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Children's Emotions in Design-Based Learning: a Systematic Review

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Abstract

Design-based learning (DBL) is gaining increasing acceptance as a motivating and practical approach that can be used to prepare young people for the challenges of the twenty-first century. Emotions are known to influence a student's academic performance in traditional learning, which raises the question as to what role emotions can play in DBL. This article presents a systematic survey of literature published in the last 20 years (searching from 1998 to 2019) and indexed in the Scopus, ERIC, and PsycINFO databases which contribute to our understanding of children's emotions in DBL. This review coded a total of 34 papers that met the inclusion criteria. Findings that reported on children's emotions are structured under three themes: (1) the affective DBL components, (2) the labeled emotions, and (3) the impact of emotions in DBL. Based on this evidence, we make recommendations for future research and compile a set of guidelines for designing DBL activities, taking into account students' emotions that can aid their learning.

Keywords Emotion · Design-based learning · Child · Learning activity · Students

Introduction

In the 1960s, Papert introduced the notion of constructionist learning, advocating technological design as an effective and motivating approach to learning. Within this intellectual tradition, Resnick and Ocko argued that design activities have the greatest educational value when students have the freedom to create things that are meaningful to themselves or others around them (Resnick and Ocko 1990). Resnick and Ocko illustrated an approach which they termed "learning through design" with learning projects, in which LEGO/Logo-based design activities help introduce a variety of mathematical or scientific concepts (Resnick and Ocko 1990). Implementing this vision, they developed the Clubhouse learning environment, which contained a variety of design tools, e.g., Kid Pix, Director, MicroWorlds Logo, and LEGO (Resnick and Rusk 1996). Numerous researchers have since used LEGO/Logo kits to apply the principles of learning through design and constructionism, mainly designed to enhance Science, Technology, Engineering, and Mathematics (STEM) learning (e.g., Barak and Doppelt 1999; Doppelt and Barak 2002; Hendricks and Fasse 2012). Following the same constructionist principles, others have developed their own child-friendly programming-based learning environments (e.g., Buechley et al. 2008; Giannakos and Jaccheri 2013; Giannakos et al. 2014).

Two decades ago, Kolodner presented a set of guidelines for "learning by design" based on case-based reasoning and problem-based learning (Kolodner et al. 2001). The typical sequence of activities in a learning by design unit involves students encountering a design challenge and attempting to arrive at a solution individually and in small groups, where they use only prior knowledge (Kolodner et al. 2001). Kolodner and her colleagues implemented the "learning by design" approach in a series of science education projects for secondary school children (grades 6 to 8) between 1995 and 2004, demonstrating its efficacy for learning science content and developing skills (Kolodner 2002a, b; Kolodner et al. 2003).

The notion of "design-based learning" (DBL) has been emphasized in several empirical investigations, targeting K-12 education from 1969 to date (e.g., Nelson 2004; Rosa 2016). Nelson (2004) reported that overall, after participating in a DBL intervention (e.g., English language and literature learning), low-achieving students made leaps of 10 to 20% in

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their test scores. However, it is not always clear what the test scores in this study assessed. Some studies evaluated DBL (e.g., Apedoe et al. 2008; Mehalik et al. 2008), targeting STEM subjects and demonstrating that students using the DBL units gained significant knowledge in terms of science conceptions. More specifically, Mehalik et al. (2008) reported that, compared to an existing scripted inquiry curriculum (which provides step-by-step instructions for student's investigation), students in DBL achieved twice pre-post knowledge gains in science content.

Furthermore, all these learning approaches which are designed to actively solve ill-structured problems, which are similar to problem-based learning, are seen as potentially suitable for preparing young students for life-long learning (Hmelo-Silver 2004). In short, these learning approaches, which are described as design-based learning, learning by design, or learning through design, are attracting growing attention and have already been demonstrated to be beneficial for students. We refer to these approaches collectively as DBL in the rest of this paper, emphasizing their similarities, rather than various subtle differences between them.

Beyond any specific learning approach, an essential aspect of learning related to emotions. One view is that emotion helps students persevere, sustains motivation, and directs their behavior (Coan and Allen 2007). Similarly, Skinner et al. (2014) argued that emotions play a vital role in organizing students' efforts and their commitment to academic work. Emotions also influence students' coping and persistence in the face of obstacles and setbacks (Skinner et al. 2014). Furthermore, it has been suggested that emotion is a vital variable that impacts how and what students learn. For instance, earlier research has demonstrated that mood can affect the cognitive evaluation of events or memories (Jenkins and Oatley 1996). Moreover, emotion can actually trigger the recall of memories, consistently across contexts, depending on past similar learning experiences (Efklides and Volet 2005).

When it comes to children, the tension between DBL and their emotions experienced in such an environment is particularly relevant and not only because of the effect of emotions on learning. It is also because the DBL approach seems to help these younger students in learning how to gain knowledge and skills independently, which is a crucial preparation for their future, when they will need to keep acquiring skills and knowledge throughout their careers. Another expected benefit from DBL is developmental, as students can learn to master their emotions, empathizing and cooperating with others, and gain the ability to strike a balance between personal and group goals through conflict management (Koh et al. 2015).

Despite such observations, researchers have not yet focused their studies on the role of emotions in a DBL context. In order to investigate this critical issue, we carried out a systematic literature survey with the following aims:

- Aim 1: To understand the current situation as described in the literature (see Table 3 and the "Results").
- Aim 2: To understand the affective DBL components which influenced students' emotions (see the "Results").
- Aim 3: To provide an overview of what and how emotions were measured in a DBL context (see Tables 4, 5, 6, 7, and 8 and the "Results").
- Aim 4: To understand the impact of emotions on students' participation in DBL (see Fig. 2 and the "Results").
- Aim 5: To articulate implications for designing DBL activities, taking into account children's emotions that may support their learning (see Table 9 in the "Discussion") and make recommendations for further related research (see the "Discussion").

In this review, we include all participants who are either elementary, middle, or high school students, collectively using the label children.

Background

Design-Based Learning

Design-based learning (DBL), learning by design, and learning through design are related approaches to learning that apply the tenets of design thinking (Rowe 1987) in a problem or project-based learning context. In general, DBL involves open exploration, learning from trial and error, reflection, teamwork, and supportive tools (Zhang et al. 2018).

Not all papers found within the structured literature search focus explicitly on DBL, and thus, they do not all mention it as such. Some studies (e.g., Apedoe et al. 2008; Doppelt and Schunn 2008; Reynolds et al. 2009; Bagiati et al. 2010; Carroll et al. 2010; Guo et al. 2016; Lacy 2016; Guo et al. 2017; Neve and Keith-Marsoun 2017; Zhang et al. 2018, 2019) did mention DBL explicitly. While others (Chu et al. 2017; Vongkulluksn et al. 2018; Chan and Holbert 2019) mentioned makerspace and maker activities that suggest a specific type of DBL, emphasizing the essence of making in constructive learning. Four studies (Marks 2017; Tae 2017; Marks and Chase 2019; Phusavat et al. 2019) explained that their cases include embedded design thinking in learning activities. Five studies (Karahoca et al. 2011; Nix et al. 2014; Milam et al. 2016; Penuel et al. 2016; Hugerat 2016) presented a design project for learning STEM, while one study presented a series of design projects for learning literacy (Menzies et al. 2016). More specifically, four studies described an Arduino-based programming activity (Buechley et al. 2008; Giannakos and Jaccheri 2013; Giannakos et al. 2014; Sáez-López and Sevillano-García 2017), while another five studies (Barak and Doppelt 1999; Doppelt and Barak 2002; Doppelt 2003; Hendricks and Fasse 2012; Li et al.

2018) described a LEGO/Logo-based design activity. These activities are relatively constructive and include many of the characteristics stipulated in the definition of DBL. One study (Bagiati et al. 2010) mentioned DBL, but did not provide enough detail to allow readers to evaluate the extent to which it actually implements a DBL approach. Another (Council 2018) positioned its learning context as project-based learning and described some features that share many characteristics that are analogous to DBL.

The DBL interventions in the studies reviewed use slightly different terminologies. Therefore, in this review, we introduce a set of criteria that characterize DBL approaches, building on earlier definitions of DBL (e.g., Davis et al. 1997; Kolodner et al. 2001; Doppelt et al. 2008; Mehalik et al. 2008; Doppelt 2009; Gerber et al. 2012; Kim et al. 2015; Chen and Chiu 2016) and related frameworks of DBL (e.g., Puente et al. 2013; Bekker et al. 2015). In addition, the structure of these characteristics refers to a general structure of the learning activity framework proposed by Van den Akker et al. (2010), classifying these characteristics by whether they refer to the learning activity, the teacher, or the grouping of children. In Table 1, we present the papers resulting from this survey in terms of the characteristics of DBL, given that publications reporting experiences with DBL are not always clear about which elements of DBL they implemented.

Learning Activity Characteristics

- The learning activity is *open-ended*, giving both teachers and students enough flexibility for teaching and learning. It should be *authentic*, giving students real-life scenarios for positioning the design challenge and arriving at a solution.
- The activity should be *multidisciplinary*, enabling students to learn and connect multidisciplinary knowledge and skills.
- The activity should involve the *design process/skills*, enabling students to acquire new knowledge and skills.

Characteristics of the Teacher's Role

- The teacher acts as a *coach*, enabling the student to make the transition from a passive to an active learner.

Characteristics of Materials and Resources

- The learning activity involves *hands-on* techniques, tools, and materials for prototyping or testing.
- The learning activity also involves *minds-on* tools and materials for design documentation and visualization during the empathizing, ideating, or defining phases.

Grouping Characteristics

- The social environment should be student-centered, fostering a *sense of responsibility* in students whenever they perform tasks individually or in a small group
- The social interaction should enable co-creation where the student can communicate and collaborate with peers and even with stakeholders.

