in a pilot with a limited number of articles that were read by two team members each. The final form (see Appendix A) included open questions and closed questions (with comment fields):

– 11 questions to collect background information about the place in the curriculum, the domain, the tools that were used, the number of students and teachers

[1] PubMed has not been searched separately because virtually all peer-reviewed journals of PubMed are subsequently tagged with MeSH terms and put into Medline.

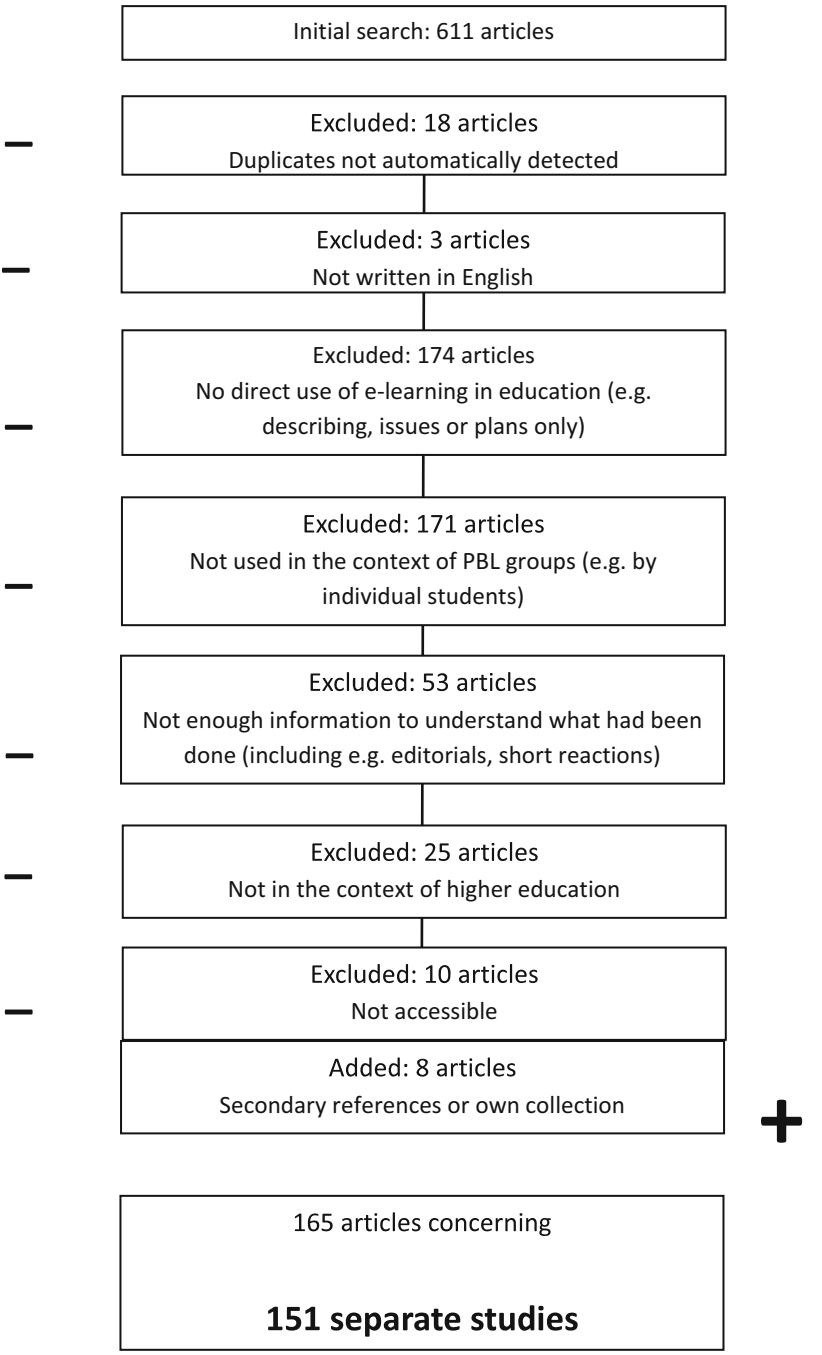

Fig. 2.1 Overview of the selection process

Table 2.1 Type of education

Type of education	Number of studies	Percentage of studies
University education (bachelor-master)	122	81
(Higher) Vocational education	6	4
Post-academic education	14	9
Education for teaching staff	11	7
Blank/other	3	2

Note that some studies concerned more than one type of education

involved, the timing of the e-learning support (before, during, and/or after group collaboration), and the motives for using e-learning.
- 4 questions regarding evaluation of the described use of e-learning, i.e., whether and how evaluation was performed, which kinds of data were collected and what the main results were.
- One question asking to categorize the use of e-learning in terms of the function of tools in the PBL process according to the categories in Table 2.1.[2]
- The reader's opinion about whether the described e-learning did support PBL groups and the option to indicate that an article described a special or innovative use of e-learning to support PBL groups.

