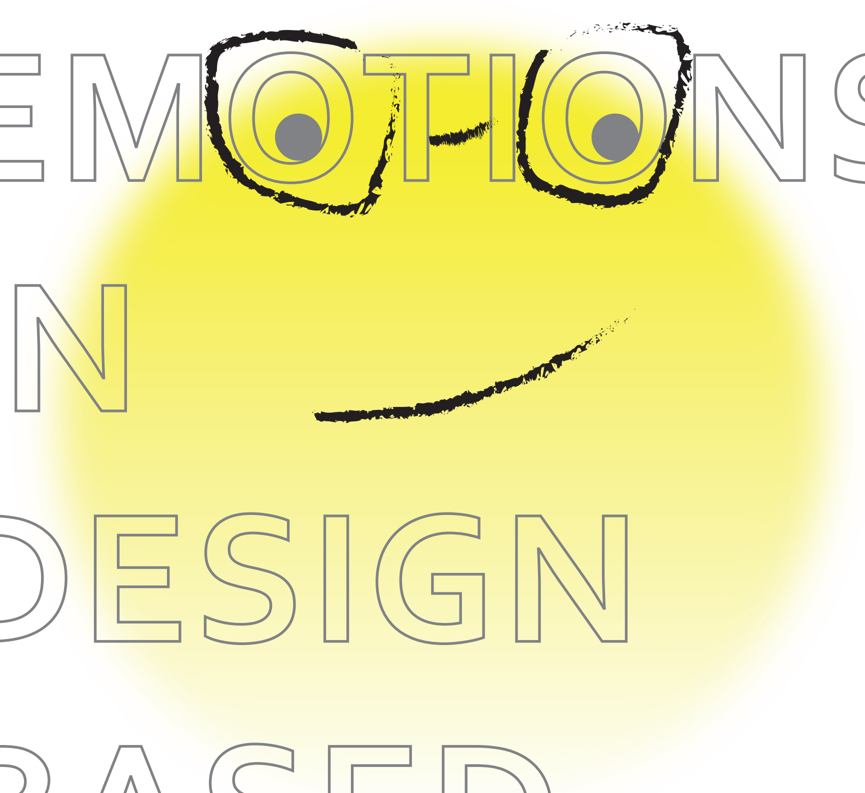
Emotions in Design-Based Learning



EMOTIONS IN DESIGN BASED LEARNING

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Doctoral Dissertation
by

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Emotions in Design-Based Learning

THESIS

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus prof.dr.ir. F.P.T. Baaijens,

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door

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geboren te Hunan, China

Dit proefschrift is goedgekeurd door de promotoren en de samenstelling van de promotiecommissie is als volgt:

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Het onderzoek of ontwerp dat in dit thesis wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

Summary

Design-based learning (DBL) is an approach to learning where students learn in a self-directed way working on open-ended design challenges that are meaningful to them, creating a public artifact that communicates their solution to the challenge [1]. DBL has been shown to help students develop twenty-first-century skills such as problem-solving, critical thinking, and collaboration. Emotions are regarded as playing an essential role in learning. This thesis examines how students experience DBL and explores the role emotions play in learning in DBL.

The inquiry into the role emotions can play in DBL started with a systematic literature review to capture the state-of-the-art in this field and an exploratory field observation involving students from a Dutch public high school (Heerbeeck College, Best). The theoretical and empirical evidence collected thus pointed out the need for tools for systematically capturing emotional data in the context of DBL. To address this need, we developed a self-reporting tool with an experience sampling approach tailored to the DBL environment. This tool was used in a three-month mixed-method field study involving students from a Dutch public high school (Eckart College, Eindhoven). This study helped gain an in-depth understanding of how students experienced emotions during a DBL curriculum. Furthermore, we conducted a qualitative study involving undergraduate students at a Dutch university (Fontys University of applied sciences, Eindhoven). This study aimed to examine learning and emotions during DBL in a post-secondary education context and speculate whether and how an emotion awareness tool helps DBL. Building on these results, we designed an intervention to support the social sharing of emotions in a school context. The intervention was evaluated in two case studies, which were carried out in the backdrop of the 2020 Covid-19 pandemic.

The works presented in this inquiry contribute to the intersection of Child-Computer Interaction and Learning Sciences fields, particularly to the sub-field focusing on design and making in learning. The four main contributions of this thesis are described as follows: (1) It describes the role that emotions can play in learning and highlights their importance, which may encourage future researchers to contribute to this area as well. (2) It introduces the Activity-and-Affect Model, which conceptualizes students'

emotional experience of DBL from a multi-dimensional view. This theoretical contribution may pave the way for a fundamental basis of conceptualizing DBL for future related research. (3) It contributes to a set of DBL guidelines considering the potential interactions between DBL activities and students' emotions. This could inspire future research and practice on how to orchestrate DBL activities that will foster positive emotional responses in students. (4) This thesis makes methodological contributions to the development of emotion measurement and emotion-related intervention in DBL. Specifically, this thesis advocates three different approaches for capturing emotions in DBL and examines how to implement an intervention involving emotion awareness tools in DBL.

Published Work from this Thesis

Aspects of the research presented in this thesis have been published and accepted in peer-reviewed conferences and journals prior to the submission of this thesis. These are listed chronologically below:

- Zhang, F.; Markopoulos, P.; Bekker, T. (**2018**) The Role of Children's Emotions during Design-based Learning Activity - A Case Study at a Dutch High School. In Proceedings of the Proceedings of the 10th International Conference on Computer Supported Education; Vol. 2, pp. 198–205.

- Zhang, F., Markopoulos, P., Bekker, T., Schüll, M., & Paule-Ruíz, M. (**2019**). EmoForm: Capturing Children's Emotions during Design Based Learning. In Proceedings of FabLearn 2019 (pp. 18-25). ACM.

- Zhang, F. (**2019**) Supporting Design-based Learning from the Lens of Emotions. 14th European Conference on Technology Enhanced Learning Doctoral Consortium. CEUR Workshop Proceedings.

- Zhang, F., Markopoulos, P. & Bekker, T. (**2020**) Children's Emotions in Design-Based Learning: a Systematic Review. Journal of Science Education and Technology, 29, 459 – 481. https://doi.org/10.1007/s10956-020-09830-y

- Zhang, F., Markopoulos, P., Bekker, T., Paule-Ruíz, M., & Schüll, M. (**2020**) Understanding Design-Based Learning Context and the Associated Emotional Experience. International Journal of Technology and Design Education. https://doi.org/10.1007/s10798-020-09630-w

- Zhang, F., Markopoulos, P., Biekens, P., Peeters, L., & Bekker, T. Understanding learning and emotions in Design-Based Learning: what and why crucial to be considered. (**2020**) In Proceedings of ACM FabLearn conference FabLearn 2020. ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3386201.3386202

- Zhang, F., Markopoulos, & Bekker, T. “Emotion Awareness in Design-Based Learning, (**2020**) IEEE Frontiers in Education Conference (FIE), Uppsala, 2020, pp. 1-8, doi: 10.1109/FIE44824.2020.9273917.

One aspect of the research presented in this thesis is under review.

- Zhang, F., Markopoulos, P., An, P, & Schüll, M. (under review) Social sharing of task-related emotions in Design-Based Learning: challenges and opportunities.

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Chapter

ONE

Introduction

Chapter 1: Introduction

Abstract: Design-based learning (DBL) is a learning approach where students learn in a self-directed fashion working on open-ended design challenges that are meaningful to them, creating a public artifact that communicates their solution to the challenge. Motivated by the notion that emotions greatly influence the learning process, this thesis examines students' DBL experiences with the lens of emotions. To address this inquiry, the research presented in this thesis focused on the following aspects: (a) investigating students' emotions experienced during DBL, (b) conceptualizing the role of emotions, and (c) developing tools capturing and supporting students' emotional awareness amidst the DBL process. In this way, this thesis aims to advance knowledge on how DBL can be supported by considering students' emotions. In addition to an overall opening (Chapter 1) and closing (Chapter 9), the presentation of this thesis includes the following four sections: (I) *exploratory understanding* about emotions students experienced in DBL (Chapter 2-3); (II) *tool design and development* about capturing emotions in DBL (Chapter 4); (III) *case studies* about emotions and learning during students' DBL experiences in-and post-secondary education (Chapter 5-6); and (IV) *interventions* regarding the impact of self-awareness and social sharing of emotions in DBL, respectively (Chapter 7-8). Overall, the tools developed and the studies presented in this thesis primarily focused on secondary school students and were extended to a post-secondary education context.

This chapter is mainly based on the paper: Zhang, F. (2019). Supporting Design-based Learning from the Lens of Emotions. 14th European Conference on Technology Enhanced Learning Doctoral Consortium. CEUR Workshop Proceedings.