Learning and Emotion

The term "emotion" can have various meanings when considered from different theoretical perspectives. From the Darwinian perspective, emotions (e.g., in the research by Ekman and others on the universality of facial expression of emotions) are part of our evolutionary heritage (Cornelius 1996). From the Jamesian perspective, bodily changes evoke the feeling state of emotion (Friedman 2010). From the cognitive perspective, emotions are seen as responses to cognitive processing (e.g., reasoning, memory, and attention) and they are associated with a person's motivation (Oatley and Johnson-Laird 2014). The social constructivist perspective describes emotions as socially constituted syndromes or transitory social roles (Averill 1980). Across these different perspectives, terms such as *feeling*, *mood*, *affect*, or *affective response* are generally considered akin to emotion (Davidson et al. 2003; Hascher 2010).

A variety of theories and models relate to emotions in learning. The control-value theory (Pekrun et al. 2002) provides a social-cognitive perspective on students' and teachers' academic emotions, integrating assumptions of attribution and expectancy-value approaches (Schutz and Pekrun 2007). Based on the proposition that emotions and appraisals play a prominent role in self-regulation theory, the dual processing self-regulation model (Boekaerts 2007) highlights two self-regulatory pathways of emotions and appraisals. The affective model of emotions and learning (Kort et al. 2001) describes three interwoven dimensions, namely, emotions, learning, and knowledge.

This review encompasses diverse theoretical perspectives on emotions in order to classify and synthesize disparate studies. Despite noting the critical connection between learning and emotion, learning has been analyzed primarily in terms of cognitive or motivational aspects (Hascher 2010). This review focuses on the cognitive, motivational, and also the social aspects of learning, considering the unique characteristics of DBL, e.g., active learning through the design process, through a teacher's coaching, and through collaborating with peers.

Table 1 Checklist of DBL criteria applied to selected studies

Study	Learning activity				Teacher Role	Materials and resource		Grouping	
	Open-end	Auth	Mult	Design process	Coaching	Hands-on	Minds-on	Student-centered	Co-creation
Apedoe (2008)	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Bagiati et al. (2010)	N/A	N/A	N/A	N/A	Y	N/A	N/A	N/A	N/A
Barak and Doppelt (1999)	Y	N/A	N/A	Y	N/A	Y	Y	N/A	Y
Buechley (2008)	Y	Y	Y	Y	Y	Y	N/A	Y	N
Carroll (2010)	Y	Y	Y	Y	Y	Y	Y	Y	Y
Chan and Holbert (2019)	N/A	N/A	N/A	Y	N/A	Y	Y	N/A	Y
Chu (2017)	N/A	Y	N/A	N/A	Y	Y	N/A	Y	N/A
Council (2018)	Y	Y	Y	N/A	Y	Y	N/A	Y	Y
Doppelt (2003)	Y	Y	Y	Y	N/A	Y	N/A	N/A	N/A
Doppelt and Barak (2002)	Y	Y	N/A	Y	N/A	Y	Y	Y	N/A
Doppelt (2008)	N/A	Y	Y	Y	N/A	Y	Y	Y	N/A
Giannakos and Jaccheri (2013)	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Giannakos (2014)	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Guo (2016)	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Guo (2017)	N/A	N/A	Y	Y	N/A	Y	Y	N/A	N/A
Hendricks and Fasse (2012)	Y	Y	Y	Y	N/A	Y	Y	N/A	Y
Hugerat (2016)	N/A	N/A	N/A	Y	Y	N/A	N/A	Y	Y
Karahoca (2011)	N/A	Y	Y	Y	Y	Y	Y	Y	Y
Lacy (2016)	Y	N/A	Y	Y	N/A	Y	Y	N/A	N/A
Li (2018)	N/A	Y	N/A	N/A	N/A	Y	N/A	Y	N/A
Marks (2017)	Y	Y	N/A	Y	Y	Y	Y	Y	Y
Marks and Chase (2019)	Y	Y	N/A	Y	Y	Y	Y	Y	Y
Menzies (2016)	Y	Y	Y	N/A	N/A	N/A	N/A	Y	Y
Milam (2016)	Y	Y	Y	Y	N/A	N/A	N/A	N/A	Y
Neve and Keith-Marsoun (2017)	N/A	N/A	Y	Y	N/A	Y	Y	N/A	Y
Nix (2014)	N/A	N/A	Y	Y	N/A	Y	N/A	N/A	Y
Penuel (2016)	Y	Y	Y	N/A	Y	N/A	N/A	N/A	N/A
Phusavat (2019)	Y	Y	N/A	Y	Y	N/A	N/A	Y	Y
Reynolds (2009)	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A	N/A
Sáez-López and Sevillano-García (2017)	Y	Y	Y	Y	N/A	Y	Y	Y	N/A
Tae (2017)	N/A	Y	Y	Y	N/A	Y	N/A	N/A	N/A
Vongkulluksn (2018)	Y	Y	Y	Y	Y	Y	N/A	Y	Y
Zhang (2018)	Y	Y	Y	Y	Y	Y	Y	Y	Y
Zhang (2019)	Y	Y	N/A	Y	N/A	Y	N/A	N/A	Y

Annotation: *Auth* authentic, *Mult* multidisciplinary

Related Studies

Puente et al. (2013) have surveyed crucial DBL characteristics in higher engineering education, contributing a deeper theoretical understanding of the DBL approach. Another study (Loderer et al. 2018) contributed to the relationships between emotions and their antecedents and outcomes in the context of a technology-based learning environment. Moreover, Davies et al. (2013) presented a survey on creative learning environments in education, contributing critical characteristics of the creative learning environment and valuable recommendations for policy, practice, and research internationally.

Two key differences between our literature survey and the studies referred to above ensure the unique contributions of this work: (1) this is the first literature review in terms of DBL in the context of K-12 and (2) this is the first literature review to reveal students' emotions in DBL.

Method

Literature Search Strategy

We carried out a systematic literature review following the approach taken by Kitchenham (2004) that covered papers written in English and published between January 1998 and December 2019. The search took place on the Scopus, ERIC, and PsycINFO databases. The general search strategy, which involved searching for title, abstract, and keywords (or headword on the PsycINFO database), including strings and combinations of keywords, is shown in Table 2.

Study Selection Process

The selection process followed the steps outlined in the PRISMA guidelines (Moher et al. 2009), as shown in Fig. 1. Through Scopus, ERIC, and PsycINFO databases, 568 results were identified using search strategies, while additional papers ($n = 4$) were identified from other sources. All duplicate records were removed, including records in the form of entire conference proceedings. Eventually, this review included 34 papers after title and abstract screening, full-text analyzing, and rolling back to relevant studies in the reference of selected papers. Two coders evaluated 66 full-text papers for eligibility (57 papers in the phase of assessing full text and nine additional papers in an antecedent search by checking the reference lists of selected papers while applying the inclusion criteria). The coder's inter-reliability had a Cohen kappa value of 0.841—conventionally, Cohen's kappa is considered very satisfactory above 0.80 (Landis and Koch 1977).

Exclusion Criteria

(a) Medical-related CONTEXT: The record is excluded if the positioning of the study is in a medical-related context (e.g., medical/veterinary/dental/nursing/healthcare/psychosis context).
(b) Adult GROUP: The record is excluded if only an adult student or a teacher is studied.
(c) No design-related TASK: The record is excluded if the activity in the study is not a design-related task. This refers to cases which do not make use of design skills and do not involve following a design process, e.g., a case study involving students in an educational game.
(d) No learning TASK: The record is excluded if the task described in the study is not designed for learning purposes, e.g., a user study of developing and evaluating a design intervention.
(e) Not focusing on emotion (RESEARCH ASPECT): The record is excluded if emotions are not studied or measured.

Inclusion Criteria

(f) A study was included if it reports on learner's emotions (subjective experience tagged with affective, motivational feelings, or perceptions) in the DBL context for students in primary, middle, or high schools.

Data Extraction Process

The data were extracted according to a predetermined template, including (1) the DBL components, (2) the labeled emotions, and (3) the impact of emotion in DBL.

DBL Component Extraction

Regarding the DBL components, this paper characterizes the various DBL interventions described in the papers that were surveyed in terms of the components in the learning activity development framework proposed by Van den Akker et al. (2010). According to this framework, the components should include the following aspects:

- Aims and objective (what learning goals do they pursue?),
- Assessment (how is their learning assessed?),
- Time (when are they learning?),
- Location (where are they learning?),
- Content (what are they learning?),
- Learning activity (how are they learning?),
- Teacher role (how is the teacher facilitating their learning?),
- Grouping (with whom are they learning?),

Table 2 Literature search strategy

Keywords	The strings and combinations of keywords
DBL(-alike) activity	("Design based learning" OR "learning by design" OR "Learning Through Design" OR "design thinking" OR "designerly thinking" OR "designerly knowing" OR "design epistemology" OR "project based learning" OR "problem based learning") AND
Emotion	("emotion*" OR "feeling*" OR "mood*" OR "affect*") AND
Children	("child*" OR "pupil*" OR "school*")