For each study a form was filled by one of the team members. Since, the focus of the form was to collect rich descriptive data about the studies, interrater reliability was not calculated. However, to ensure consistency, the team met twice during the reading process to discuss experiences and preliminary results. When all data had been collected the first, second, and last author analysed and described the results regarding background information, the didactical/pedagogical use of e-learning and the implementation and evaluation respectively. These results were then discussed during a final team meeting.

2.3 Results

General characteristics of the selected studies are briefly summarized in Sect. 2.3.1. Subsequently, in Sect. 2.3.2 the focus is on describing the different ways that e-learning was used to support PBL learning principles and processes.

[2]Two other ways to categorize the use of e-learning were included in the form, but subsequently not used for analysis.

2.3.1 Characteristics of the Studies

2.3.1.1 Curriculum, Domain, and Tools

The majority of studies concerned university education, more often with undergraduate students than with graduate students (although this was not always specified). The domain of education was most often medicine or health science, followed by education or teaching, engineering, and science.

Almost half of the studies involved 50 students or less. A minority of studies involved more than 200 students (up to 2000 students). The number of teachers that participated is often not reported. In four studies, no teachers were involved (Table 2.2).

A large number of tools were used. These were classified in the following categories:

- Multimedia, ranging from visual materials to interactive cases/environments
- Simulations and serious games, including e.g., simulators, first-person and multiuser online games
- Tools to communicate and share information synchronously or asynchronously, often embedded in a Learning Management System (LMS) such as Blackboard™, Moodle™, WebCT™ and ClassFronter™ (such as file-sharing, discussion fora, chat, videoconferencing, journals, wikis, blogs, and e-portfolios) but also standalone applications (e.g., plain e-mail or other web 2.0 tools such as Diigo™, Zotero™, or Facebook™)
- Tools to perform specific tasks or produce artefacts (e.g., Matlab™, videocreation tools, 3D-modeling tools, or even hardware such as educational robots)
- Other tools, e.g., notepads or scheduling tools

Most of the tools were existing tools, commercially available or freeware. In a few studies, tools had been developed specifically to support PBL, for example, to guide students through PBL steps or to provide scaffolding, automated feedback, tutoring, or self-assessment. Examples of how tools were used are given in Sect. 2.3.2.

Table 2.2 Number of students involved

Number of students involved	Number of studies	Percentage of studies
50 or less	65	43
51–200	43	28
More than 200	21	14
Unknown	22	15

2.3.1.2 Goal and Evaluation

The reasons given to use e-learning with PBL groups differed across the included studies and they were not always clearly described. When e-learning was aimed explicitly at supporting or improving the PBL process, the following specific goals were mentioned often: enhancing authenticity (mostly in an online setting but also in a face-to-face setting), making PBL and/or learning more attractive (for example by adding competitive elements or a fun factor), increasing flexibility or efficiency, enhancing specific learning skills (such as problem-solving, argumentation, cooperation, self-directed learning, reflection, or critical thinking), or offering automated scaffolding or tutoring.

Often, however, it seemed that the main goal was not to support PBL principles and processes, but, for example to enable distance-based PBL or to introduce PBL as a new learning method replacing more traditional methods. Brodie (2009), for example, describes how e-learning support was used to enable PBL in "virtual teams" for distance-based students, mostly working professionals.

Some of the studies described implementations for specific research purposes, e.g., to compare PBL with other learning methods or to learn more about specific aspects of PBL or learning in general, for example to examine which (synchronous or asynchronous) tools work best in a distributed course (Overbaugh & Casiello, 2008), to compare the quality of videoconferencing discussions with face-to-face discussions (Andres & Akan, 2010; Andres & Shipps, 2010; De Jong & Verstegen, 2009), to compare examining real patients or digital photographs in the field of dermatology (Amri, ELHani, & Alkhateeb, 2012), or to examine how 3D attributes affect social, cognitive, and teaching presence (Omale, Hung, Luetkehans, & Cooke-Plagwitz, 2009).