1.1. Background

"Kevin started by building a car out of LEGO. After racing the car down a ramp several times, Kevin added a motor to the car and connected it to the computer. When he turned on the motor, the car moved forward a bit--but then the motor fell off the body of the car and began vibrating across the table. Rather than trying to fix this bug (or giving up since his car had 'failed'), Kevin became intrigued with the vibration of

the motor. He began to wonder whether he might be able to use the vibrations to power a vehicle (Resnick, Ocko, and Papert 1988, p17 [2]*).”*

Kevin’s car prototype failed in attaching to a motor sensor, making Kevin likely experience a short moment of confusion and feeling upset. Soon after, Kevin’s curiosity started to play a role in exploring an alternative problem space. Some of the things portrayed in this scenario [2] may be conducive to learning. However, the learning context seems like a black box in which we do not know how and why learning occurs. From a research perspective, this lack of knowledge about factors influencing learning motivates the current doctoral research project [3] to study emotions during design and learning activities from a fine-grained perspective and help students deal with emotional resources that may facilitate or impede learning.

1.1.1. Emotions in Learning

“Emotions are the very stuff of what it means to experience the world.” (Cornelius, 1996, pp.3)[4]

Students spend many hours at school and experience varied and often intense emotions: they work and play there, they are evaluated, they experience friendship and belonging, but also disappointment and negative experiences. Students’ emotions like anxiety, pride, and frustration can often be triggered by many classroom events, e.g., taking an exam (or being assessed), teamwork, and the teacher’s instruction [5]. Despite a clear connection between learning and emotion, learning has been so far analyzed mostly in cognitive or motivational aspects [5]. There is a need for more research to examine the affective processes of learning.

Apart from the affective impact of an educational environment on students, emotions largely impact students’ learning and achievement. As an illustration, emotions can influence students’ attention, motivation, and engagement, but also they can modify their choice of learning strategies [6]. More specifically, previous research has shown that positive emotions can ease working on tasks and enable students to be open for feedback and recognize their mistakes [7,8]. Research has also noted that negative emotions may facilitate or impede learning, e.g., turning away from that learning situation [5]. Taken together, it is essential to consider students’ emotions in an educational setting. This might be why, in the past decades, the volume of research investigating the educational context with an emotional lens has been growing [9].

Furthermore, there are considerable differences in emotions experienced by different students even when undergoing the same situation and even within one culture [6]. Students can also differ in understanding who they are, what they are feeling, and how to react to emotions experienced in school [10], as their emotional development involves age-related change throughout childhood, adolescence, and adulthood. For example, early adolescence (approximately age 12) starts to gain more complex thoughts, information process, and reasoning, which allows them to interpret and understand emotions [11]. Understanding adolescents' emotions are critical [12], given that particular emotional states during this period could increase the risk of mental health and mood disorders [13]. In this thesis, we study students' emotions, primarily focusing on secondary school students (adolescents ages 12 to 15). We deemphasize the focus of how emotional development changes, given the fact that the changes associated with emotional experience during adolescence require a more extended period of ethnographic observation.

1.1.2. Design-Based Learning

The notion that design activities are essential in learning has already been pointed out and advocated in the last century. For example, Papert and Harel claimed that knowledge construction is optimal when students invent, make, and publicly share objects [14]. Resnick and Ocko argued that design activities have the most educational value when students are free to create meaningful things for themselves or others around them [15]. Davis, Hawley, McMullan, and Spilka argued that design is a powerful tool for transforming the curriculum and accommodating various ways students learn [16]. Inspired by this vision, there has been growing interest and implementation in incorporating design activities into education, e.g., [17–22].

With this backdrop, Design-Based Learning (DBL) has emerged as a learning approach that applies Design Thinking [23] in a problem-based or project-based learning context. The application of design thinking in learning allows students to develop designerly ways of doing and knowing [24] from moving back and forth of a sequence of design phases (e.g., insights, investigation, ideation, and implementation). In this way, students experience and construct the concepts and knowledge presented in the design project. This DBL process involves open exploration, learning from trial and error, reflection, teamwork, and supportive tools [25,26]. Other approaches that are compatible with DBL (e.g., [20,27–31]) include, design-based science (DBS; e.g., [18,32]), learning by design (LBD; [1,33,34]), learning through design [15], technological/engineering design-based learning (T/E DBL; e.g., [35,36]), and maker education (e.g., [37,38]) (see Table 1.1).

Table 1.1. Aims of the Approaches that are Compatible with Design-Based Learning (DBL)

Other terminologies	Aims/objectives
design-based science (DBS; e.g., [18,32])	Students construct scientific understanding and real-world problem-solving skills by engaging in the design of artifacts.
learning by design (LBD; [1,33,34])	Students learn science content and develop the skills and understanding needed to solve ill-structured problems by achieving design challenges.
learning through design (e.g. [15,39])	Students can learn about mathematical and scientific ideas and the design process itself while working on design projects.
technological/engineering design-based learning (T/E DBL; e.g., [35,36])	Students can achieve a blend of learning end-goals, e.g., STEM content and practices that are both requisite and inherent to the design of the technological/engineering solution.
maker education (learning by making; e.g., [38,40])	Students engage and experiment with media and the materials while constructing knowledge and collaborating.

Specifically, David et al. [18] pointed out the idea of incorporating design activities into education, especially in science education, has received much attention by researchers, e.g., in the UK [41] and in the US [19,42]. As an illustration, Kolodner et al. (e.g., [19,43,44]) developed programs targeting secondary school students from grades 6 to 8 in the US. In this case, the design challenge is used to help students identify what they need to learn and structure their multiple iterations of constructing, evaluating, and revising.

In this current thesis, we refer to the conception of DBL developed by Kolodner et al. [1] that is based initially on conceptual underpinnings taken from Case-Based Reasoning [45] and Problem-Based Learning [46]. In particular, we investigate DBL programs implemented in the Netherlands that are consistent with the key characteristics documented in the studies abroad.

1.1.3. Design-Based Learning and Emotions

Students may sometimes experience powerful emotions during DBL. Emotions can be pretty intense when dealing with and learning from trial and error, working collaboratively in a team, and interacting with the teacher [47–50]. For example, the student may frequently make mistakes and experience failures when building and testing prototypes and developing design concepts. Rather than such a failure resulting in negative emotions, e.g., feeling disappointed or anxious as one would expect in a traditional learning context, such episode may trigger curiosity, excitement, or motivation to explore new design solutions in DBL. This apparent contradiction to earlier conceptions of the role of emotions in the classroom calls for a focused investigation as to whether such conceptions apply to DBL or if other contingencies characterize emotions in a DBL environment. This thesis, therefore, sets out to understand these emotional facets of DBL.

1.1.4. The Scope and Grounding of this Research

In this thesis, we study the phenomenon of emotions from a student's perspective; a comprehensive investigation of emotions from a teacher's perspective is beyond the scope of this research. We first reviewed related DBL studies that involved young students in the K-12 range in gaining an overview of evidence described in the literature. Followed-up, we carried out studies that primarily focused on secondary school students (students aged between 12 and 15) and were extended to a post-secondary education context (with 3rd-year undergraduate students). All the field studies presented in this thesis were conducted during 2016 and 2020 in the Netherlands.

The theoretical pillar of **emotions** in this thesis is the control-value theory (CVT) of achievement emotions [51,52], which provides a social-cognitive perspective on students' emotions, integrating assumptions of attribution and expectancy-value approaches [53]. In line with this theory, Pekrun also devised a classification of academic emotions [4], including not only achievement emotions and three other academic emotions (e.g., epistemic, topic, and social emotions). We choose this as the theoretical grounding of emotions in this research, considering its relevance for students' cognitive, motivational, and social aspects of learning within academic settings.

Further, this thesis studies DBL in the classroom context based on the theoretical pillar of the **DBL framework,** building on earlier definitions of DBL, e.g. [16,19,22,28,54–57] and related frameworks of DBL, e.g. [25,27]. This thesis also refers to the **curriculum development framework** [58] as a pedagogical pillar, which provides a general structure of the learning activity framework in school education. We choose them as the theoretical grounding of the DBL concept in this thesis as these are valid frameworks for use in a formal learning context.

1.1.5. Research Challenges

By reviewing the literature on studying or measuring student's emotions within the DBL context, this thesis identifies three main challenges, as follow:

C1 - The methodological challenge of measuring emotions in the DBL context.

There is increasing attention on studying or measuring emotion as a part of effectiveness evaluation of DBL, e.g., [29,59–61]. Unlike emotion research in laboratory settings, studying or measuring emotions within the DBL context takes place in a natural environment. This makes the data collection in DBL more complex and challenging than laboratory studies. Research methods such as interviews, focus groups, observations, videotaping, and questionnaires are commonly used to measure emotions in the DBL context. Surveys (e.g., using questionnaires for emotion measurement) pertain to pre-and-post evaluation of students' overall emotional state before and after the DBL intervention are not sufficient or explicit in examining the relationship between specific emotions and contextual DBL factors. Therefore, there is a need for methodological development of emotion measurement within DBL to ensure the collection of reliable and informative data.

C2 - The understanding of the constructive component of the DBL context is lacking.