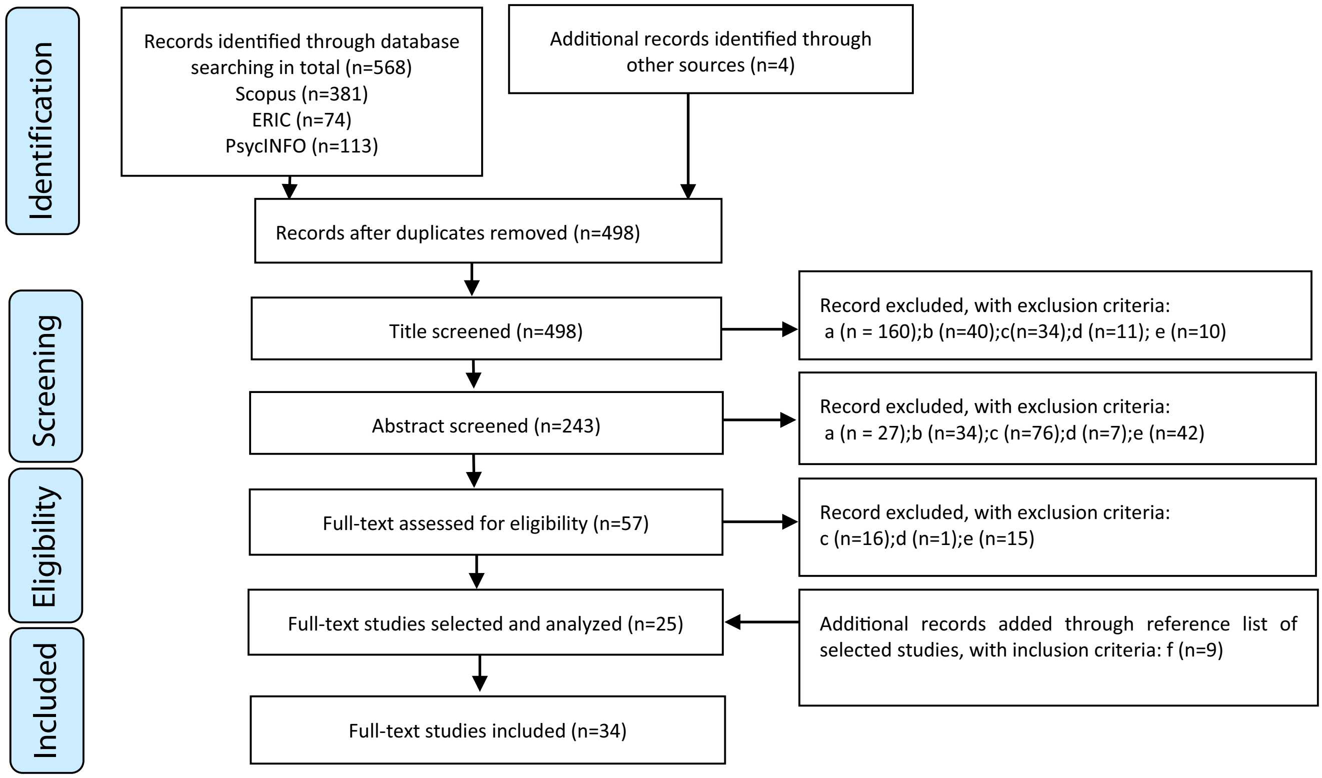

Fig. 1 PRISMA flow chart of study selection process

- Material and resources (with what are they learning?),
- Rationale (why are they learning?).

This paper reports on the DBL components which influenced students' emotions in the studies reviewed (as seen in the "Results" for the relevant DBL components). In the "Discussion", this paper proposes a set of guidelines with implications for researchers and practitioners designing DBL from the perspective of DBL components.

Labeled Emotion Extraction

This paper classifies related studies in terms of the four categories of academic emotions in the classification scheme devised by Pekrun (2014). This categorization was preferred because these emotions within academic settings are especially relevant for student's cognitive, motivational, and social aspects of learning. Overall, this categorization of academic emotions includes

- Achievement emotions (i.e., emotions related to achievement activities and outcomes, e.g., the success and failure resulting from these activities),
- Epistemic emotions (i.e., emotions triggered by cognitive problems when tackling new, non-routine tasks),
- Topic emotions (i.e., emotions related to the topics presented in lessons),
- Social emotions (i.e., emotions related to teacher/student interaction and group learning).

The studies reviewed are summarized in Table 4 in terms of the emotion labels, the reported motivations for studying emotions, and the foundations of emotion measurement. Moreover, emotions were classified in the four categories mentioned above to reveal patterns related to the approaches followed, e.g., how the same type of emotion is measured by different scholars and in different research contexts.

Emotion Impact Extraction

Finally, we identify how different papers reported the effects of emotions on students' participation in DBL activities. Such effects include aspects such as engagement, motivation, and self-efficacy.

Results

Overview of Reviewed Papers (Aim 1)

The selected papers are summarized and compared in Table 3, which also includes standard elements of a systematic literature review, namely the primary research method used for examining emotions, the geographic and year distribution,

Table 3 Summary of selected paper description

Study	Location	Age[a]	Participant (*N*)	Setting (*N*)	Con	Duration time	Main research method
Apedoe (2008)	USA	14–18	*N*(c) = 79, *N*(i) = 5	N/A	Y	8 weeks	Survey, observation
Bagiati (2010)	USA	14–15	*N*(c) = 83, *N*(i) = 1	4 (class)	Y	N/A	Pre and post questionnaire
Barak and Doppelt (1999)	Israel	15–18	*N*(c) = 83	1 (school)	N	2 years	Interview
Buechley (2008)	USA	10–14	*N*(c) = 10, *N*(i) = 2	1 (class)	N	*T*(c) = 1 week, *T*(n) = 15 h	Survey
Carroll (2010)	USA	12–13	*N*(c) = 24, *N*(i) = 5	1 (class)	N	*T*(c) = 3 weeks, *T*(n) = 12 h	Ethnographic observation, pre and post interview
Chan and Holbert (2019)	USA	6–10	*N*(c) = 15	3 (group)	N	*T*(c) = 2–4 months	Portfolio analysis, interview
Chu (2017)	USA	8–11	*N*(c) = 124, *N*(i) = 6	3 (class)	N	*T*(c) = 4 days, *T*(n) = 4.3 h	Questionnaire, video coding,
Council (2018)	USA	7–12	*N*(c) = 12	N/A	N	N/A	Survey
Doppelt (2003)	Israel	16–18	*N*(c) = 54, *N*(i) = 10	5 (school)	N	3 years	Questionnaire, observation Interview
Doppelt and Barak (2002)	Israel	15–18	*N*(c) = 56	1(school)	N	5 years	Questionnaire, observation, interview
Doppelt (2008)	USA	14–15	*N*(c) = 464	9 (school)	Y	4–6 weeks	Questionnaire
Giannakos and Jaccheri (2013)	Norway	12, 1-7—18	*N*(c) = 29 (in P1), *N*(i) = 9 (in P1), *N*(c) = 37 (in P2)	3 (work-shop)	N	N/A (in P1), *T*(n) = 5 days (in P2)	Interview, survey, observation
Giannakos (2014)	Norway	12, 1-7—18	*N*(c) = 37	3 (work-shop)	N	5 days	Questionnaire
Guo (2016)	USA	N/A	*N*(c) = 15, *N*(i) = 1	2 (class)	N	36 weeks	Video coding, interview
Guo (2017)	USA	N/A	*N*(c) = 185	51 (group)	N	N/A	Video coding, pre and post survey
Hendricks and Fasse (2012)	USA	13–14	*N*(c) = 136 (in P1[b]), *N*(c) = 84 (in P2[b]), *N*(i) = 3	11 (class)	Y	4 weeks	Questionnaire
Hugerat (2016)	Israel	15	*N*(c) = 230	1 (school)	Y	N/A	Questionnaire
Karahoca (2011)	Turkey	10–15	*N*(c) = 16, *N*(i) = 2	4 (group)	N	*T*(c) = 12 weeks, *T*(n) = about 17 h	N/A
Lacy (2016)	USA	N/A	*N*(c) = 6, *N*(i) = 2	1 (school)	N	30 days	Observation, interview, course handouts and student works
Li (2018)	USA	14–18	*N*(c) = 75	6 (school)	Y	1 year	Pre and post survey
Marks (2017)	USA	10–12	*N*(c) = 89	2 (class)	Y	*T*(n) = 9 h, *T*(c) = 3 weeks	Pre and post survey
Marks and Chase (2019)	USA	10–12	*N*(c) = 44	2 (class)	Y	*T*(n) = 9 h, *T*(c) = 3 weeks	Pre and post survey
Menzies (2016)	UK	11–12	*N*(c) = 1328	12 (school)	Y	20 months	Survey, interview
Milam (2016)	USA	N/A	*N*(c) = 150	5 (school)	N	4 months	Emailing letters
Neve and Keith-Marsoun (2017)	USA	N/A	*N*(c) = 25, *N*(i) = 9	8 (group)	N	4 weeks	Survey, focus group
Nix (2014)	USA	13–18	*N*(c) = 124, *N*(i) = 2	4 (class)	N	9 months	Survey, observation
Penuel (2016)	USA	N/A	*N*(c) = 592, *N*(i) = 11	8 (school)	N	8 weeks	Survey
Phusavat (2019)	Thailand	10	*N*(c) = 40, *N*(i) = 3	1 (school)	N	N/A	Observation, interview
Reynolds (2009)	USA	N/A	*N*(c) = 193, *N*(i) = 7	4 (school)	Y	8 weeks	Survey
Sáez-López and Sevillano-García (2017)	Spain	10–11	*N*(c) = 109	4 (school)	Y	*T*(c) = 1 year, *T*(n) = 20 h	Questionnaire, interview, focus group
Tae (2017)	Korea	7–8	*N*(c) = 105	N/A	Y	N/A	Questionnaire
Vongkulluksn (2018)	USA	8–12	*N*(c) = 100	4 (grade)	N	1 semester	Questionnaire, observation, interview

Table 3 (continued)

Study	Location	Age[a]	Participant (*N*)	Setting (*N*)	Con	Duration time	Main research method
Zhang (2018)	Netherlands	12–13	*N*(c) = 9, N(i) = 2	4 (group)	N	*T*(c) = 2 weeks, *T*(n) = about 1.7 h	Questionnaire, interview
Zhang (2019)	Netherlands	13–14	*N*(c) = 30	9 (group)	N	*T*(c) = 3 months	Questionnaire

Annotation: *Con* comparison to a control group, *N(c)* number of child participant who was in the experiment group and involved in the data collection process, *N(i)* number of an adult participant who was involved in the DBL activity acting as an instructor (i.e., teacher, facilitator, instructor), *Setting (N)* number of the setting for a complete DBL activity, *Session (N)* number of the units/stages which formed a complete DBL activity/program, *Duration time T(c)* spanning in a calendar timespan. *Duration time T(n)* actual total time cost

[a] The ages presented in studies are equivalent to corresponding grades according to the local education system

[b] P1 stands for the first part of the survey/evaluation, P2 stands for the second part of the survey/evaluation

the sample of students, and whether they include a comparison to a control group.