In the majority of studies (92%) evaluation results were reported. The focus of the evaluation and the kind of data that were presented depended on the reasons for using e-learning with PBL groups. About two-thirds of those studies were descriptive studies or case studies; about one-third (38 studies) had an experimental or quasi-experimental design. Table 2.3 gives an overview of the kind of data that were collected. Descriptive and case studies provided innovative ideas and indications of the potential value of e-learning tools and facilities, but no hard evidence that e-learning did improve PBL principles and processes. Most of the (quasi-)experimental studies are focused on very specific research questions, sometimes not even directly related to PBL (see above). Occasionally, the results of this research can inform the design of online PBL learning. Some researchers have, for instance, found that, when students are asked to work on PBL problems using only text chat, ill-defined problems evoke more interaction than well-defined problems, but that the participation was then more inequitable. It seems that scaffolding in the early stages of exchange is particularly important to stimulate more equal participation (Kapur & Kinzer, 2007; Suebnukarn & Haddawy, 2006; Suebnukarn, Haddawy, & Rhienmora, 2008). Similarly, Thomas and McGregor (2005) reported that computer-mediated communication led to earlier and better communication in high achieving groups, but that low achieving groups did not do so well. Even then, though, the

Table 2.3 Kind of evaluation data reported in the studies

Kind of data	Number of studies	Percentage of studies
Data/experiences about implementation process	8	5
Data about use of an application (e.g., log data)	45	30
Attractivity to students (questionnaires and/or interviews)	100	66
Attractivity to teaching staff (questionnaires and/or interviews)	23	15
Efficiency: use of resources	5	3
Efficiency: involving students (or others) at distance	18	12
Effectivity: learning results	44	29
Effectivity: reducing drop-out	3	2
Other	19	13
Blank/I don't know	17	11

Note that some studies concerned more than one type of education

results are difficult to generalize because of the diversity in settings, domains, target groups of students and tools that are used.

2.3.2 Ways to Use e-Learning to Support PBL

Two ways of supporting PBL principles and processes were more prominently present in the included studies: e-learning to support contextual learning and e-learning to support collaborative learning. This is visible in the results of the categorization in Fig. 2.2 and in the more elaborate descriptions of about the implemented learning activities on the data-collection forms. Below, these themes are discussed and elaborated, using representative examples drawn mostly from the team discussions and from the set of articles that had been marked as special or innovative by team members. Subsequently, in Sect. 2.3.2.3, examples of the other categories are given. Please note that examples are meant to illustrate the different ways of using e-learning to support PBL groups. They are not meant to be exhaustive, nor to be necessarily the best examples.

2.3.2.1 e-Learning to Support Contextual Learning

One way to support contextual learning is to use existing digital tools and facilities that are or could be used on the work floor, also in authentic learning tasks (Table 2.4). In Ellis et al. (2008), for example, students were expected to use professional pharmacy databases during and in between tutorial sessions. Lovell and Baker (2009) described how students produced digital narratives (using video,

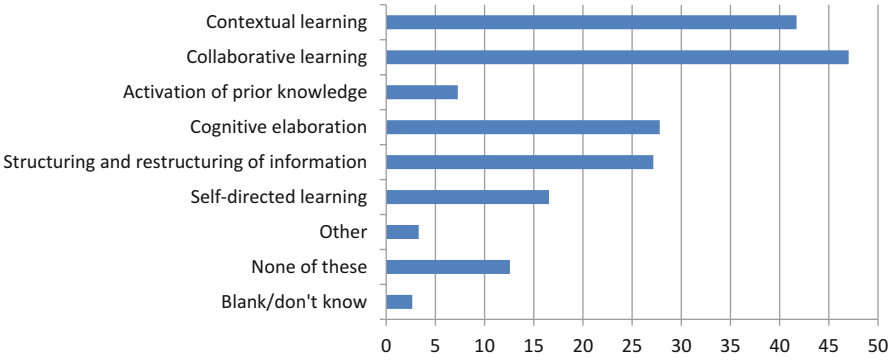

Fig. 2.2 Categorization in terms of support for PBL processes in percentages of the total number of studies (*note*: more than one answer was allowed)

audio, text, animations, etc.) to show what they learned about youth transitions, thus engaging them to relate to their own experiences.

Another frequently used way to support contextual learning is to enhance authenticity by enriching PBL problems with multimedia. Sometimes it was possible to use real digital information, for example X-rays from patients (Bridges et al., 2012). Pulman et al. (2012) described how the impact of illnesses like dementia on all aspects of life was illustrated with a range of resources including podcasts, stories, and poems. In Beadle and Santy (2008) all the PBL problems in a course were presented as taking place in one "virtual" town called Aisling; the town's library contained the learning resources for the students.