Our knowledge about the DBL components is still limited. For instance, earlier DBL frameworks (e.g. [1,25,62]) address the critical elements of instructional settings, such as the teacher's role, assessment, design elements, project characteristics, reflection, and collaborative learning. These elements are interweaved when zooming into specific affective contextual DBL factors. As an illustration, when a teacher is coaching a team of students on their design process, the aforementioned instructional elements (e.g., the teacher's role, the design element, and collaborative learning) are interrelated. Therefore, these elements cannot be treated independently from each other as has been done for different aspects of DBL. Moreover, given the complex nature of a highly opportunistic [63] design process and self-directed learning in a DBL context, a more fine-grained understanding and description of students' activities experienced in DBL seems to be lacking.

C3 - Tools supporting emotion awareness in the DBL classroom are lacking.

Scaffolding emotional experiences are considered essential for successful learning and teaching [49,64,65]. This is especially true in the context of DBL for two reasons. First, DBL is an emotional place where collaboration, negotiation with peers, or conflicts in teamwork may elicit students' emotions. Consequently, students need to develop the ability to identify their feelings timely during the process. Second, students following such an active learning approach as DBL have to take responsibility for their projects [62] and develop skills to control their emotions. However, little prior work has been done, and little is known about developing and designing such a tool that will support emotion awareness in the context of DBL.

1.2. Research Questions

To summarize, the consideration of emotions in DBL highlights an interesting tension: a further and better understanding of constructing, designing, and developing a DBL environment necessitates the investigation of emotions as a probe to the DBL environment. Importantly, such an investigation can provide fundamental knowledge and advance the understanding of means to support the DBL classroom using emotions as an educational tool. The research questions in this doctoral research are elaborated as follows:

RQ1. *What is a suitable tool for capturing students' emotions in DBL?*

- 1-a: How students' emotions were measured in DBL?
- 1-b: What should be considered for a tool capturing students' emotions in DBL?

RQ2. *What are the affective DBL components that influence emotions?*

- 2-a: What are the components that can be used to describe DBL systematically?
- 2-b: What are the DBL components that may have an impact on students' emotions?

RQ3. *What are the impacts of emotions and emotional awareness on DBL?*

- 3-a: What are the effects of emotions in DBL?
- 3-b: How students' emotion awareness influence DBL?
- 3-c: How students' sharing of emotions influence DBL?

RQ4. *How can we support DBL taking into account student's emotions?*

- 4-a: How can we take into account students' emotions in different phases of DBL?
- 4-b: How can students' emotion awareness support DBL?

- 4-c: How can social sharing of emotions support DBL?

1.3. Research Approach

Design-based research (also known as design research in education) [66–68] is an emerging paradigm in educational research, highlighting the intertwined nature of design and research. By definition [69], design-based research is "*a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories* ([69] *p.6)*". It has been advocated that design-based research can compose a coherent methodology that bridges theoretical research and educational practice [67] and is suitable to address complex problems in educational practice for which no clear guidelines for solutions are available [68]. Previous DBL research [70] has already used the design-based research approach to understand, compare and evaluate the complex situations of students' DBL experiences through iterative analysis and implementation.

We assume design-based research is a suitable methodological framework for the investigation described in this thesis for two reasons. First, research on emotions in DBL is still a developing realm, which is relatively unexplored; we do not yet understand the emotional facets of the DBL context well enough to propose concrete testable hypotheses relating to our research questions. We do not yet know how emotional data can be collected during DBL in the first place. Assessing emotions in DBL is not a straightforward task as emotions are malleable and responsible for the complex DBL processes in a naturalistic setting. Experimental research has very limited ecological validity in such a naturalistic setting of DBL. Second, the solution direction needs to be both theoretically and practically relevant. The approach of this research project matches the nature of design-based research in that its central goal of advancing our knowledge about the characteristics of learning and the processes to design and develop learning are intertwined. This research project involves several research stages through a continuous cycle of sub-studies with a *descriptive* aim (e.g., RQ2), *explain* aim (e.g., RQ3), or *design and develop* aim (e.g., RQ1 and RQ4).

Various methods have been applied and adopted in the different parts of this research within a design-based research methodological framework. For example, methods including interviews, naturalistic observation, and diaries have been used in multiple cases following a case-study methodology to understand the nature of DBL activities and how emotions are experienced.

Further, a descriptive and theoretical model is proposed to codify the insights emerging from the case studies and inform the design of an intervention, which is evaluated in a design research approach.

1.4. Thesis Structure

Given the importance of emotions in learning, there comes a need to use a suitable instrument to measuring emotions (**RQ1**) and to have a further and better understanding of the role of emotions in DBL (**RQ2-3**). Such an investigation is an important step in defining the DBL experience and laying the foundation for emotion awareness tools that might support the DBL classroom (**RQ4**).

The presentation of this thesis includes the following four sections (as also seen in Figure 1.1): (I) **Discovery**: initial familiarization with the field, in which we address exploratory understanding about emotions students experienced in DBL through a literature review and a pilot case study. (II) **Definition**: tool design and development, in which we introduce tools such as EmoForm, EmoLens, and EmoWatch for capturing emotions in DBL. (III) **Development**: case studies of emotions in DBL in and post-secondary education. We present a case study with high school students and a case study with undergraduate students in the Netherlands. (IV) **Demonstration**: application of self-awareness and social sharing of emotions, in which we report intervention studies with undergraduate students and high school students, respectively.

Below, we outline the abstracts of these four sections and highlight the research questions addressed in each chapter:

Section I: Discovery: Initial Familiarization with the Field

Chapter 2 – A Systematic Literature Review

This chapter presents a systematic literature review that examines current research on studying or measuring emotions in DBL (to answer **RQ1a**). Specifically, this review classifies the affective DBL components (to partly answer **RQ2**) and establishes the relation between DBL components and students' emotions (to partly answer **RQ3a**) in the secondary education context. We also compile a list of guidelines for designing DBL activities (to partly answer **RQ4-a**) in this chapter.

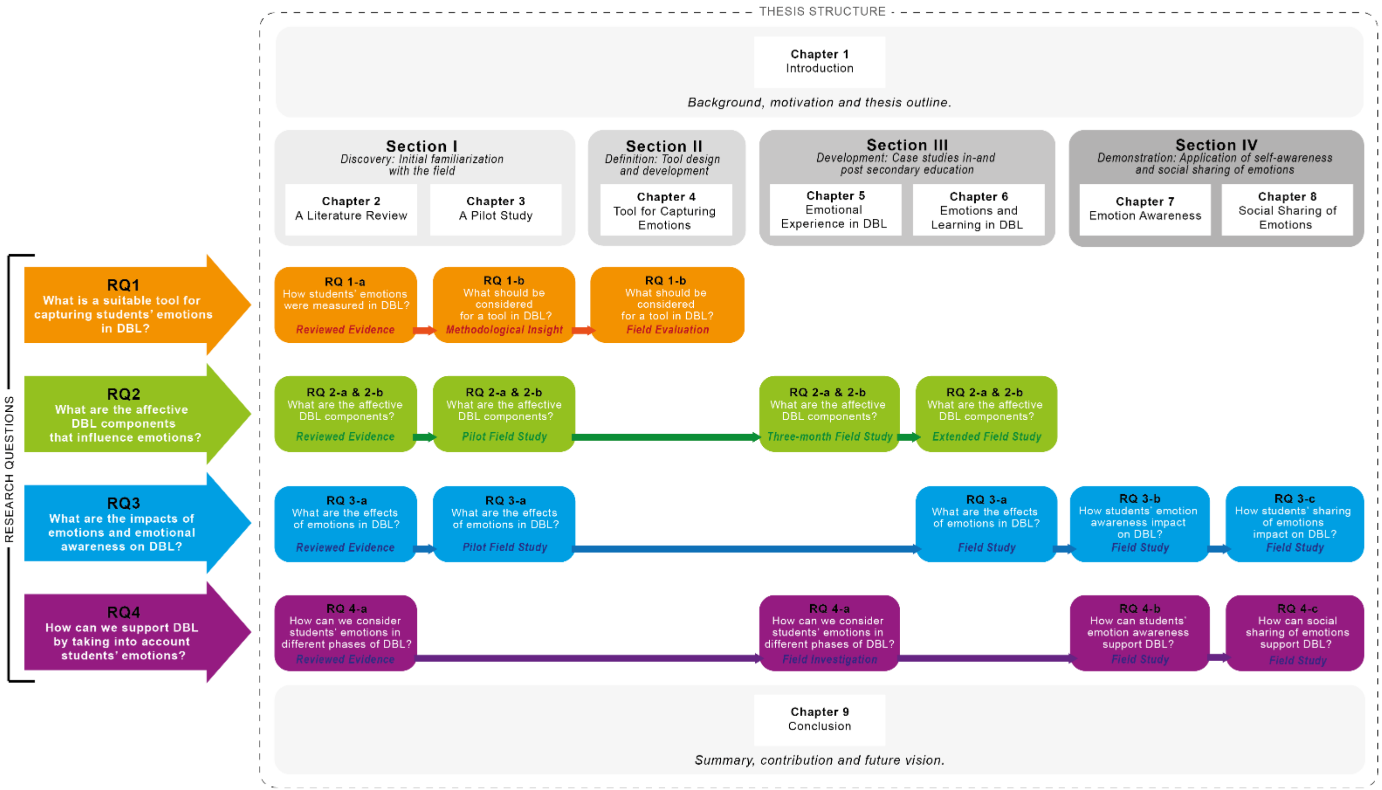

Figure 1.1. Visual Overview of the Thesis Structure

Chapter 3 – A Pilot Case Study: At a Dutch High School

In chapter 3, we report an exploratory case study at a Dutch high school (Heerbeeck College, Best) that was explored in the early phase of this research to develop a deeper understanding of students' emotional experience during DBL (to partly answer **RQ2** and **RQ3a**). This chapter contributes to several methodological insights regarding conducting emotion research in the realm of DBL (to partly answer **RQ1b)**.