Research Method

Most reviewed papers combine multiple sources of data. The four most used methods for assessing emotions in the 34 selected papers are questionnaires, interviews, observations, and video coding, as shown in Table 3. Some studies used tailor-made questionnaires. For instance, one study (Doppelt and Schunn 2008) developed the DBLEQ questionnaire for measuring how children perceive the impact of DBL learning activities on learning outcomes. A few items in DBLEQ are related to emotions such as curiosity and interest. Another study (Zhang et al. 2019) developed the EmoForm questionnaire for capturing children's DBL activities and their associated emotion. This EmoForm was designed to measure eight emotions related to learning activities and outcomes during DBL, including enjoyment, relaxation, boredom, frustration, contentment, pride, hopelessness, and anxiety. A case study (Zhang et al. 2018) introduced an Emotion card for recording children's overall feelings during each DBL session, which was used together with an adapted Geneva Emotion Wheel (GEW) (Scherer 2005).

Interviews and observations are often combined in order to understand students' emotions (e.g., Carroll et al. 2010; Lacy 2016; Vongkulluksn et al. 2018). For instance, one study (Carroll et al. 2010) used an ethnographic approach, including observation and pre- and post-project interviews. Another study (Lacy 2016) combined observations and interviews with both children and teachers.

Likewise, video coding has been used as an approach to studying emotions. For example, one study (Guo et al. 2016) conducted a video data analysis of DBL sessions to carefully examine the factors (including behavioral, cognitive, and emotional factors) affecting female students' engagement. Their analysis is, however, confined to assessing the overall level of emotional engagement, rather than analyzing and interpreting specific emotion indicators. Another study (Chu et al. 2017) combined a questionnaire-based survey with video coding. Their in-depth qualitative video analysis focused on six students selected according to the preliminary results from the questionnaire.

Except for the most frequently used approaches we mentioned earlier, one study (Milam et al. 2016) captured students' emotions from conversations in their emails corresponding with children, and another (Chan and Holbert 2019) captured emotions from children's portfolio analysis.

The papers reviewed report both qualitative and quantitative data analysis. For example, a hierarchical level modeling analysis of the survey data in one study (Penuel et al. 2016) helped identify the relative impact of different variables on children's emotions. Similarly, another study (Vongkulluksn et al. 2018) performed hierarchical linear modeling to understand the changes in children's self-efficacy, interest development, and achievement emotions. The descriptive coding (Saldaña 2009; Miles et al. 2014) for qualitative data analysis was also used in the studies reviewed (e.g., Lacy 2016; Vongkulluksn et al. 2018).

More information about how observational and interview data were analyzed would be needed in some studies to help evaluate how representative the results are. For example, a study (Phusavat et al. 2019) claimed that observation and interview had been applied to evaluate the effectiveness of their DBL pedagogy. However, limited information was provided on how data was collected and analyzed. Similarly, one study (Nix et al. 2014) reported on children's enjoyment and engagement with DBL based on classroom observation without describing how the classroom observations were protocolled and analyzed.

Quasi-experimental Comparisons

Numerous studies compared DBL to non-DBL approaches. For instance, one study (Doppelt and Schunn 2008) examined pre-post differences in learning electronics, comparing a curricular DBL activity ($n = 464$) with a scripted inquiry ($n = 248$). Another study (Reynolds et al. 2009) compared children in their DBL program ($n = 193$) with other children ($n = 262$) in the same school's science classroom that did not implement DBL. Similarly, in Apedoe et al. (2008), children learning chemistry following a DBL unit ($n = 79$) were compared with their peers ($n = 58$) in the same school who did not follow DBL. Whereas these studies compared students in the same school, another study (Hugerat 2016) compared DBL children ($n = 230$) in one school with children ($n = 228$) from another school who were taught by traditional non-DBL pedagogy. All these studies demonstrated the positive effects of DBL, such as increased students' enjoyment (Hugerat 2016), interest in taking a science class (Doppelt and Schunn 2008), and interest in engineering (Apedoe et al. 2008; Reynolds et al. 2009).

An attitude survey reported in Li et al. (2018) compared DBL intervention children ($n = 75$) with children ($n = 26$) who were enrolled in other science or math courses. Similarly, the study by Menzies et al. (2016) reported on an attitudinal survey comparing DBL intervention children ($n = 1328$) with children ($n = 1516$) in a control group that was not given access to intervention materials and professional development. Li et al. (2018) reported that DBL did not significantly influence students' attitudes toward STEM careers, while Menzies et al. (2016) noted that DBL had no apparent impact on students' literacy and engagement. On the other hand, these two studies also mentioned the potential positive effect of DBL from classroom observations and participants' feedback. For instance, DBL was perceived to be of benefit in terms of teamwork, communication, research skills (Menzies et al. 2016), and engagement as well as stamina during problem-solving and while overcoming unfamiliar challenges in the classroom (Li et al. 2018).

Within the general DBL context, one study (Sáez-López and Sevillano-García 2017) compared children ($n = 109$) in a DBL project using physical computing technologies (e.g., handling devices, sensors and Raspberry Pi) with children ($n = 35$) in a DBL that did not involve such technological resources from two other schools. Similarly, Tae (2017) compared DBL children ($n = 105$) using advanced technology, e.g., IoT-based Cloudbit and MaKey, with children ($n = 107$) taught without using such technologies but using some recycled materials instead. When it comes to using high-tech materials, students' motivation and enthusiasm were found to be increased (Sáez-López and Sevillano-García 2017), and their interest in topics related to science, technology, and mathematics was found to be enhanced as well (Tae 2017).

A single case experiment (Hendricks and Fasse 2012) compared children's self-reports before and after participating in the DBL class. This study indicated that DBL students had higher self-efficacy in science and had better attitudes to science. Moreover, a comparative qualitative phenomenological study by Bagiati et al. (2010) involved a total of 84 children from the control and DBL group. DBL in a computer science course was compared with a group that used a teacher-oriented pedagogy. This study concluded that DBL had a positive effect on students' disposition toward the content. Factors that influenced this were the instructor, the book content, and the amount of time spent on hands-on activities.

Geographic and Year Distribution

A total of 21 of the 34 reviewed publications relate to studies that were executed in the United States and four in Israel; the remaining studies are quite spread out geographically. As some groups have produced multiple versions of the publications coded, it appears that a relatively small number of research centers ($N = 5$) have consistently addressed emotions in DBL and have presented more than a single publication on this topic.

A total of 14 publications have been published since 2016 compared to 13 in the 10 years before that. It appears that the rate of publication increased from 2016.

Student Population Sample

Most of the studies involved typically developing children, where the authors do not report them having special needs. Just a few studies targeted underrepresented student populations in STEM education (e.g., including female and low-achieving students) or students with special needs. For example, two studies (Doppelt and Barak 2002; Doppelt 2003) described a DBL program targeting low-achieving students, which lasted 5 years. Both studies reported that the students who participated found DBL very interesting and noted a positive impact of the DBL intervention on their self-esteem and self-confidence.

Council's research (2018) examined how students with disabilities participated in classroom activities in a general education classroom. These students—under the special education category of "specific learning disability" (SLD) and "other health impairment" (OHI)—were struggling and lacked motivation in all learning settings. As Council (2018) explained, this study had selected a convenient sample of 12 students. In the study, DBL was assumed to be an approach that could motivate these students to learn, which was also confirmed by empirical evidence from interviewing the teachers and students who participated. Students' emotions, such as interest and enjoyment, were measured to help explain how DBL affects the motivation, attitude, and achievement of these students.

Some studies (Giannakos and Jaccheri 2013; Giannakos et al. 2014; Guo et al. 2016, 2017) reported on evaluations involving female students. Two studies (Giannakos and Jaccheri 2013; Giannakos et al. 2014) presented an evaluation with a total of 37 girls who were involved in a DBL workshop, measuring their emotions and intentions to participate in DBL in future. Two other studies (Guo et al. 2016, 2017) showcased two independent case studies about high school female students' engagement when learning biology during DBL. Notably, one of the studies (Guo et al. 2017) reported that girls were more motivated in groups with a majority of girls.

Similarly, a DBL Summer Bootcamp (Neve and Keith-Marsoun 2017) targeted groups of students who are underrepresented in STEM education, and there was a 1-week DBL workshop (Buechley et al. 2008) involving nine girls and one boy, aged between 10 and 14. Moreover, some mentioned that a study had been implemented in a specific type of school setting. For instance, Bagiati et al. (2010) conducted a study in a public gymnasium high school to investigate the effect of DBL on students' interest in engineering; a study by Nix et al. (2014) was implemented in a special admit school; and a study by Carroll et al. (2010) took place in a public charter school.

The remaining studies did not target a specific student population. However, in some cases, diversity was achieved (, e.g., in Reynolds et al. 2009; Penuel et al. 2016). The study by Vongkulluksn et al. (2018), in particular, investigated the differences in students' emotions when engaged in DBL between a lower-level (e.g., grades 3–4) and a higher-level class (e.g., grades 5–6). Additionally, one study (Milam et al. 2016) implemented a DBL program across four elementary schools and one middle school. This study noted that the elementary school students were more comfortable in engaging with—and more active in communication with—the design stakeholder than the middle school students.

The Affective DBL Components (Aim 2)

To provide an overview of how the studies we reviewed implemented DBL, we summarize and categorize these studies according to Van den Akker's framework (2010), which is discussed in the "Methods" above. More specifically, we report on the DBL components that are highlighted as affective factors in the reviewed papers. Note that a few studies (e.g., Tae 2017; Council 2018; Li et al. 2018) reported the overall effect of DBL on children's motivation or interest, but lack of details of which DBL components are related to the reported emotions. The other studies have, to a different extent, addressed various DBL components, except for the component of location and rationale. The following subsections present the results described in 34 reviewed studies on how the other eight DBL components appeared to be related to children's emotional feelings.

The Content Component

The content generally refers to the subject matter or the knowledge that is gained in a learning activity. Some studies examine children's attitudes to the overall subjects presented in their DBL program. For example, one study (Hendricks and Fasse 2012) surveyed children's interest in and attitude to a science class that implemented a DBL pedagogy. In this study, children were asked to rate their agreement level on attitude-related statements, e.g., "I feel tense when someone talks to me about science," "It makes me nervous to even think about doing science," and "It scares me to have to take a science class" at two points in time (i.e., the 3rd week during this DBL intervention, and 11 weeks after completing the intervention). Their results illustrated the fact that the number of students reporting feeling scared about taking the science class was significantly reduced. Another study (Hugerat 2016) reported children's feelings of satisfaction and enjoyment when they were interacting with scientific content during DBL using the statements in a questionnaire, e.g., "I feel satisfied in learning science" and "I enjoy the tasks I carry out in science classes." Statistically significant results in this study suggested that children's perception (e.g., level of satisfaction and enjoyment) about a science class involving DBL was more positive than in traditional learning. Furthermore, another study (Doppelt and Schunn 2008) identified that some of the most influential characteristics from a DBL environment were, e.g., "Interest in Science Topics" by analyzing the mean scores from the questionnaire.