Interactive cases allowed students to gather additional information or to explore options, often simulating an authentic role, e.g., with virtual patients, authentic interactive patient cases that allowed students to practice clinical reasoning in a similar way as they would in real life. Virtual patients were sometimes discussed in tutorial group meetings, but also used as self-study material. A range of software tools was used to implement interactive patient cases; some have even been implemented in Second Life (Savin-Baden et al., 2010, 2011).

In a simulation or game, students could take on authentic roles and perform authentic tasks that they would not (yet) be able to perform in real life. Hallinger et al. (2010) replaced the PBL problem with a game for change management that students played in teams of two to four. The aim was to provide an authentic context, but also to give students opportunities for elaboration and restructuring, thus stimulating critical thinking. Sancho et al. (2009) described Nucleo, an environment where students, as avatars, learnt programming in a simulated software design team. In an effort to improve group dynamics, Nucleo assigned roles to students based on their learning style profile. In some studies, high-fidelity simulators were used to integrate skills training in PBL. In Harris et al. (2012), for example, more traditional PBL tutorial group meetings were alternated with sessions with a "Human Patient Simulator" in the simulation centre.

Table 2.4 Different ways to use e-learning to support contextual learning

e-Learning support	Aim	Examples
Using real tools and facilities	Authentic learning tasks	Ellis, Goodyear, Brillant, and Prosser (2008), Lovell and Baker (2009), Stanimirovic and Trifunovic (2011)
Adding multimedia to the PBL problem	Illustrate problem, authentic context	Beadle and Santy (2008), Bridges et al. (2012), Pulman et al. (2012)
Interactive cases	Authentic information gathering and reasoning	Bakrani, Poulton, and Beaumont (2010), Savin-Baden et al. (2010, 2011), Wünschel, Wülker, and Kluba (2009)
Games, simulations, and simulators	Authentic learning tasks, role-playing, realistic interaction	Good, Howland, and Thackray (2008), Hallinger, Lu, and Showanasai (2010), Harris, Ryan, and Rabuck (2012), Liaw et al. (2010), Sancho, Moreno-Ger, Fuentes-Fernández, and Fernández-Manjon (2009), Schiller (2009), Winston and Szarek (2005)
Communication facilities for role players	Authentic role-playing scenarios	Candela et al. (2009), Chen, Li, and Wang (2012), De Nooijer (2013), Edwards (2005), Gwozdek, Klausner, and Kerschbaum (2008), Peterson (2009)

Mediating all communication was used to simulate the way that teams would collaborate in the workplace, thus enabling authentic role-playing scenarios. Chen et al. (2012) described a set-up where students can take on the roles of project manager, (assistant) team leader, or team member. The groups used a wiki to manage team activity, and to share knowledge and information. In each cycle, roles were divided anew, based on performance, peer review, and teacher observations. In Edwards (2005) the role-play also involved communication between PBL groups. In an expert-team approach students in a PBL group all took on a different role in the life of "Laura," a child just placed in custody. The problem case developed week by week, and in between sessions the students that were placed in the same role (in different PBL groups) could discuss with each other using asynchronous communication tools. Staff members were sometimes involved as role players. In Candela et al. (2009), for example, the focus was on developing leadership skills. A website and asynchronous discussion facilities were used to create a virtual nursing school where the students played the role of staff and the teacher played the role of dean. In Gwozdek et al. (2008) dental hygiene students used a blog to interact with a patient played by a staff member. De Nooijer (2013) described how a more advanced 3D virtual environment was used to enable students to take on the authentic role of a consultant and to visit stakeholders in their "offices" in the virtual world. Interaction with stakeholders was partly pre-programmed in "bots," but students could also make appointments for interviews with human role-players. Peterson (2009) involved external tutors from relevant industries to enhance the authenticity of the learning experience.

2.3.2.2 e-Learning to Support Collaborative Learning

Table 2.5 shows examples of how different tools could be used to support e-learning. The most commonly encountered form of supporting collaborative learning was to provide students with tools to communicate in between face-to-face sessions and share resources for self-study, often using discussion boards or wikis and, more recently, other Web 2.0 tools such as Diigo™, Zotero™, or Facebook™ (e.g., Buus, 2012). Sharing information digitally, for example in a wiki, also made everyone's contributions more visible and allowed teachers to react promptly and adequately. Ng and Lai (2012), for example, described how student teachers used wikis to work on problems and produce teaching material for their own students, receiving feedback from peers and course instructors (which led to frequent revisions, as shown by logs). Students were also encouraged to exchange references and other resources that they had found. In practice, however, students often preferred discussing face-to-face or they used other communication tools, such as plain e-mail (Zorko, 2009). Lan et al. (2012) found, however, that mobile access to asynchronous discussions led to more interaction, information sharing, and reflective thinking and to better participation.