Section II: Definition: Tool Design and Development

Chapter 4 – Tool for Capturing Emotions: EmoForm and other Possibilities

In this chapter, we introduce *EmoForm,* a research tool used to measuring emotion changes over time in the DBL classroom (to answer **RQ1b**). We constructed this tool based on existing approaches for recording emotions and a general model of DBL. We also implemented the reliability and validity evaluation of this tool embedded in a three-month-long DBL project.

To illustrate future directions regarding tools for capturing emotions in DBL, we present two works-in-progress tools: (1) *EmoLens*, a working observation toolkit for use in the DBL classroom; and (2) *EmoWatch*, a sensor-based wearable device for self-recording emotions in the DBL classroom.

Section III: Development: Case Studies of Emotions in DBL in-and post-Secondary Education

Chapter 5 – Emotional Experience in DBL: A Three-month Field Study

Chapter 5 presents a three-month field study at a Dutch high school (Eckart college, Eindhoven) that aims to reconstruct the manner and sequence of activities during DBL at a fine-grained level of description and examine the relationship between these activities and students' emotional experiences (to answer **RQ2**). In this case study, we used a mixed-method research approach and collected survey data from EmoForm, observational data from EmoLens, and interviews.

Based on this data, the Affect-and-Activity model of DBL is introduced for describing the dynamic interaction with types of activities and its associated emotions experienced in DBL. The three dimensions in this model are identified and provide the backbone of this DBL model, showing how each contributes to the broader view of DBL and its associated emotions. We also discuss implications regarding support for DBL, taking the students' feelings into account (to partly answer **RQ4a**).

Chapter 6 – Emotions and Learning in DBL: In a University Environment

Chapter 6 reports a case study at a Dutch university (Fontys University of Applied Sciences, Eindhoven), investigating DBL aspects that allow learning and emotions to occur. More specifically, we present the results in three parts: (a) an empirical understanding of students' perception and attitude of learning in DBL (to partly answer **RQ2**); (b) students' perception of emotions' impact in DBL (to partly answer **RQ3a**); and (c) implications for educators steering DBL activities taking into account of students' feelings.

Section IV: Demonstration: Application of Self-awareness and Social Sharing of Emotions

Chapter 7 – Emotion Awareness: An Intervention Study

In chapter 7, we present an intervention study of using EmoForm to support emotion awareness in DBL. Our results illustrated the ways how self-tracking with EmoForm facilitates emotion awareness (to answer **RQ3b**). Furthermore, this chapter identifies some design choices to be taken into account in related emotion awareness tool development for the DBL classroom. Finally, we present a summary of strategies towards emotion awareness in DBL and discuss the design implications for future studies (to answer **RQ4b**).

Chapter 8 – Social Sharing of Emotions: An Intervention Study

In this chapter, we showcase an intervention (which is evaluated in two case studies) to help students share their feelings when doing a specific DBL task. Specifically, these two intervention studies aim to investigate how the sharing of task-related emotions influences students' DBL experiences (to answer **RQ3c**) and how to support the social sharing of task-related emotions conducive to DBL (to answer **RQ4c**). This study reveals how the students experienced this social sharing of task-related emotions and their values through this experience and use of the toolkit. This chapter also discusses implications for extending the positive effect of emotion sharing to broader learning contexts following an active learning approach.

[Section I]

Discovery: Initial Familiarization with the Field

Chapter

TWO

A Systematic Literature Review

Chapter 2: A Systematic Literature Review

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 21st 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 chapter presents a systematic survey of literature published in the last twenty years (searching from 1998 until 2019) and indexed in the Scopus, ERIC, and PsycINFO databases, which contribute to our understanding of students' emotions in DBL. This review coded a total of 34 papers that met the inclusion criteria. Findings that reported on students' emotions are structured under three themes: (1) the affective DBL components; (2) the labeled emotions; (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.

This chapter is based on the paper: Zhang, F., Markopoulos, P. & Bekker, T. (2020) Children's Emotions in Design-Based Learning: a Systematic Review. J Sci Educ Technol 29, 459–481. https://doi.org/10.1007/s10956-020-09830-y

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2.1. Introduction

In the 1960s, Seymour 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 [15]. 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 [15]. 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 [71]. 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. [59,60,72]. Following the same constructionist principles, others have developed their own child-friendly programming-based learning environments, e.g. [73–75].

Two decades ago, Kolodner presented a set of guidelines for "Learning by Design" [19] based on case-based reasoning [1] and problem-based learning [76]. 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 [19]. Kolodner and her colleagues implemented the "Learning by Design" approach in a series of science education projects for secondary school students (grades 6 to 8) between 1995 to 2004, demonstrating its efficacy for learning science content and developing skills [1,34,77].

The notion of "Design-Based Learning" (DBL) has been emphasized in several empirical investigations, targeting K-12 education from 1969 to date, e.g. [20,78]. Nelson [20] 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 percent in their test scores. However, it is not always clear what the test scores in this study assessed. Some studies evaluated DBL, e.g. [22,30], targeting STEM subjects and demonstrating that students using the DBL units gained significant knowledge in terms of science conceptions. More specifically, Mehalik et al. [22] 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 that are designed to actively solve ill-structured problems, which is similar to problem-based learning, are seen as potentially suitable for preparing young students for life-long learning [76]. 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 chapter, emphasizing their similarities rather than various subtle differences between them.

Beyond any specific learning approach, an essential aspect of learning relates to emotions. One view is that emotion helps students persevere, sustains motivation, and directs their behavior [79]. Similarly, Skinner et al.

[80] 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 [80]. 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 [81]. Moreover, emotion can trigger the recall of memories consistently across contexts, depending on past similar learning experiences [82].

When it comes to young students, 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 young students in learning how to gain knowledge and skills independently, which is 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 [83].

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 to understand the current situation as described in the literature. Despite the fact that the primary focus of this research is to understand the emotions that secondary school students experience in DBL, this review includes the range of K-12 students to gain an overview of how younger students emotionally experience DBL as described in the literature.

Specifically, this chapter addresses the following research questions:

- How students' emotions were measured in DBL in current literature? (RQ1-a)
- What are the affective DBL components that influence students' emotions? (RQ2)
- What are the effects of emotions in DBL? (RQ3-a)
- How can we take into account students' emotions in different phases of DBL? (RQ4-a)

This chapter is structured as follows: sub-section 2.4.1 presents the overall current situation of students' emotions as described in the DBL literature. This is followed by sub-section 2.4.2, which reports the affective DBL components which influenced students' emotions (RQ2). Sub-section 2.4.3 describes an overview of what and how emotions were measured in a

DBL context (RQ1a). Follow-up sub-section 2.4.4 outlines the impact of emotions on students' participation in DBL (RQ3-a). This chapter ends with discussing implications for designing DBL activities, taking into account students' emotions that may support their learning (RQ4-a), as seen in subsection 2.5.2.

2.2. Background

2.2.1. 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 [23] in a problem-based or project-based learning context. In general, DBL involves open exploration, learning from trial and error, reflection, teamwork, and supportive tools [26].

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. [26,29,90,30,61,84–89] did mention DBL explicitly. While others [91–93] mentioned makerspace and maker activities that suggest a specific type of DBL, emphasizing the essence of making in constructive learning. Four studies [94–97] explained that their cases include embedded design thinking in learning activities. Five studies [98–102] presented a design project for learning STEM, while one study showed a series of design projects for learning literacy [103]. More specifically, four studies described an Arduino-based programming activity [73–75,104], while another five studies [59,60,72,105,106] 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 [84] mentioned DBL but did not provide enough detail to allow readers to evaluate the extent to which it actually implements a DBL approach. Another [107] 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. [16,19,22,28,54–57] and related frameworks of DBL, e.g. [25,27]. In addition, the structure of these characteristics refers to a general structure of the learning activity framework proposed by Akker et al. [58], classifying these characteristics by whether they refer to the learning activity, the teacher, or the grouping of students. In Table 2.1, we present the papers resulting from

Table 2.1. Checklist of DBL Criteria Applied to Selected Studies.