A study (Buechley et al. 2008) presented an evaluation of using LilyPad as a design tool in a DBL workshop (as a part of the summer science program). In this study, children's interest in electronic fashion design topics and interest in broader subject topics, including programming and electronics, were measured by survey questions. This study's results showed that six of the eight participants would be interested in pursuing an electronic fashion-related class and engage in electronic fashion-related activities at home. However, only three were interested in working with programming or electronics in their own time. The data in this study is too limited to allow generalization. It suggests that the interest of those children may not be transformed by brief exposure to such workshops so that they become intrinsically oriented toward technology topics, but is mainly driven by the right choice of context and problem domain.

More specifically, another study (Penuel et al. 2016) examined the association between emotions (incl. excitement and boredom) and the situation of connecting tasks to the design challenge. The results revealed that the feelings connected to the DBL design challenge were significantly associated with students' reports of being both excited and bored during the class. Specifically, this study mentioned "seventy percent of lessons that students reported being connected to the challenge were ones where they also reported being excited," suggesting a positive association between excitement and connectedness to the design challenge. Moreover, it also mentioned "thirty-one percent of lessons that students reported being connected to the challenge were ones where they also reported being bored," which suggested that boredom seemed to be negatively associated with connectedness to the design challenge. Importantly, this study also concluded that the different abilities among teachers influenced the degree to which children perceived their learning tasks to be connected to the unit's design challenge.

Furthermore, in one study (Vongkulluksn et al. 2018), the complexity of children's design projects was found to likely be linked to the development of children's interest. Vongkulluksn et al. (2018) reported a quantitative trend that children's situational interest in DBL seemed to decline as time progressed. They also noted the potential relationship between the complexity of task content and this trend of children's declining interest and explained that the complexity of design projects probably had to do with children's overambitious goals for their projects.

The Learning Activity Component

One study (Carroll et al. 2010) reported from their ethnographic case study that passive listening activities were likely to be related to children's boredom. This study described children's quotations from interviews supporting this boredom phenomenon "it is kind of boring listening to everybody talk and stuff … it would have been better if it was just mostly projected instead of talking. When they just kept talking, we just wanted to get to the work so that we could just have fun." This illustrated children's preference for times spent on actively doing compared to sitting and listening.

Another study (Chu et al. 2017) reported instructional activity during DBL and its associated effect by video coding children's behaviors. For instance, Chu et al. (2017) explained that sometimes children felt pleasure in explaining procedures to others, which potentially reinforced their understanding of concepts. Interestingly, Chu et al. (2017) also mentioned that instructing others, however, was sometimes associated with feeling irritated or frustrated. Further, Chu et al. (2017) identified two situations based on their analysis that may result in frustration due to giving instructions. For example, the first possible situation was when a child wanted to complete his/her own or others' activities at a higher standard than the other child wanted to. The second was when the child had to tell others how to do it, but was not able to perform an activity himself/herself.

Vongkulluksn et al. (2018) argued that children's frustration might be raised from the iterative design process. This study described a quotation from the child (who had a higher level of interest at the beginning of the DBL but tended to experience frustration and low interest in the success of the outcome) that "This is supposed to be the final product of the middle arm, but I have to make it over again… I am just trying to make everything perfect right now, so I have to make it again." Another study (Chan and Holbert 2019) based on the analysis of children's portfolios briefly mentioned students' reflections involving emotions. Moreover, Zhang et al. (2018) reported that most children in a DBL study perceived prototyping as their favorite activity, and some children enjoyed showing their designs to others. In a more recent study, students reported feeling content about the outcomes of prototyping and had positive feelings about making activities in particular (Zhang et al. 2019).

The Teacher's Role Component

A few studies have reported the teacher's role as a coach in DBL. For example, they demonstrate that the teacher's guiding role is useful to establish students' sense of independence about their learning (Doppelt and Barak 2002). However, this study did not focus on the teacher's role; thus, the reported evidence is sparse and mainly based on interviewing a few students who emphasized their freedom to choose their design activities under the teacher's guidance.

The teacher avoiding assuming the role of an authority figure toward students has been argued to enhance students' sense of trust and responsibility (Phusavat et al. 2019). Rather teachers and students are seen as forming a community for developing a DBL pedagogy in schools, arguing that "by allowing students' collaboration to take place effectively, the students who had participated in the pilot project expressed their satisfaction in how they were trusted by the teachers," (Phusavat et al. 2019). Furthermore, students perceive the teacher-student relationship as more favorable when the teacher provides assistance and support as well as when the teacher shows interest in their achievements (Hugerat 2016). Finally, Penuel et al. (2016) emphasize how important it is for coaching in DBL to address students' emotions.

The Grouping Component

The grouping component refers to the consideration of those with whom students are learning. A study (Giannakos and Jaccheri 2013) reported how working in groups made the DBL activity more enjoyable and that students found it easier to relax and to try new things with their friends, a view also supported by another two studies (Carroll et al. 2010; Zhang et al. 2018).

A further study (Guo et al. 2016) reported that positive group interactions were the source of children's fun and enjoyment in design activities. More specifically, two other studies mentioned how a positive interaction between students and their design clients/stakeholders is fun (Milam et al. 2016) and fuels students' enthusiasm (Phusavat et al. 2019).

The Materials and Resource Component

There are a few considerations in the reviewed literature regarding the impact of materials and resources on emotions. Lacy (2016) reported that they did not perceive any risk from equipment, while another study (Chu et al. 2017) reported how making materials that were very new to students directly available to them in the classroom made them overexcited and impatient to start using them.

One study (Barak and Doppelt 1999) mentioned that children felt curious about LEGO and the mechanism behind it. Finally, another study (Doppelt and Schunn 2008) emphasized the importance of a well-prepared instructional design documentation worksheet.

The Assessment Component

The possible relationship between self-assessment in DBL and students' emotions is discussed in Vongkulluksn et al. (2018), who described a participant's positive evaluation of his progress and his interest in finishing the project. They further explain the positive relationship between success and interest based on observations and interviews in which students tended to express their interest in terms of a successful progress evaluation. Besides, this study suggested that repeated failures that are part and parcel of an iterative design may reduce interest and cause frustration in some students.

The Aims and Objective Component

Interestingly, in terms of failure and iterative practice, one study (Marks 2017; Marks and Chase 2019) in particular compared children's attitudes to failure in the process-focused mindset with a content-focused mindset during iterative prototyping activities. In this study, the learning objective for children in the process-focused mindset was described in terms of good designers using iterative prototyping to create their designs. Three tenets were taught for this process-focused group of children, including "(a) make mistakes and learn from them, (b) go through cycles of make-test-think, and (c) take many tries." The results in this study illustrated the fact that the process-focused learning objectives had a positive effect on children's attitudes to failure and their desire to make more iterations during prototyping.

The Time Component

Some reviewed studies (e.g., Hendricks and Fasse 2012) performed a pre- and post-evaluation to examine the effect of their DBL interventions. Another study (Vongkulluksn et al. 2018) investigated the development of children's situational interest and achievement emotions at three time points in a semester-long DBL curriculum. The quantitative analysis in this study showed that children expressed relatively high levels of interest at the beginning of the semester. However, their situational interest and self-efficacy tended to decrease at the mid-point and end-point of this semester.

Moreover, children's confusion and frustration were associated with reduced situational interest. Some influential factors from the qualitative analysis in this study explained this decreasing interest, which may relate to diverse factors such as the complexity of the design challenges and the students' self-evaluation of their progress. Their results suggested that children's emotions fluctuated, and their emotions changed as time progressed during the three checkpoints of the DBL project.

Besides, Vongkulluksn et al. (2018) also mentioned the frustration and concern about time constraints in children's projects during DBL.

Reported Emotions (Aim 3)

Three types of research motivations for studying or measuring emotions are summarized in Table 4, e.g., whether studying emotions is named as an explicit research aim in these studies, be that as an outcome indicator or as a predictor of some other outcome. Overall, the primary motivation for the reviewed studies is to evaluate a DBL activity.

For example, 14 of the studies reviewed measured students' attitudes and perceptions of the DBL environment. Two studies (Doppelt and Barak 2002; Doppelt and Schunn 2008) adapted questionnaires from the curriculum design model (Waks 1995) for measuring emotions aroused by the DBL classroom environment. Another study (Hugerat 2016) adapted questionnaires from the class climate model in mathematics class (Zedan 2008) in order to measure students' perceptions of DBL.

Similarly, 12 of the studies reviewed measured students' motivation and interest in STEM-related topics, careers, and future similar activities in order to characterize the effectiveness of a DBL activity. In line with this research agenda, interest is most frequently measured. Other often reported positive emotions are satisfaction, enthusiasm, enjoyment, and curiosity. Negative emotions are assessed in only two studies (Hendricks and Fasse 2012; Giannakos et al. 2014); however, their analysis concludes that DBL had a promising positive effect on students' interest, motivation, and intention to participate in DBL-related activities in the future. On the other hand, a quantitative study with a similar goal-setting found no effect of the DBL upon students' attitudes to STEM careers (Li et al. 2018).

On the other hand, some studies were designed to understand students' emotional engagement (Guo et al. 2016, 2017), fun (Sáez-López and Sevillano-García 2017; Chu et al. 2017), and emotions (Vongkulluksn et al. 2018; Zhang et al. 2018, 2019; Chan and Holbert 2019) in a DBL context.