Communication tools were also often used to enable PBL in online settings when students and teachers were not (all) at the same place at the same time. Distance-based PBL courses were opened up to, for example, working professionals who were not able or willing to attend face-to-face meetings. For synchronous discussions in online PBL groups videoconferencing or virtual classrooms were used more often in recent years, replacing text-based facilities like chat rooms. With suitable synchronous communication tools online tutorial group sessions could be very similar to face-to-face meetings. De Jong and Verstegen (2009) found that—with motivated participants, good technical facilities, and careful preparation—the quality of the discussions can be equally good in synchronous online PBL sessions. This was, however, not always the case (Van Tilburg, 2014). In a laboratory experiment, Andres and colleagues showed in 2010 that the quality of interaction (and the resulting team productivity) was higher in face-to-face discussions than in synchronous videoconferencing discussions, suggesting that meeting face-to-face may still be preferable if there are no reasons to use online options (see Table 2.5 for references).

Using asynchronous tools for discussions in online PBL groups, such as discussion boards or wikis changed the procedure and the form of discussion. This often led to less interaction between students. Labelling messages was reported to lead to more and more effective communication (Chanlin et al., 2009). Some studies also reported positive effects of asynchronous communication. Beadle and Santy (2008), for example, found that students can be more outspoken and blunt in discussion forums, which in their case was not seen as a disadvantage, because it enabled the teachers to address issues related to social inclusion which was the focus of the course. Hawkes (2006) found that asynchronous communication showed more signs of reflection, although the communication was less interactive compared to face-to-face communication. There were also some indications that less verbal or

Table 2.5 Different ways to use e-learning to support collaborative learning

e-Learning support	Aim	Examples
Communication tools for face-to-face PBL groups	Sharing resources, communication in between face-to-face sessions	Alamro and Schofield (2012), Buus (2012), Lan, Tsai, Yang, and Hung (2012), Ng and Lai (2012), Tambouris et al. (2012), Varga-Atkins, Dangerfield, and Brigden (2010), Zorko (2009)
Communication tools for online PBL groups	Synchronous or asynchronous discussions within PBL groups	Anderson, Mitchell, and Osgood (2008), Andres and Akan (2010), Andres and Shipps (2010), Beadle and Santy (2008), Bozic and Williams (2011), Chagas, Faria, Mourato, Pereira, and Santos (2012), Chanlin, Chen, and Chan (2009), De Jong and Verstegen (2009), Hawkes (2006), Pack (2010), Rienties et al. (2012), Tseng, Chang, and Lou (2012), Tseng, Chiang, and Hsu (2008). Van Tilburg (2014), Yeh (2010), Zhu, Valcke, and Schellens (2009)
Communication tools for mixed groups	Collaborative learning with students from different institutions, countries, professions, etc.	Annerstedt, Garza, Huang-DeVoss, Lindh, and Rydmark (2010), Brodie (2009), Ioannou, Brown, Hannafin, and Boyer (2009), Miers et al. (2007), Nerantzi (2012)
Combination of tools, specifically developed/ composed for PBL	Guiding the PBL process in explicitly structured interactions or steps	Garcia-Robles, Diaz-del-Rio, Vicente-Diaz, and Linares-Barranco (2009), King et al. (2010), Rienties et al. (2012)
		STELLAR: Jeong and Hmelo-Silver (2010), Hmelo-Silver, Chernobilsky, and Jordan (2008), Hmelo-Silver, Derry, Bitterman, and Hatrak (2009), Derry, Hmelo-Silver, Nagarajan, Chernobilsky, and Beitzel (2006)

less extraverted students may communicate more freely online (De Jong & Verstegen, 2009; Tseng et al., 2012). In a study by Zhu et al. (2009) Asian students were less positive about participating in online PBL discussions than Western-European students, but it did have a positive impact on their motivation and learning strategies.

Using distance-based PBL groups allows students from different institutions to learn together, either between groups or within groups. In the GlobalEd project, for example, groups of students were assigned to represent a real-world country. After a period of preparation where they learned about the country they represented, they negotiated a treaty on a real-world political issue with at least one other group from another country (Ioannou et al., 2009). Nerantzi (2012) described a small-scale study where ten participants from seven different institutions worked in two PBL groups for using Web 2.0 tools. She found that participants valued working in

online, multidisciplinary groups, although they missed face-to-face contacts and reported some problems around structuring the communication using new tools.