Study	Learning Activity				Teacher Role	Materials & Resource		Grouping	
	Open-end	Authentic	Mult	Design process	Coach	Hands-on	Minds-on	Student-centred	Co-creation
Apedoe 2008 [30]	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Bagiati 2010 [84]	N/A	N/A	N/A	N/A	Y	N/A	N/A	N/A	N/A
Barak 1999 [59]	Y	N/A	N/A	Y	N/A	Y	Y	N/A	Y
Buechley 2008[73]	Y	Y	Y	Y	Y	Y	N/A	Y	N
Carroll 2010 [85]	Y	Y	Y	Y	Y	Y	Y	Y	Y
Chan 2019 [91]	N/A	N/A	N/A	Y	N/A	Y	Y	N/A	Y
Chu 2017 [92]	N/A	Y	N/A	N/A	Y	Y	N/A	Y	N/A
Council 2018 [107]	Y	Y	Y	N/A	Y	Y	N/A	Y	Y
Doppelt 2003 [105]	Y	Y	Y	Y	N/A	Y	N/A	N/A	N/A
Doppelt 2002 [72]	Y	Y	N/A	Y	N/A	Y	Y	Y	N/A
Doppelt 2008 [86]	N/A	Y	Y	Y	N/A	Y	Y	Y	N/A
Giannakos 2013 [74]	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Giannakos 2014 [75]	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Guo 2016 [87]	Y	Y	Y	Y	N/A	Y	Y	Y	Y
Guo 2017 [88]	N/A	N/A	Y	Y	N/A	Y	Y	N/A	N/A
Hendricks 2012 [60]	Y	Y	Y	Y	N/A	Y	Y	N/A	Y
Hugerat 2016 [98]	N/A	N/A	N/A	Y	Y	N/A	N/A	Y	Y
Karahoca 2011 [99]	N/A	Y	Y	Y	Y	Y	Y	Y	Y

Lacy 2016 [89]	Y	N/A	Y	Y	N/A	Y	Y	N/A	N/A
Li 2018 [106]	N/A	Y	N/A	N/A	N/A	Y	N/A	Y	N/A
Marks 2017 [94]	Y	Y	N/A	Y	Y	Y	Y	Y	Y
Marks 2019 [95]	Y	Y	N/A	Y	Y	Y	Y	Y	Y
Menzies 2016 [103]	Y	Y	Y	N/A	N/A	N/A	N/A	Y	Y
Milam 2016 [100]	Y	Y	Y	Y	N/A	N/A	N/A	N/A	Y
Neve 2017 [61]	N/A	N/A	Y	Y	N/A	Y	Y	N/A	Y
Nix 2014 [101]	N/A	N/A	Y	Y	N/A	Y	N/A	N/A	Y
Penuel 2016 [102]	Y	Y	Y	N/A	Y	N/A	N/A	N/A	N/A
Phusavat 2019 [96]	Y	Y	N/A	Y	Y	N/A	N/A	Y	Y
Reynolds 2009 [29]	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A	N/A
Sáez-López 2017 [104]	Y	Y	Y	Y	N/A	Y	Y	Y	N/A
Tae 2017 [97]	N/A	Y	Y	Y	N/A	Y	N/A	N/A	N/A
Vongkulluksn 2018 [93]	Y	Y	Y	Y	Y	Y	N/A	Y	Y
Zhang 2018 [26]	Y	Y	Y	Y	Y	Y	Y	Y	Y
Zhang 2019 [90]	Y	Y	N/A	Y	N/A	Y	N/A	N/A	Y

Annotation: Mult multidisciplinary.

this survey in terms of DBL characteristics, 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 mind-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.

2.2.2. 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 [4]. From the Jamesian perspective, bodily changes evoke the feeling state of emotion [108].

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 [109]. The social constructivist perspective describes emotions as socially constituted syndromes or transitory social roles [110]. Across these different perspectives, terms such as *feeling*, *mood*, *affect,* or *affective response* are generally considered akin to emotion [5,111].

A variety of theories and models relate to emotions in learning. The control-value theory [51,52] provides a social-cognitive perspective on students' and teachers' academic emotions, integrating assumptions of attribution and expectancy-value approaches [53]. Based on the proposition that emotions and appraisals play a prominent role in self-regulation theory, the dual processing self-regulation model [112] highlights two self-regulatory pathways of emotions and appraisals. The affective model of emotions and learning [113] 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 [5]. 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.

2.2.3. Related Studies

Puente and colleagues [27] have surveyed crucial DBL characteristics in higher engineering education, contributing a deeper theoretical understanding of the DBL approach. Another study [114] contributed to the relationships between emotions and their antecedents and outcomes in the context of a technology-based learning environment. Moreover, Davies et al. [115] 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. This chapter presents the first literature review to reveal students' emotions in DBL.

2.3. Method

2.3.1. Literature Search Strategy

We carried out a systematic literature review following the approach taken by [116] 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 2.2.

Table 2.2. 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
Students	("child*" OR "pupil*" OR "school*")

2.3.2. Study Selection Process

The selection process followed the steps outlined in the PRISMA guidelines [117], as shown in Figure 2.1. 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 the title and abstract screening, full-text analyzing, and rolling back to relevant studies in the reference of selected papers. As seen in Appendix A, 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 [118].

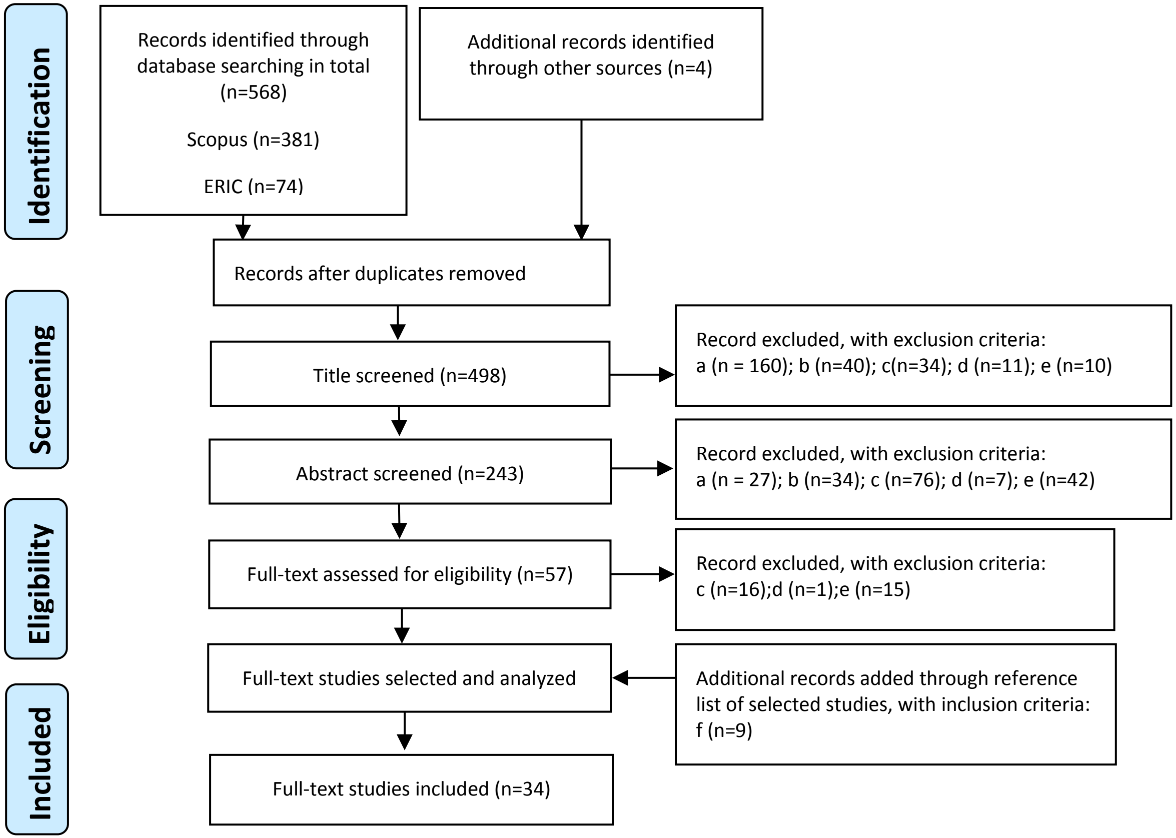


Figure 2.1. PRISMA Flow Chart of the Study Selection Process.

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 that 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.

2.3.3. 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 Akker and colleagues [58]. 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?),
- Material and Resources (with what are they learning?),
- Rationale (why are they learning?).

This chapter reports on the DBL components that influenced students' emotions in the studies reviewed (as seen in section 2.4.2). In discussion section 2.5., this chapter proposes a set of guidelines with implications for researchers and practitioners designing DBL from the perspective of DBL components.

Labeled Emotion Extraction

This chapter classifies related studies in terms of the four categories of academic emotions in the classification scheme devised by Pekrun [6]. This categorization was preferred because these emotions within academic settings are especially relevant for students' 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 2.4 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.

2.4. Results

2.4.1. Overview of Reviewed Papers

The selected papers are summarized and compared in Table 2.3, which also includes standard elements of a systematic literature review, namely the primary research method used for examining emotions, the geographic and year distribution, 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 2.3. Some studies used tailor-made questionnaires. For instance, one study [86] developed the DBLEQ questionnaire for measuring how students 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 [90] developed the EmoForm questionnaire for capturing students' DBL activities and their associated emotions. 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 [26] introduced an Emotion card for recording students' overall feelings during each DBL session, which was used together with an adapted Geneva Emotion Wheel (GEW) [119].