Table 4 Clarification of reported emotions on underlying reference and research motivation

Study	Emotion reported and its corresponding theoretical reference	Research motivation for reporting emotion
Barak (1999)	Interest, Curiosity, Enthusiasm	(1) Evaluate children's attitudes or perceptions of the DBL intervention outcome.
Carroll (2010)	Enjoyment, Boredom	
Council (2018)	Enjoyment, interest	
Doppelt (2003)	Interest, Excitement, Enjoyment	
Doppelt and Barak (2002)	Interest, Curiosity *The instrument referred to the questionnaire (*Waks 1995)	
Doppelt (2008)	Interest, Curious *The instrument referred to the questionnaire (*Waks 1995)	
Hugerat (2016)	Satisfaction, Enjoyment, Favourable *The instrument was adapted from a validated questionnaire by* (Zedan 2008)	
Lacy (2016)	Relaxation, Comfortable	
Marks (2017)	Affective reactions (incl. Terrible, anger, sad) *The instrument refers to School Failure Tolerance scale by* (Clifford 1988)	
Marks and Chase (2019)	Affective reactions *The instrument refers to School Failure Tolerance scale by* (Clifford 1988)	
Menzies (2016)	Enthusiasm, Enjoyment, Pride	
Milam (2016)	Interest	
Penuel (2016)	Excitement, Boredom *The instrument was adapted from the scale* (Morozov et al. 2014)	
Phusavat (2019)	Satisfaction, Enthusiasm	
Apedoe (2008)	Interest	(2) Evaluate children's motivation and interest in topics, career, or future similar activities.
Bagiati et al. (2010)	Interest	
Buechley (2008)	Interest, Happy, Content, Ecstatic	
Giannakos and Jaccheri (2013)	Enjoyment, Satisfaction, Relaxation *The instrument has adapted the construct of enjoyment from* (Venkatesh et al. 2002), *and of satisfaction from* (Lin et al. 2005)	
Giannakos (2014)	Enjoyment, Happiness (incl. Satisfied, excited, curious), Anxious (incl. Insecure, helpless) *The instrument has adapted the construct of enjoyment from* (Venkatesh et al. 2002), *and of happiness and anxiety from* (Kafai and Peppler 2011)	
Hendricks and Fasse (2012)	Interest, attitude (incl. Tense, Nervous, Scare) *The instrument refers to* (Aschbacher et al. 2009) *and* (Weinburgh and Steele 2000)	
Karahoca (2011)	Interest, Enthusiasm, Curiosity	
Li (2018)	Interest	
Neve and Keith-Marsoun (2017)	Interest	
Nix (2014)	Interest, Enjoyment, Excitement, Satisfaction	
Reynolds (2009)	Interest	
Tae (2017)	Interest, Satisfaction *The instruments referred to STEAM course satisfaction scale and affective achievement of STEAM scale from* (Park 2014)	
Chan and Holbert (2019)	Emotional reflection	(3) Understand children's emotions, fun, and emotional engagement.
Chu (2017)	Fun (incl. Satisfaction, Frustration) *The instrument has adapted the smileyometer* (Read and Macfarlane 2006)	
Guo (2016)	Interest, Curiosity, Enjoyment, Frustration *The instrument refers to the video coding indicator developed by* (Nieswandt and Mceneaney 2012)	
Guo (2017)	Excitement	
Sáez-López and Sevillano-García (2017)	Fun (incl. Happiness, Enthusiasm, Relaxation, Enjoyment) *The instrument was adapted from the scale* (Laros and Steenkamp 2005)	

Table 4 (continued)

Study	Emotion reported and its corresponding theoretical reference	Research motivation for reporting emotion
Vongkulluksn (2018)	Interest, frustration, confusion, excitement, curiosity *The situational interest instrument was adapted from the scale* (Danielson et al. 2015); *and the achievement emotion instrument was adapted from the scale* (Pekrun et al. 2011)	
Zhang (2018)	Enjoyment, elation, pride, satisfaction, surprise, shame, anger *The emotion card instrument is adapted from Five Degrees of Happiness by* (Hall et al. 2016) *which was initially adapted from smileyometer* (Read and Macfarlane 2006), *and GEW questionnaire is adapted from Geneva Emotion Wheel 1.0 by* (Scherer 2005)	
Zhang (2019)	Enjoyment, Relaxation, Boredom, Frustration, Contentment, Pride, Hopelessness, Anxiety *The EmoForm instrument was based on achievement emotion theory* (Pekrun et al. 2011) *and MemoLine concept* (Vissers et al. 2013; Sim et al. 2016)	

Driven by the motivation of understanding emotions in DBL, three reviewed studies (Vongkulluksn et al. 2018; Zhang et al. 2018, 2019) referred to the theory of achievement emotion (Pekrun et al. 2007). However, most studies are not explicitly founded on theories of emotions, particularly when studying emotions is not their primary aim.

There is limited consistency regarding measurement across the studies reviewed. Two studies used adaptations of the smileyometer (Read and Macfarlane 2006), albeit for slightly different purposes: Chu et al. (2017) use it to assess students' fun in DBL, while Zhang et al. (2018) measured students' overall emotional state through the design thinking process.

In order to measure students' emotional engagement and interest in DBL, a study (Penuel et al. 2016) examined student's affective response using a single sentence-completion survey statement: "Today in science class, I felt… (Excited, Bored, Like a Scientist)", which they adapted from an earlier study based on the model of emotional engagement in the agentive science environment (Morozov et al. 2014). Another study (Hendricks and Fasse 2012) examined students' attitudes, using several emotions as indicators in a survey tool (including interest, tense, nervous, and scared) by referring to two existing scales—the Is Science Me (ISME) scale (Aschbacher et al. 2009) and the Modified Attitudes towards Science Inventory (MATSi) scale (Weinburgh and Steele 2000). Differently, Tae (2017) referred to the STEAM course satisfaction scale and affective achievement on the STEAM scale (Park 2014).

The study carried out by Guo et al. (2016) adapted the coding scheme proposed by Nieswandt and Mceneaney (2012) to analyze students' emotional engagement during DBL. In order to measure student's affective reaction to failure in DBL, Marks (2017) and Marks and Chase (2019) referred to the School Failure Tolerance scale by Clifford (1998).

In the following subsections, we present the reported emotions by categories (namely, achievement, epistemic, topic, and social emotions as in Pekrun (2014)), and in particular, showcase emotions under the same labels. As already mentioned, the theoretical underpinning across the 34 reviewed studies is not very clear and consistent, and in some cases, the description for some emotion labels is implicit. Therefore, the following subsections present emotion labels in categories that are derived from the survey statements, coding scheme, or quotations from interviews, rather than repeat the findings these studies reported (e.g., the emotions as positive outcome from their studies—"98% pupils enjoyed DBL" or "Students had a higher level of satisfaction in DBL"). We intend to use these descriptions to inspire future emotion measurement development in the context of DBL.

Achievement Emotions

Achievement emotions are emotions that relate to learning activities as well as success and failure resulting from these activities (Pekrun 2014). In Table 5, we summarized nine activity-related achievement emotions (including interest, satisfaction, enjoyment, happiness, anxiety, frustration, and boredom), and four outcome-related achievement emotions (including excitement, feeling terrible or sad, and anger).

As an illustration, achievement interest was measured by a study (Guo et al. 2016) based on indicators of interest, such as eagerness to work or actively seeking feedback. Another study (Barak and Doppelt 1999) described a student's interest in the learning activity with quotations extracted from a debriefing interview with students: "I liked these lessons a lot, it is not old-fashioned learning…it stimulates thought, and it is fun."

Satisfaction was assessed using a three-item scale in a study (Giannakos and Jaccheri 2013). Similarly, another study

Table 5 Extracted achievement emotions

Emotion	Quotation/description
Interest	"It stimulates thought and is fun" (Barak and Doppelt 1999); Video coding the sub-indicators of interest, such as eager to work, actively seeking feedback.,[b] (Guo et al. 2016);
Satisfaction	I am satisfied with the activity; I am pleased with the activity; my decision to attend the activity was a wise one[a] (Giannakos and Jaccheri 2013); I feel satisfied in learning science; I am satisfied with the class where I study science[a] (Hugerat 2016);
Enjoyment	Attending the activity was enjoyable. Attending the activity was exciting. I was feeling good in the activity[a] (Giannakos and Jaccheri 2013; Giannakos et al. 2014); I enjoyed the tasks I carry out in science classes[a] (Hugerat 2016); I enjoyed doing the project; the project was fun to do[a] (Council 2018) Verbal expression of having fun or liking tasks/activity[b] (Guo et al. 2016);
Happiness	Indicating by the feeling of satisfied, excited, and curious[a] (Giannakos et al. 2014), I was happy[a] (Sáez-López and Sevillano-García 2017).
Excitement	Excitement about their successful model testing[b] (Guo et al. 2017).
Anxiety	Indicating the feeling of insecurity and helpless[a] (Giannakos et al. 2014).
Terrible	I would feel terrible if I made a mistake[a] (Marks 2017).
Sad	Ad feedback would make me feel very sad; I get sad if I make errors when I am trying to learn[a] (Marks 2017).
Anger	If I make a lot of mistakes, I feel very moody or angry[a] (Marks 2017).
Frustration	Indicating be the level of how frustration does makerspace activities make you?[a] (Vongkulluksn et al. 2018)
Boredom	"It is kind of boring listening to everybody talk and stuff … it would have been better if it was just mostly project instead of talking" (Carroll et al. 2010);

[a] Description from survey statement

[b] Description from video coding scheme; "" quotation from an interview

(Hugerat 2016) used two similar statements with the more specific context of learning science, as shown in Table 5.

Furthermore, enjoyment is defined as the degree to which an activity is perceived to be personally enjoyable in two studies (Giannakos and Jaccheri 2013; Giannakos et al. 2014). And in one study (Guo et al. 2016), classroom videos were analyzed, coding verbal expressions indicating fun or liking the tasks/activity as indicators of enjoyment in DBL.

Happiness was considered to be the extent to which a person felt happy during the activity in general, including feeling satisfied, excited, and curious as sub-indicators of happiness in one study (Giannakos et al. 2014). Another (Sáez-López and Sevillano-García 2017) used a single item survey statement, "I was happy" to measure students' level of fun during DBL.

Excitement was mentioned in passing in one study (Guo et al. 2017) associated with the moment of testing a model, but without explanation as to the definition of the emotion or its measurement.