Finally, in some studies combinations of communication tools were used to organize the PBL process into explicitly structured "scripted" interaction. The Stellar platform (Jeong & Hmelo-Silver, 2010, see Table 2.5 for more references) offered a set of video cases and online learning resources and supports a set-up where the PBL process is organized in eight steps, which were partly online, e.g., studying video cases, research and design activities, and partly face-to-face, e.g., discussions and presentations. Some of the online activities were individual and others were collaborative. The explicitly scripted interaction was meant to function like scaffolding for students. It was also used to make it possible for tutors to facilitate several groups of students at the same time. Another example was described by King et al. (2010) where interdisciplinary groups engaged in PBL at a distance using a virtual classroom with videoconferencing and shared whiteboard facilities, amongst others. Their set-up included the participation of (human) standardized patients and a combination of large group and small group activities in break-out rooms. They found that this use of technology created novel forms of interaction, but there were quite some technical issues as well. Garcia-Robles et al. (2009) described a blended learning format where (small) PBL groups worked on problems without a tutor; only the chairpersons interacted with the facilitator and the other chairpersons using different communication tools in the Virtual Learning Environment (VLE). Rienties et al. (2012) compared two conditions of online asynchronous PBL where one condition was more explicitly structured. Although one would, in general, expect this to improve the discussion, Rienties found that this is not always the case and that it is much influenced by student characteristics, such as autonomy and motivation. The structured design triggered more equal levels of activity of autonomous and control-oriented learners, but also a decrease in input from the autonomous learners.

2.3.2.3 Other Functions of e-Learning in PBL Groups

Studies focusing exclusively on supporting only one of the PBL processes were relatively rare. The other categories (activation of prior knowledge, cognitive elaboration, structuring and restructuring of information, and self-directed learning) were seen more often in combination with the two largest categories described above. Stimulating cognitive elaboration was often claimed to be a side effect of computer-mediated communication. Lu, Lajoie, and Wiseman (2010), for example, claimed that a shared workspace on an interactive whiteboard supported the discussions during face-to-face sessions and Yeh (2010) claimed an online learning and working environment makes the collaboration explicit and facilitates a community of practice. Yet, not all studies reported positive effects of computer-mediated communication on cognitive elaboration. Owens, Dearnley, Plews, and Greasley (2010), for example, reported that experienced status differences and rivalry might have

influenced the learning process in a negative way. The effects seemed to be moderated by group composition and dynamics.

In a few studies facilitating elaboration during PBL group sessions was the main focus. Lan, Sung, Tan, Lin, and Chang (2010) gave an example of how mobile devices were used to make notes and share them during face-to-face discussions. Mok, Whitehill, and Dodd (2008) argued that mind mapping and concept mapping techniques are suitable to support PBL. Indeed, mapping tools have been used, sometimes in combination with interactive whiteboards, to visualize concepts and explicitly structure group discussions. Verstegen and Roebertsen (2013) used mapping tools both in the brainstorming phase, to collectively activate and structure prior knowledge, and in the reporting phase to synthesize and integrate newly found knowledge. The advantage of digital mind and concept maps is that they can be easily shared between members of a PBL group. Thus, mind maps that were made collectively during a brainstorm discussion could be used to provide directions for self-study; and concept maps made individually during self-study could be used as an advance organizer for reporting sessions (e.g., Bridges, Botelho, & Tsang, 2010; Bridges, Dyson, & Corbet, 2009). Fonteijn (2015) used concept mapping tools with the additional goal to allow one tutor to guide several PBL groups simultaneously.

Similarly, a side effect of mediating communication between PBL group members may be that the structuring of information and/or cognitive elaboration is stimulated, for example by using specific formats or protocols, or by using visualization tools. However, only in a few studies this was an explicit goal. Chang et al. (2012) described how students used MobiTOP, a mobile tool that helped them to collect geographical data in a systematic way during field trips. In the context of PBL this could be seen as a scaffold to stimulate structuring information and elaboration. Stewart, MacIntyre, Galea, and Steel (2007) described the use of FRAP, a tool that was used in a PBL group (without tutor) to track investigative pathways, results, and reflections in a series of nodes. This track was used later by tutors/mentors to check what had been done and discussed. Kazi, Haddawy, and Suebnukarn (2009) described their efforts to let an Intelligent Tutoring System automatically check the causal graphs of a PBL (medical) case created by students, thus assessing the quality of the students' discussion.