Interviews and observations are often combined in order to understand students' emotions, e.g. [85,89,93]. For instance, one study [85] used an ethnographic approach, including observation and pre-and post-project interviews. Another study [89] combined observations and interviews with both students and teachers.

Likewise, video coding has been used as an approach to studying emotions. For example, one study [87] conducted a video data analysis of DBL sessions to carefully examine the factors (including behavioral, cognitive, and emotional factors) affecting female students' engagement. However, their analysis is confined to assessing the overall level of emotional engagement rather than analyzing and interpreting specific emotion indicators. Another study [92] combined a questionnaire-based survey with video coding. Their

Table 2.3. Summary of Selected Paper Description

Study	Location	Age*	Participant (N)	Setting (N)	Con	Duration time	Main research method
Apedoe 2008 [30]	USA	14-18	N(c)=79, N(i)=5	N/A	Y	8 weeks	Survey, observation
Bagiati 2010 [84]	USA	14-15	N(c)=83, N(i)=1	4 (class)	Y	N/A	Pre & post questionnaire
Barak 1999 [59]	Israel	15-18	N(c)=83	1 (school)	N	2 years	Interview
Buechley 2008 [73]	USA	10-14	N(c)=10, N(i)=2	1 (class)	N	T(c)=1 week, T(n)=15 hours	Survey
Carroll 2010 [85]	USA	12-13	N(c)=24, N(i)=5	1 (class)	N	T(c)=3 weeks, T(n)=12 hours	Ethnographic observation, pre & post interview
Chan 2019 [91]	USA	6-10	N(c)=15	3 (group)	N	T(c)= 2-4 months	Portfolio analysis, interview
Chu 2017 [92]	USA	8-11	N(c)=124, N(i)=6	3 (class)	N	T(c)= 4 days, T(n)=4.3 hours	Questionnaire, video coding, Survey
Council 2018 [107]	USA	7-12	N(c)=12	N/A	N	N/A	Survey
Doppelt 2003 [105]	Israel	16-18	N(c)=54, N(i)=10	5 (school)	N	3 years	Questionnaire, observation Interview

Doppelt 2002 [72]	Israel	15-18	N(c)=56	1(school)	N	5 years	Questionnaire, observation, interview
Doppelt 2008 [86]	USA	14-15	N(c)=464	9 (school)	Y	4-6 weeks	Questionnaire
Giannakos 2013 [74]	Norway	12, 17-18	N(c)=29 (in P1), N(i)=9 (in P1), N(c)=37 (in P2)	3 (workshop)	N	N/A (in P1), T(n)=5 days (in P2)	Interview, survey, observation
Giannakos 2014 [75]	Norway	12, 17-18	N(c)=37	3 (workshop)	N	5 days	Questionnaire
Guo 2016 [87]	USA	N/A	N(c)=15, N(i)=1	2 (class)	N	36 weeks	Video coding, interview
Guo 2017 [88]	USA	N/A	N(c)=185	51 (group)	N	N/A	Video coding, pre & post survey
Hendricks 2012 [60]	USA	13-14	N(c)=136 (in P1*), N(c)=84 (in P2*), N(i)=3	11 (class)	Y	4 weeks	Questionnaire
Hugerat 2016 [98]	Israel	15	N(c)=230	1 (school)	Y	N/A	Questionnaire

Karahoca 2011 [99]	Turkey	10-15	N(c)=16, N(i)=2	4 (group)	N	T(c)= 12 weeks, T(n)=about 17 hours	N/A
Lacy 2016 [89]	USA	N/A	N(c)=6, N(i)=2	1 (school)	N	30 days	Observation, interview, course handouts & student works
Li 2018 [106]	USA	14-18	N(c)=75	6 (school)	Y	1 year	Pre & post survey
Marks 2017 [94]	USA	10-12	N(c)=89	2 (class)	Y	T(n)= 9 hours, T(c)= 3 weeks	Pre & post survey
Marks 2019 [95]	USA	10-12	N(c)= 44	2 (class)	Y	T(n)= 9 hours, T(c)= 3 weeks	Pre & post survey
Menzies 2016 [103]	UK	11-12	N(c)=1328	12 (school)	Y	20 months	Survey, interview
Milam 2016 [100]	USA	N/A	N(c)=150	5 (school)	N	4 months	Emailing letters
Neve 2017 [61]	USA	N/A	N(c)=25, N(i)=9	8 (group)	N	4 weeks	Survey, focus group
Nix 2014 [101]	USA	13-18	N(c)=124, N(i)=2	4 (class)	N	9 months	Survey, observation
Penuel 2016 [102]	USA	N/A	N(c)=592, N(i)=11	8 (school)	N	8 weeks	Survey
Phusavat 2019 [96]	Thailand	10	N(c)=40, N(i)=3	1 (school)	N	N/A	Observation, interview

Reynolds 2009 [29]	USA	N/A	N(c)=193, N(i)=7	4 (school)	Y	8 weeks	Survey
Sáez-López 2017 [104]	Spain	10-11	N(c)=109	4 (school)	Y	T(c)=1 year, T(n)=20 hours	Questionnaire, interview, focus group
Tae 2017 [97]	Korea	7-8	N(c)=105	N/A	Y	N/A	Questionnaire
Vongkulluksn 2018 [93]	USA	8-12	N(c)=100	4 (grade)	N	1 semester	Questionnaire, observation, interview
Zhang 2018 [26]	Netherlands	12-13	N(c)=9, N(i)=2	4 (group)	N	T(c)= 2 weeks, T(n)= about 1.7 hours	Questionnaire, interview
Zhang 2019 [90]	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 student participants in the experiment group and involved in the data collection process. N(i) number of an adult participant 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. **Note:** *The ages presented in studies are equivalent to corresponding grades according to the local education system. *P1 stands for the first part of the survey/evaluation, P2 stands for the second part of the survey/evaluation.

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 [100] captured students' emotions from conversations in their emails corresponding with students, and another [91] captured emotions from students' 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 [102] helped identify the relative impact of different variables on students' emotions. Similarly, another study [93] performed hierarchical linear modeling to understand the changes in students' self-efficacy, interest development, and achievement emotions. The descriptive coding [120,121] for qualitative data analysis was also used in the studies reviewed, e.g. [89,93].

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 [96] 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 [101] reported students' 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 [86] examined pre-post differences in learning electronics, comparing a curricular DBL activity (n = 464) with a scripted inquiry (n = 248). Another study [29] compared students in their DBL program (n = 193) with other students (n = 262) in the same school's science classroom that did not implement DBL. Similarly, in [30], students 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 [98] compared DBL students (n = 230) in one school with students (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 [98], interest in taking a science class [86], and interest in engineering [29,30].

An attitude survey reported in [106] compared DBL intervention students (n = 75) with students (n = 26) who were enrolled in other science or math courses. Similarly, the study by [103] reported on an attitudinal survey comparing DBL intervention students (n = 1328) with students (n = 1516) in a control group that was not given access to intervention materials and professional development. Li et al. [106] reported that DBL did not significantly influence students' attitudes toward STEM careers, while [103] 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 [103], and engagement as well as stamina during problem-solving and while overcoming unfamiliar challenges in the classroom [106].

Within the general DBL context, one study [104] compared students (n = 109) in a DBL project using physical computing technologies (e.g., handling devices, sensors, and Raspberry Pi) with students (n = 35) in a DBL that did not involve such technological resources from two other schools. Similarly, a study [97] compared DBL students (n = 105) using advanced technology, e.g., IoT-based Cloudbit and MaKey, with students (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 [104], and their interest in topics related to science, technology, and mathematics was found to be enhanced as well [97].

A single case experiment [60] compared students' 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 [84] involved a total of 84 students 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 ten years before that. It appears that the rate of publication increased from 2016.

Student Population Sample

Most of the studies involved typically developing students, 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 [72,105] described a DBL program targeting low-achieving students, which lasted five 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 [107] 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 [107] explained, this study had selected a convenient sample of twelve 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 [74,75,87,88] reported on evaluations involving female students. Two studies [74,75] 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 the future. Two other studies [87,88] showcased two independent case studies about high school female students' engagement when learning biology during DBL. Notably, one of the studies [88] reported that girls were more motivated in groups with a majority of girls.

Similarly, a DBL Summer Bootcamp [61] targeted groups of students who are underrepresented in STEM education, and there was a one-week DBL workshop [73] 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, Bagitai et al. [84] conducted a study in a public gymnasium high school to investigate the effect of DBL on students' interest in engineering; a study by [101] was implemented in a special admit school; and a study by [85] 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 [29,102]. The study by [93], in particular, investigated the differences in students' emotions when engaged in DBL between a lower-level (e.g., Grade 3-4) and a higher-level class (e.g., Grade 5-6). Additionally, one study [100] 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.