Anxiety was referred to in two sub-indicators (insecure and helpless) in a study (Giannakos et al. 2014). Feeling terrible, sad, and angry were all used as survey items to measure student's failure tolerance during DBL in one study (Marks 2017). Frustration was measured using the survey statement "Indicating the level of how frustrated does makerspace activities make you?" in one study (Vongkulluksn et al. 2018), while frustration was defined as a verbal expression of frustration or negative feelings in another study (Guo et al. 2016). Moreover, Carroll et al. (2010) described the emotion of boredom in an interview quotation.

Epistemic Emotions

As defined by Pekrun (2014), epistemic emotions are feelings triggered by cognitive problems when presented with new or non-routine tasks. We summarized four epistemic emotions that emerged in reviewed studies, including curiosity, interest, and enjoyment in Table 6. For example, curiosity was briefly highlighted as asking curiosity questions in the coding scheme in a study (Guo et al. 2016), while another (Doppelt and Schunn 2008) used the phrase "making me curious" in their questionnaire. As a survey item for measuring motivation at school, a study (Menzies et al. 2016) used a statement illustrating student's interest; i.e., "what we learn at school makes me interested to learn about new things." Likewise, epistemic enjoyment was treated as one of the survey items for measuring motivation at school in the same study, Menzies et al. (2016) used the statement "I enjoy learning new things."

Table 6 Extracted epistemic emotions

Emotion	Quotation/description
Curiosity	Making me curious[a] (Doppelt and Schunn 2008); Asking curiosity questions[b] (Guo et al. 2016);
Interest	What we learn at school makes me interested to learn about new things[a] (Menzies et al. 2016).
Enjoyment	I enjoy learning new things[a] (Menzies et al. 2016).
Frustration	Verbal expression of frustration or negative feelings[b] (Guo et al. 2016).

[a] Description from survey statement

[b] Description from video coding scheme

Topic Emotions

As described by Pekrun (2014), topic emotions refer to feelings related to the topics presented in lessons. Table 7 describes two positive topic emotion labels (including interest and enthusiasm) and another three negative emotion labels (including tense, nervous, and scared). One (Buechley et al. 2008) used students' quotations showing their interest in DBL-related topics, while another two (Doppelt 2003; Menzies et al. 2016) framed survey statements to measure students' interest in topics. Furthermore, in addition to some positively phrased questionnaire statements, a study which measured students' attitude toward science class included three negative emotion labels—tense, nervous, and scared. A study (Menzies et al. 2016) used an enthusiasm label with a survey statement: "I am enthusiastic about most of the things we do in class" to measure the level of getting involved in the school.

Social Emotions

Social emotions are feelings regarding teacher-student interaction and student-student interaction in group learning (Pekrun 2014). The studies reviewed examples of social enjoyment and relaxation. For example, Carroll et al. (2010) described students' enjoyment in DBL using the example of a student's interview quotation, which was full of words like "fun" and "liked." Giannakos and Jaccheri (2013) quoted one student who found the exercise enjoyable and relaxing (see Table 8).

It is important to note that almost all studies are interested in positive emotions such as fun and enjoyment, which, to some extent, suggests that DBL is received positively. However, overall little attention is paid to measuring them quantitatively and to providing a theoretically founded definition of emotions. This may be due to the fact that research so far has not yet drawn explicit links between DBL components and emotions, especially in quantitative terms.

The Impact of Emotions in DBL (Aim 4)

The impact of emotions in DBL has been addressed to different extents in the studies reviewed. For example, one study (Giannakos et al. 2014) found that enjoyment had no significant effect on students' intention to join similar activities in the future, whereas happiness had a positive effect, and anxiety had a negative effect. Another study (Zhang et al. 2018) reported sparse evidence (from just two students) who said that enjoyment facilitated their learning during minds-on activities but did not find similar evidence for hands-on activities. Besides, in a study by Zhang et al. (2018), three students mentioned that pride and elation had a generally positive influence on them during DBL.

Table 7 Extracted topic emotions

Emotion	Quotation/description
Interest	"It is amazingly fun, I learned a lot, and we get a cool garment out of the class" (Buechley et al. 2008); Learning through project creation is very interesting to me; the subject was taught interestingly and attractively[a] (Doppelt 2003); Sometimes, I do extra work outside of school because I am interested in the topic[a] (Menzies et al. 2016);
Enthusiasm	I am enthusiastic about most of the things we do in class[a]. (Menzies et al. 2016); I was enthusiastic[a] (Sáez-López and Sevillano-García 2017)
Relaxation	I was relaxed and comfortable[a] (Sáez-López and Sevillano-García 2017)
Tense	I feel tense when someone talks to me about science[a] (Hendricks and Fasse 2012).
Nervous	It makes me nervous to even think about doing science[a] (Hendricks and Fasse 2012).
Scare	It scares me to have to take a science class[a] (Hendricks and Fasse 2012).

[a] Description from survey statement; "" quotation from an interview

Table 8 Extracted social emotions

Emotion	Quotation/description
Enjoyment	"I thought that the project was enjoyable. I enjoyed it. It was fun because I was working with my friends and we were chatting and messaging. It was really fun. I liked it…" (Carroll et al. 2010);
Relaxation	"It is easier to relax and to try new things when your friends are there" (Giannakos and Jaccheri 2013).

Note: quotation from an interview

Interestingly, a study (Vongkulluksn et al. 2018) investigated students' situational interest development in DBL, through three time-repeated measurements over a semester-long DBL course. In particular, this study intended to explore not only the correlation between students' development of interest and their self-efficacy, but also the correlation between interest development and achievement emotions, emphasizing frustration, confusion, excitement, and curiosity. Vongkulluksn et al. (2018) reported that students' positive emotional reactions to DBL were likely to be associated with relatively high self-efficacy and interest. More specifically, the situational interest across the three time points was correlated with excitement, curiosity, and frustration. On the other hand, confusion was negatively correlated with interest at the end of the semester. Their results suggest that that the function of frustration is completely different compared to excitement and curiosity. Initially triggered situational interest did not always evolve into sustained interest when design iterations frustrated students.

Discussion

The main objectives of this review were to understand the existing body of research on emotions in DBL (aim 1), to understand which components of DBL affected students' feelings (aim 2), and to determine what K-12 students' emotional reactions were as reported in DBL studies (aim 3). One crucial finding of this review is that DBL overall has a positive effect on students' interest in and motivation for related topics and activities. Other positive emotions, such as satisfaction, enjoyment, happiness, excitement, curiosity, enthusiasm, and relaxation, were also mentioned as among the positive outcomes from DBL program evaluations. What is more, Marks (2017) and Marks and Chase (2019) also reported a positive effect of DBL mindset interventions on students' affective reaction to failure, which confirms claims that DBL is a promising approach for education (Davis et al. 1997; Martin 2015; Papavlasopoulou et al. 2017).

Emotions are considered to be factors that motivate and facilitate learning processes, but also as affective outcomes reflecting (the appraisal of) success versus failure, or pleasant versus unpleasant learning (Fiedler and Beier 2014). This systematic literature survey identified a variety of DBL components that have been found to impact on student's emotions. While the evidence found is still sparse and tentative, the picture that emerges is that of a bi-directional mechanism relating to how students' emotions relate to their participation in a DBL activity. The global bi-directional relationship between emotion and DBL is outlined (see Fig. 2), with one direction relating to how the DBL components affect students' emotions and the second to how emotions affect their learning and participation in DBL. One of the objectives of this review was to understand the impact of emotions on students' participation in DBL (aim 4). Figure 2 maps studies relevant to the illustrated bi-directional relationships without emphasizing the strength of the evidence or whether the corresponding study reports a positive or negative relationship. Noting that the extent of robust findings in the studies reviewed is varied, this diagram is designed to outline the emerging pattern of their bi-directional relationship based on the studies reviewed. This review provides an overview of which aspects of DBL were investigated in the studies reviewed and what relationship they were likely to have to four types of academic emotions.

The final objectives of this review were to articulate implications for practice and make recommendations for future related research (aim 5). Based on the studies reviewed and their reported empirical evidence, we intend to explain our reflection, which may suggest a direction for future work. In the following section, we specifically discuss how these recommendations and implications build on the reviewed studies and related literature.

Recommendations for Future Research (Aim 5)

Research on emotions in DBL is a developing field. Overall, the studies we reviewed still seem to be loosely connected and highly fragmented. They all adopt different emotion conceptions or theoretical approaches, except for studies by the same group, which shares or links to the same prior instrument, model, or theory.

There are a variety of ways of describing emotions in DBL. For instance, three topic emotions, interest, enthusiasm, and excitement, all describe the emotional state of being willing and motivated to learn more about the topics presented in

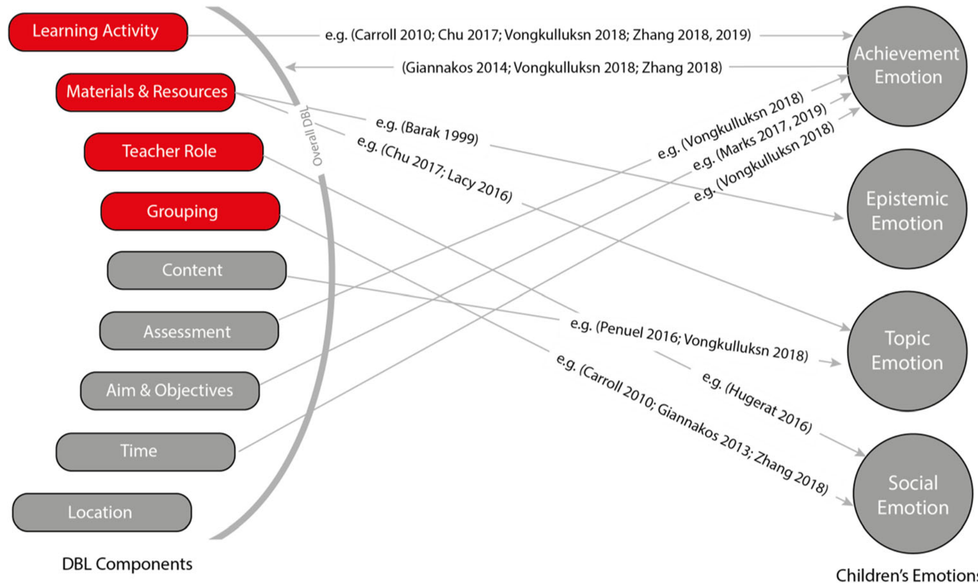

Fig. 2 The interplay of students' emotions between DBL. Note: The red blocks of DBL components outstand as the DBL characteristics, while the rest as non-characteristics DBL components compared with other learning approaches. This figure listed some examples of studies which reported such relationship, more detailed information can be found in two sub-sections of the "Result"—"The Affective DBL Component (Aim 2)" and "The Impact of Emotions in DBL (Aim 4)"

DBL. For example, in Table 4, the happiness label was mentioned in one study (Sáez-López and Sevillano-García 2017) as a sub-indicator for measuring students' fun in DBL, while another (Giannakos et al. 2014) defined happiness as three sub-indicators—satisfied, excited, and curious.