Implicitly, some of the e-learning implementations may also enhance ownership or self-directed learning, for example by sharing resources in a VLE or wiki. Rossiter, Petrulis, and Biggs (2010) introduced online quizzes to support self-study so that students would come to the face-to-face discussions better prepared. Other efforts to support PBL groups by supporting the self-study period may exist, but were not found in this review study (see Sect. 2.4.3).

2.4 Discussion

The aim of the literature study reported in this chapter was to gain further insights into how e-learning can support PBL groups, to inspire teachers, and to provide a framework for future research on e-learning for PBL groups. The research questions for this literature review were:

1. In which setting is e-learning used to support PBL groups?
2. Which reasons are given for the use of e-learning to support PBL groups and how is this evaluated?
3. In which ways is e-learning used to support the PBL principles and processes (i.e., activation of prior knowledge, cognitive elaboration, structuring and restructuring of information, collaborative learning, contextual learning, and self-directed learning)?

After discussing the limitations of this study in Sect. 2.4.1, discussion of the research questions will be provided in Sect. 2.4.2, followed by directions for future research in Sect. 2.4.3.

2.4.1 Limitations of This Literature Review Study

A recurring discussion point in the research team was the term PBL. What should be considered PBL and what not? The descriptions in the articles did not always give much detail and that made it hard to make decisions on inclusion or exclusion. The decisions of different team members were not always completely consistent and this had to be resolved in the group discussions. Given the exploratory nature of this review study, focusing on getting an overview of how PBL groups are supported, this was considered acceptable. Naturally, the search strategy and search terms that were used in this literature study limited the studies that were considered. Some interesting and innovative applications of e-learning were excluded because they were not (yet) used in PBL groups, for example the Idea Storming Cube which can be used as a game in a group to stimulate a brainstorm: participants are first asked to brainstorm individually and then to react to the brainstorm results of others (Huang, Yeh, Li, & Chang, 2010); or only used in primary or secondary education, for example, Connection Log, a computer-based scaffold that is designed to structure the individual and group activities and to help students to construct arguments explicitly (Belland, 2010). We may also have missed e-learning that supports and stimulates students to better prepare for PBL group meetings during their self-study time. Some articles described guidelines or general experiences but not one specific application of e-learning and were, therefore, also excluded.

2.4.2 Using e-Learning to Support PBL Groups

The results show that studies regarding the use of e-learning with PBL groups in higher education mainly took place in the domains of medicine and health science, education and teaching, engineering, and science, presumably because this is where PBL is most often applied. In about half of the studies relatively small groups of students were involved (i.e., 50 or less), but there were also large studies involving up to 2000 students. A wide variety of e-learning tools and facilities were used, mostly existing tools that were not specifically developed to support principles and processes underlying PBL.

The main goal of the studies was not always to improve student learning. Often, for example, the reason to use e-learning was to enable PBL in distance learning or to do research regarding specific aspects of learning. The majority of the studies provided evaluation data, quite often in the form of log data or opinions of students. Even when quantitative data regarding learning results or efficiency were given, these were hard to generalize, given the diversity of implementations and settings. Similar interventions can have positive effects in one case and negative effects in another.

The studies in this literature review provided insight in how e-learning was used to support PBL processes and principles. Two aspects were supported most explicitly: contextual learning and collaborative learning. Contextual learning was stimulated by illustrating PBL problems with multimedia that show the context, but also by enabling students to execute authentic learning tasks, taking on authentic roles so that they learn and apply new knowledge in an environment that is similar to their (potential) future workplace, sometimes also using real or simulated equipment. Applications of e-learning made it possible to offer students (immersive) learning experiences in a safe and controlled environment that would not be possible otherwise. Integration between theory and practice was further stimulated in some studies where students could study problem cases and practice-related skills together in a virtual environment.

Some e-learning tools had been specifically developed to guide and improve collaborative learning by explicitly structuring the interaction between students in a group and between students and teachers. This was a way to support (inexperienced) PBL students and tutors, but also led to novel forms of interaction. More often, however, existing communication tools were used to support collaborative learning, to share resources or communicate in between face-to-face sessions or to enable online PBL. When face-to-face discussions are difficult to arrange online synchronous discussions can—when carefully organized—be acceptable replacements. Online discussions can help to enrich the learning experience, for example when it is possible to organize interprofessional learning or to involve real stakeholders (or role-players) like domain experts, patients, or customers in the PBL discussions.