2.4.2. The Affective DBL Components (RQ 2)

To provide an overview of how the studies we reviewed implemented DBL, we summarize and categorize these studies according to Akker's framework [58], which is discussed in the Methods section 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. [97,106,107], reported the overall effect of DBL on students' motivation or interest but lack 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 students' 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 students' attitudes to the overall subjects presented in their DBL program. For example, one study [60] surveyed students' interest in and attitude to a science class that implemented a DBL pedagogy. In this study, students 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 [98] reported students' 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 students' perception (e.g., level of satisfaction and enjoyment) about a science class involving DBL was more positive than in traditional learning. Furthermore, another study [86] 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 [73] 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, students' 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 students may not be transformed by brief exposure to such workshops so that they become intrinsically oriented toward technology topics but are mainly driven by the right choice of context and problem domain.

More specifically, another study [102] 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 a connectedness to the design challenge. Importantly, this study also concluded that the different abilities among teachers influenced the degree to which students perceived their learning tasks to be connected to the unit's design challenge.

Furthermore, in one study [93], the complexity of students' design projects was found to likely be linked to the development of students' interests. Vongkulluksn et al. [93] reported a quantitative trend that students' 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 students' declining interest and explained that the complexity of design projects probably had to do with students' overambitious goals for their projects.

The Learning Activity Component

One study [85] reported from their ethnographic case study that passive listening activities were likely to be related to students' boredom. This study described students' 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 students' preference for times spent on actively doing compared to sitting and listening.

Another study [92] reported instructional activity during DBL and its associated effect by video coding students' behaviors. For instance, Chu et al. [92] explained that sometimes students felt pleasure in explaining procedures to others, which potentially reinforced their understanding of concepts. Interestingly, Chu et al. [92] also mentioned that instructing others, however, was sometimes associated with feeling irritated or frustrated. Furtherly, Chu et al. [92] 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 student wanted to complete his/her own or others' activities at a higher standard than the other student wanted to. The second was when the students had to tell others how to do it but were not able to perform an activity themselves.

Vongkulluksn et al. [93] argued that students' frustration might be raised from the iterative design process. This study described a quotation from the student (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 [91] based on the analysis of students' portfolios briefly mentioned students' reflections involving emotions. Moreover, Zhang et al. [26] reported that most students in a DBL study perceived prototyping as their favorite activity, and some students 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 [90].

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 [72]. 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 [96]. 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*," [96]. 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 [98]. Finally, Penuel et al. [102] 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 [74] 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 [26,85].

A further study [87] reported that positive group interactions were the source of students' 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 [100] and fuels students' enthusiasm [96].

The Materials and Resources Component

There are a few considerations in the reviewed literature regarding the impact of materials and resources on emotions. Lacy [89] reported that they did not perceive any risk from equipment, while another study [92] 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 [59] mentioned that students felt curious about LEGO and the mechanism behind it. Finally, another study [86] 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. [93], who described a participant's positive evaluation of his progress and 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 & Objectives Component

Interestingly, in terms of failure and iterative practice, one study [94,95] in particular compared students' attitudes to failure in the process-focused mindset with a content-focused mindset during iterative prototyping activities. In this study, the learning objective for students 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 students, 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 students' attitudes to failure and their desire to make more iterations during prototyping.

The Time Component

Some reviewed studies, e.g. [60], performed a pre-and post-evaluation to examine the effect of their DBL interventions. Another study [93] investigated the development of students’ situational interest and achievement emotions at three-time points in a semester-long DBL curriculum. The quantitative analysis in this study showed that students 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, students’ 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 students’ emotions fluctuated, and their emotions changed as time progressed during the three checkpoints of the DBL project.

Besides, Vongkulluksn et al. [93] also mentioned the frustration and concern about time constraints in students’ projects during DBL.

2.4.3. Reported Emotions (RQ1-a)

Three types of research motivations for studying or measuring emotions are summarized in Table 2.4, 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, fourteen of the studies reviewed measured students’ attitudes and perceptions of the DBL environment. Two studies [72,86] adapted questionnaires from the curriculum design model [122] for measuring emotions aroused by the DBL classroom environment. Another study [98] adapted questionnaires from the class climate model in mathematics class [123] in order to measure students’ perceptions of DBL.

Similarly, twelve 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 [60,75]; 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 [106].

Table 2.4. 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 [59]	Interest, Curiosity, Enthusiasm	
Carroll 2010 [85]	Enjoyment, Boredom	
Council 2018 [107]	Enjoyment, interest	
Doppelt, 2003 [105]	Interest, Excitement, Enjoyment	
Doppelt 2002 [72]	Interest, Curiosity	
	The instrument referred to the questionnaire [122]	
Doppelt 2008 [86]	Interest, Curious	
	The instrument referred to the questionnaire [122]	
Hugerat 2016 [98]	Satisfaction, Enjoyment, Favourable	(1) Evaluate students' attitudes or perceptions of the DBL intervention outcome.
	The instrument was adapted from a validated questionnaire by [123]	
Lacy 2016 [89]	Relaxation, Comfortable	
Marks 2017 [94]	Affective reactions (incl. Terrible, anger, sad)	
	The instrument refers to School Failure Tolerance scale by [124]	
Marks 2019 [95]	Affective reactions	
	The instrument refers to School Failure Tolerance scale by [124]	
Menzies 2016 [103]	Enthusiasm, Enjoyment, Pride	
Milam 2016 [100]	Interest	
Penuel 2016 [102]	Excitement, Boredom	
	The instrument was adapted from the scale [125]	
Phusavat 2019 [96]	Satisfaction, Enthusiasm	

Apedoe 2008 [30]	Interest	(2) Evaluate students' motivation and interest in topics, careers, or future similar activities.
Bagiati. 2010 [84]	Interest	
Buechley 2008 [73]	Interest, Happy, Content, Ecstatic	
Giannakos 2013 [74]	Enjoyment, Satisfaction, Relaxation *The instrument has adapted the construct of enjoyment from* [126] *and of satisfaction from* [127]	
Giannakos 2014 [75]	Enjoyment, Happiness (incl. satisfied, excited, curious), Anxious (incl. insecure, helpless) *The instrument has adapted the construct of enjoyment from* [126] *and of happiness and anxiety from* [128]	
Hendricks 2012 [60]	Interest, attitude (incl. Tense, Nervous, Scare) *The instrument refers to* [129] *and* [130]	
Karahoca 2011 [99]	Interest, Enthusiasm, Curiosity	
Li 2018 [106]	Interest	
Neve 2017 [61]	Interest	
Nix 2014 [101]	Interest, Enjoyment, Excitement, Satisfaction	
Reynolds 2009 [29]	Interest	
Tae 2017 [97]	Interest, Satisfaction *The instruments referred to STEAM course satisfaction scale and affective achievement of STEAM scale from* [131]	
Chan 2019 [91]	Emotional reflection	(3) Understand students' emotions, fun, and emotional engagement
Chu 2017 [92]	Fun (incl. Satisfaction, Frustration) *The instrument has adapted the smileyometer* [132]	
Guo 2016 [87]	Interest, Curiosity, Enjoyment, Frustration	

	The instrument refers to the video coding indicator developed by [133]
Guo 2017 [88]	Excitement
Sáez-López 2017 [104]	Fun (incl. Happiness, Enthusiasm, Relaxation, Enjoyment) *The instrument was adapted from the scale* [134]
Vongkulluksn 2018 [93]	Interest, frustration, confusion, excitement, curiosity *The situational interest instrument was adapted from the scale* [135]*, and the achievement emotion instrument was adapted from the scale* [136]
Zhang 2018 [26]	Enjoyment, elation, pride, satisfaction, surprise, shame, anger *The emotion card instrument is adapted from Five Degrees of Happiness by* [137] *which was initially adapted from smileyometer* [132]*, and the GEW questionnaire is adapted from Geneva Emotion Wheel 1.0 by (Scherer 2005)*
Zhang 2019 [90]	Enjoyment, Relaxation, Boredom, Frustration, Contentment, Pride, Hopelessness, Anxiety *The EmoForm instrument was based on achievement emotion theory* [136] *and MemoLine concept* [138,139]

On the other hand, some studies were designed to understand students' emotional engagement [87,88], fun [92,104], and emotions [26,90,91,93] in a DBL context. Driven by the motivation of understanding emotions in DBL, three reviewed studies [26,90,93] referred to the theory of achievement emotion [52]. 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 [132], albeit for slightly different purposes: Chu et al. [92] use it to assess students' fun in DBL, while Zhang et al. [26]) measured students' overall emotional state through the design thinking process.

In order to measure students' emotional engagement and interest in DBL, a study [102] 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 [125]. Another study [60] 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 [129] and the Modified Attitudes towards Science Inventory (MATSi) scale [130]. Differently, Tae [97] referred to the STEAM course satisfaction scale and affective achievement on the STEAM scale [131].

The study carried out by [87] adapted the coding scheme proposed by [133] to analyze students' emotional engagement during DBL. In order to measure student's affective reaction to failure in DBL, Marks and Chase [94,95] referred to the School Failure Tolerance scale by [124].

In the following subsections, we present the reported emotions by categories (namely, achievement, epistemic, topic, and social emotions as in [6]), 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 a 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 [6]. In Table 2.5, 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).