In addition to this, various methods were used to measure emotions. Most of the emotions reported in these papers are extracted and summarized from children's emotion-related verbalizations during interviews. On some occasions, the emotions mentioned were reported through verbal emotion-related items in questionnaires. In some cases, the verbal emotion-related items used in the survey are pre-selected by researchers rather than reported spontaneously by students to evaluate the outcome of DBL. Other studies (e.g., Guo et al. 2016; Chu et al. 2017) identified children's emotions by partly using non-verbal video coding indicators (e.g., students' behaviors). Several of the studies reviewed used observation to collect data.

Importantly, future research could triangulate such findings by combining self-reporting (e.g., questionnaires, mini-survey items, interviews) with observation measures (e.g., direct observation and videotaping). To further ensure reliability, psychophysiological measurements (e.g., heart rate, skin conductance) could provide a supplementary source of observation data in future studies. On the other hand, future work may focus on developing tools for collecting multimodal DBL classroom data in order to supplement self-reporting surveys or indirect observations of children's emotions. It would also be valuable in future work to explore and validate whether technology-embedded emotion capturing tools (e.g., Balaam et al. 2010; Beardsley et al. 2019), which are used in other contexts, would be useful in the DBL context.

Despite the overall positive effectiveness claimed by the studies reviewed, this is not to say that the DBL environment is a pure paradise in which no negative feelings can be evoked. For instance, one study (Carroll et al. 2010) mentioned an incident of children feeling boring by passive listening, and another study (Chu et al. 2017) mentioned children feeling frustrated when they were reluctantly instructing others. However, the evidence of specific incidents involving children's associated negative emotions is minimal. This is partly because measuring emotions only served as one source of evidence to prove the effectiveness of DBL in most of the studies. It is also partly because the evaluations reported in most of the studies reviewed were made at a high-level perspective, which may result in overlooking episodes during the process.

For example, most recent investigations of students' emotions focused on applying design thinking rooted in STEM subjects, except for a few rooted in geography or literacy. Future research on children's emotional responses to DBL content could go beyond STEM subjects to also explore the relevance of DBL in learning arts subjects. Furthermore, it appears interesting to examine affective outcomes of DBL in the long term, e.g., how and whether DBL develops a more enduring interest in STEM.

With regard to the component of the teacher's role during DBL, empirical evidence from the studies reviewed has shown that the teacher's behavioral investment (e.g., assistance in prototyping) and emotional investment (e.g., showing interest in students' achievement) are vital for children. Future research could examine the impact of teacher's behavioral and emotional investment in children's learning and emotions in the long term.

Some studies examining children's emotional responses to grouping focused on the social-emotional layer of the interaction and collaborative learning with peers. Only a few (e.g., Milam et al. 2016; Phusavat et al. 2019) mentioned, to a limited extent, the positive interactions between children and stakeholders. Future research could pay attention not only to students' collective emotions during their interactions within the group but also to the emotions resulting from interacting with different stakeholders.

Even though the locations of DBL programs varied from the classroom, to summer camp, to workshops, an investigation of location components in DBL was lacking in the 34 studies reviewed. Future studies may investigate the effect on children's feelings toward DBL from different locations and learning settings (i.e., formal, non-formal, and informal learning). Besides, advanced technologies create more platforms and tools for learning online nowadays. It would also be valuable to pay attention to the different emotions children experienced in both offline and online DBL learning in the future.

Overall, it is clear that research on DBL has so far paid little attention to emotions. Most of the evidence presented is limited and anecdotal, which researchers report incidentally, as their primary focus is not the study of emotion as such. In cases where the emotional impact of DBL is touched upon in earlier studies, these mainly highlight achievement and topic emotions rather than epistemic or social emotions, and focus much more on positive rather than negative emotions. Therefore, further research could explore the diverse epistemic emotions and social emotions during DBL, also addressing negative emotions and how these arise. Another question for further inquiry relates to the impact of emotions in DBL (e.g., engagement in DBL, motivation for participating in DBL) and, more specifically, their impact in different phases of the DBL process. For example, it is arguable that satisfaction could impact ideation and brainstorming, which may lead to developing superficial concepts. Future research could pay

Table 9 DBL guidelines

DBL component	Guidelines	Reference source
Content	• Connect learning content to the design challenge and the DBL process to make it more interesting and attractive.	Penuel et al. (2016)
	• Carefully moderate the complexity of the design challenges during iteration.	Vongkulluksn et al. (2018)
Learning Activity	• Combine passive listening and hands-on experimentation activities (e.g., teaching and introducing learning content should not all be provided in one block before hands-on activities).	Carroll et al. (2010)
	• Create a climate in which mistakes and failures are accepted to trigger curiosity in children.	Marks (2017); Marks and Chase (2019)
Materials & Resources	• Prefer appealing modern technologies/kits (e.g., Lego-Logo, Lego NXT kits, Scratch, Raspberry Pi, LilyPad) that engage children, triggering their curiosity and building up their enthusiasm.	Sáez-López and Sevillano-García (2017)
	• DBL should not neglect the need for well-structured materials and resources (e.g., instructional worksheets) to motivate children and trigger their interest and curiosity in the topics covered.	Doppelt and Schunn (2008)
Teacher's Role	• Carefully regulate the amount of support so that children feel independent about their learning	Doppelt and Barak (2002)
	• Show interest in students' achievements (e.g., their design ideas, designs created, and progress in projects).	Hugerat (2016)
	• Actively help children draw links between their tasks and the design challenge.	Penuel et al. (2016)
	• Moderate peer feedback moments, to enable children to listen and accept peer critique and feedback.	Zhang et al. (2019)
	• Provide emotional regulation support for children, especially during iterations.	Vongkulluksn et al. (2018)
Grouping	• Try to create a comfortable atmosphere within mixed-gender groups, especially in cases where they contain a gender minority.	Guo et al. (2016, 2017)
	• Try to cultivate children's sense of responsibility and encourage them to volunteer to offer help to peers.	Chu et al. (2017)
	• Involve various stakeholders (e.g., those with external businesses as clients, involving professionals as experts, and consulting intended users).	Milam et al. (2016); Phusavat et al. (2019)
Time	• Carefully set a feasible project time constraint, considering the complexity of the design challenge and the checkpoints during the project.t	Vongkulluksn et al. (2018)

attention to the role of negative emotions during a DBL activity and how to help children cope with their potential adverse effects.

In particular, research is still needed to develop a comprehensive understanding of the impact of emotions during DBL. This is because we cannot assume that the results of examining the role of emotion in children's learning and their engagement within a traditional learning context could transfer to a DBL context in which learning tasks are different. The degree of engagement is highly contingent on the context of learning. Moreover, it is not clear that positive emotion is always conducive to better student performance during DBL. For example, fundamental research on learning and memory in laboratory settings (Fiedler and Beier 2014) reveals that, compared to a positive mood, a negative mood leads to increased accuracy, careful responding, and fewer heuristic mistakes. Future research should examine the impact of emotions—and especially negative emotions—on DBL, and scrutinize the potential negative impact of positive emotion on a DBL task and on engagement with it.

Implications for Practice: DBL Guidelines (Aim 5)

Previous research has shown that a positive environment can encourage creative thinking and open-mindedness (Hascher 2010). Based on the potential relationship between students' emotions and DBL components in the literature surveyed, we compile a list of guidelines as implications for instructional practice, with the aim of designing DBL activities that will foster a positive emotional response in children. These guidelines, as shown in Table 9 which were derived from the cases in the studies reviewed that are specific to DBL, are presented within the structure of DBL components discussed above.

It is important to note that this list of guidelines has only been discussed piecemeal in the studies reviewed and covers the DBL components only partially. Future work could aim to validate the impact of this set of guidelines in practice and to extend the guidelines to cover the remaining DBL components.

Conclusion

This review of children's emotions in the context of DBL compiled accumulated evidence for several advantages related to this approach: excitement, satisfaction, pride, enjoyment, enthusiasm, curiosity, happy students, relaxing, interest in taking part, self-efficacy, a favorable attitude to the teacher, and a greater interest in science. Moreover, most of the studies reviewed demonstrated DBL's strength in engaging and motivating underrepresented students in learning STEM subjects, including low-achieving students, female students, and students with disabilities. Nevertheless, such beneficial evidence is piecemeal and equivocal, as the studies mostly reported on students' emotions as a secondary issue, leaving many questions unanswered regarding the emotional aspects of DBL. The affective benefits of DBL are compelling in their own right. However, in the literature surveyed, they are often considered as instrumental for further aims (e.g., attracting students to scientific and technological higher education, or attracting females to engage with programming). On the other hand, assessing affective outcomes is also useful for profiling the quality of the educational process and consequently for improving the DBL process (e.g., how much students are motivated to do homework, their self-efficacy, and curiosity). However, relatively few studies focus explicitly on measuring emotions in order to improve the experience of the student in DBL. In this regard, the authors have identified some elements that may be key for successful DBL: exploring the effect of emotions on DBL, establishing a framework for dealing with students' emotions in order to have successful DBL, involving the teacher's expertise and conduct, providing an environment that is safe from critique and in which it is safe to fail, and engaging students in activities which they will find meaningful. Overall, this literature review provides an overview of the state of the art relating to K-12 students' emotions when engaged in DBL, providing a detailed description of these along with the key components of DBL.

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