2.4.3 Risks of Applying e-Learning in PBL Groups

PBL is a coherent educational approach. Various factors and underlying principles seem to influence each other in subtle and expected ways. Changes in one element can seriously damage other elements and have a negative impact on student learning (Barrows, 2002). Some salient risks observed during this literature study are:

- Technical problems: e-learning tools did not work as intended or not at all.
- Tools changing communication in a negative way, e.g., in some asynchronous discussion tools it is difficult to follow the thread of the conversation.
- Tools taking too much time and attention: even if tools work well they may become a distraction, cause cognitive overload, or learning to use them may take valuable time and attention away from PBL discussions.
- Offering digital learning resources for self-directed learning becomes prescribing the same resources to all students, which leads to poorer discussions.
- Proceduralising PBL: prescribing a sequence of interaction forms in detail may lead to a teacher-led, directive processes rather than student-centred learning.

Furthermore, we noted during the selection of studies that in a number of studies the introduction of e-learning had led to PBL being changed into students solving problems individually with a computer rather collaborative small-group learning.[3]

2.4.4 Future Directions

In this literature study, there are only a few examples of e-learning used to stimulate cognitive elaboration and the structuring and restructuring of information. This is surprising since the lack of "deeper" discussion and the skipping of vital steps in cognitive elaboration are reported as potential problems in PBL groups (e.g., Dolmans, Wolfhagen, van der Vleuten, & Wijnen, 2001; Moust, Berkel, & Schmidt, 2005). Although supporting these processes was claimed to be a side effect of using communication tools such as discussion fora or wikis, the experiences seem to be mixed. Our own experience is that such online communication tools are hardly used when face-to-face meetings are relatively close in time. More promising for future research seem to be tools to stimulate brainstorming, tools to (visually or otherwise) structure information, argumentation tools or other tools to stimulate critical thinking. It is, however, not clear yet how these tools can be optimally used in face-to-face and online settings. It would also be interesting to investigate whether the combination of verbal and nonverbal interactions could stimulate shy or less verbal students to contribute more to the group discussions or could support intercultural PBL groups. Lajoie et al. (2014), for example, explore how online PBL can support

[3] These studies were subsequently excluded because this was one of the exclusion criteria.

intercultural learning facilitating a mixed group of students from Canada and Hong Kong learning about giving bad news to patients from different cultures. It would also be worthwhile to study the limits of structuring interactions, as Dillenbourg (2002) claims that scripting does not always lead to the expected results and over-scripting may have disadvantages too, e.g., disturbing natural interactions or increasing cognitive load.

Almost all studies in our sample describe applications of e-learning at the micro-level of supporting PBL groups in one activity or one course at the most. This may explain why we have found very little about supporting self-directed learning, a competence that develops over a longer period of time. Our search strategy may have led to exclusion of some studies in this area (see above). It also seems likely, though, that self-directed learning is still a "black box," i.e., both teachers and researchers have little insight in what students do and how this works (Bridges et al., 2012). It is a challenge for instructional designers, teachers, and researchers to start thinking about e-learning to support PBL at the curriculum level, to employ different forms of e-learning at different moments in time in order to provide extra scaffolds for PBL group meetings and self-study early on and to help students gradually develop self-directed learning skills up to a level where they can function in PBL groups with less tutor support.

A number of papers used e-learning to be able to collect data for educational research. The use of computers makes it easier to collect group discussions, to register student activity, and so on. Although recommendations were given for improvement based on the analysis of these data, continuous monitoring and analysis of such data would allow PBL to be constantly improved and adapted to the needs of the groups. Within the learning analytics community, the areas of social learning analytics (Shum & Ferguson, 2012) as well as dispositional learning analytics (Shum & Crick, 2012) might be relevant starting points for PBL applications.

2.5 Conclusions

E-learning is used to support PBL with different goals, not only to improve student learning, but also to enable PBL in distance learning or for research purposes. From the literature review above, it was evident that a wide variety of e-learning tools and facilities are being used in PBL. These are often adaptations of existing tools used to support contextual and/or collaborative learning. Some e-learning tools have been specifically developed to guide and improve collaborative learning in PBL by explicitly structuring the interaction between students in a group and between students and teachers. The review also yielded examples of how e-learning tools and facilities can be used to stimulate cognitive elaboration and the (re)structuring of information, thus helping to counteract known bottlenecks in PBL such as superficial discussions in tutorial groups or "PBL fatigue" resulting in the skipping of vital steps. Other areas indicating growth potential are learning analytics and the support

of self-directed learning, but this would require a longitudinal approach supporting the development of students over a longer period of time.

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