Table 2.5. Extracted Achievement Emotions

Emotion	Quotation/Description
Interest	"It stimulates thought and is fun" [59]; Video coding the sub-indicators of interest, such as eager to work, actively seeking feedback.,^ [87];
Satisfaction	I am satisfied with the activity; I am pleased with the activity; my decision to attend the activity was a wise one* [74]; I feel satisfied in learning science; I am satisfied with the class where I study science* [98];
Enjoyment	Attending the activity was enjoyable. Attending the activity was exciting. I was feeling good in the activity* [74,75]; I enjoyed the tasks I carry out in science classes* [98]; I enjoyed doing the project; the project was fun to do* [107] Verbal expression of having fun or liking tasks/activity^ [87];
Happiness	Indicating by the feeling of satisfied, excited, and curious* [75], I was happy* [104].
Excitement	Excitement about their successful model testing^ [88].
Anxiety	Indicating the feeling of insecurity and helpless* [75].
Terrible	I would feel terrible if I made a mistake* [94].
Sad	Ad feedback would make me feel very sad; I get sad if I make errors when I am trying to learn* [94].
Anger	If I make a lot of mistakes, I feel very moody or angry* [94].
Frustration	Indicating be the level of how frustration does makerspace activities make you?* [93]
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" [85];

Note: *description from survey statement; ^ description from video coding scheme; "" quotation from an interview.

As an illustration, achievement interest was measured by a study [87] based on indicators of interest, such as eagerness to work or actively seeking feedback. Another study [59] 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 [74]. Similarly, another study [98] used two similar statements with the more specific context of learning science, as shown in Table 2.6.

Furthermore, enjoyment is defined as the degree to which an activity is perceived to be personally enjoyable in two studies [74,75]. And in one study [87], 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 [75]. Another [104] 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 [88] 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 [75]. Feeling terrible, sad, and angry were all used as survey items to measure students' failure tolerance during DBL in one study [94]. Frustration was measured using the survey statement "*Indicating the level of how frustrated does makerspace activities make you?*" in one study [93], while frustration was defined as a verbal expression of frustration or negative feelings in another study [87]. Moreover, Carroll et al. [85] described the emotion of boredom in an interview quotation.

Epistemic Emotions

As defined by Pekrun [6], 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 2.6. For example, curiosity was briefly highlighted as asking curiosity questions in the coding scheme in a study [87], while another [86] used the phrase "*making me curious*" in their questionnaire. As a survey item for measuring motivation at school, a study [103] 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. [103] used the statement "*I enjoy learning new things*."

Table 2.6. Extracted Epistemic Emotions

Emotion	Quotation/Description
Curiosity	Making me curious* [86]; Asking curiosity questions^ [87];
Interest	What we learn at school makes me interested to learn about new things* [103].
Enjoyment	I enjoy learning new things* [103].
Frustration	Verbal expression of frustration or negative feelings^ [87].

Note: *description from survey statement; ^ description from video coding scheme.

Topic Emotions

As described by Pekrun [6], topic emotions refer to feelings related to the topics presented in lessons. Table 2.7 describes two positive topic emotion labels (including interest and enthusiasm) and another three negative emotion labels (including tense, nervous, and scared). One [73] used students' quotations showing their interest in DBL-related topics, while another two [103,105] framed survey statements to measure students' interest in topics.

Table 2.7. 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" [73]; Learning through project creation is very interesting to me; the subject was taught interestingly and attractively* [105]; Sometimes, I do extra work outside of school because I am interested in the topic* [103];
Enthusiasm	I am enthusiastic about most of the things we do in class*. [103]; I was enthusiastic* [104]
Relaxation	I was relaxed and comfortable* [104]
Tense	I feel tense when someone talks to me about science* [60].
Nervous	It makes me nervous to even think about doing science* [60].
Scared	It scares me to have to take a science class* [60].

Note: *description from survey statement; "" quotation from an interview.

Furthermore, in addition to some positively phrased questionnaire statements, a study that measured students' attitude toward science class included three negative emotion labels – tense, nervous, and scared. A study [103] 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 [6]. The studies reviewed examples of social enjoyment and relaxation. For example, Carroll et al. [85] 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 [74] quoted one student who found the exercise enjoyable and relaxing (see Table 2.8).

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 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.

Table 2.8. 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…" [85] ;
Relaxation	"It is easier to relax and to try new things when your friends are there" [74].

Note: "quotation from an interview.

2.4.4. The Impact of Emotions in DBL (RQ3-a)

The impact of emotions in DBL has been addressed to different extents in the studies reviewed. For example, one study [75] 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 [26] 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. [26], three students mentioned that pride and elation had a generally positive influence on them during DBL.

Interestingly, a study [93] 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. [93] 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.

2.5. Discussion

The main objectives of this review were to understand the existing body of research on emotions in DBL, understand which components of DBL affected students' feelings, and determine what K-12 students' emotional reactions were as reported in DBL studies. 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's more, Marks [94,95] 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 [16,38,140].

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 [141]. 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 Figure 2.2), 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. Figure 2.2 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 chapter 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.

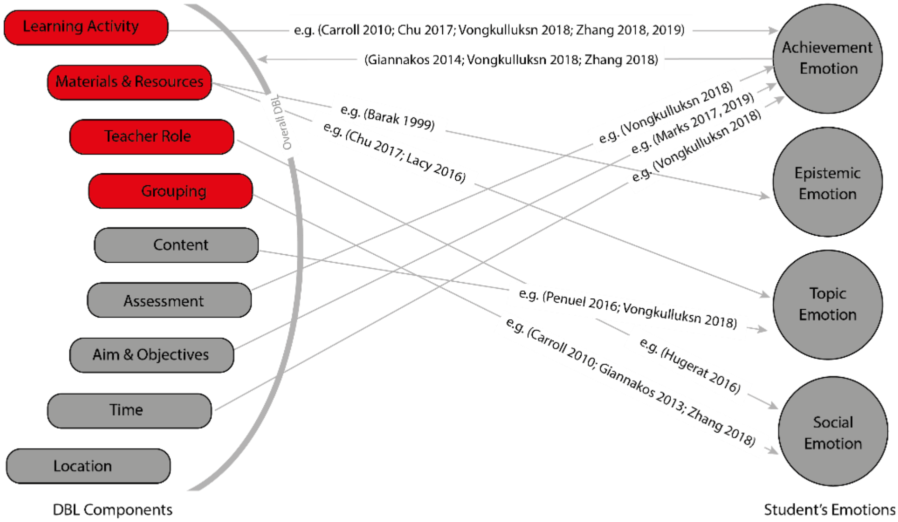


Figure 2.2. The Interplay of Students' Emotions between DBL.

Note: The red blocks of DBL components outstand as the DBL characteristics, while the rest as non-characteristic DBL components compared with other learning approaches.

This figure lists some examples of studies (the justification was based on the clarity of the data presented) that reported such a relationship; more detailed information can be found in two sub-sections of the Result section - the affective DBL component and the impact of emotions in DBL.

The final objectives of this review were to articulate implications for practice and make recommendations for future related research. 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.

2.5.1. Recommendations for Future Research

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 DBL. For example, in Table 2.4, the happiness label was mentioned in one study [104] as a sub-indicator for measuring students' fun in DBL, while another [75] 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 students' 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. [87,92], identified students' 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 students' emotions. It would also be valuable in future work to explore and validate whether technology-embedded emotion capturing tools, e.g. [64,142] 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 [85] mentioned an incident of students feeling boring by passive listening, and another study [92] mentioned students feeling frustrated when they were reluctantly instructing others. However, the evidence of specific incidents involving students' 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 partially because the evaluations reported in most of the studies reviewed were made from a macro-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 students' 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 students. Future research could examine the impact of teacher's behavioral and emotional investment in students' learning and emotions in the long term.

Some studies examining students' emotional responses to grouping focused on the social-emotional layer of the interaction and collaborative learning with peers. Only a few, e.g. [96,100], mentioned, to a limited extent, the positive interactions between students 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 students' 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 students 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, 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 effects 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 attention to the role of negative emotions during a DBL activity and how to help students 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 students' 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 [141] 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.

2.5.2. Implications for Practice: DBL Guidelines (RQ4-a)

Previous research has shown that a positive environment can encourage creative thinking and open-mindedness [5]. 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 students. These guidelines, as shown in Table 2.9, 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.

Table 2.9. 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.	[102]
	• Carefully moderate the complexity of the design challenges during iteration.	[93]
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).	[85]
	• Create a climate in which mistakes and failures are accepted to trigger curiosity in students.	[94,95]
Materials & Resources	• Prefer appealing modern technologies/kits (e.g., Lego-Logo, Lego NXT kits, Scratch, Raspberry Pi, LilyPad) that engage students, triggering their curiosity and building up their enthusiasm.	[104]
	• DBL should not neglect the need for well-structured materials and resources (e.g., instructional worksheets) to motivate students and trigger their interest and curiosity in the topics covered.	[86]
Teacher's Role	• Carefully regulate the amount of support so that students feel independent about their learning	[72]
	• Show interest in students' achievements (e.g., their design ideas, designs created, and progress in projects).	[98]

	• Actively help students draw links between their tasks and the design challenge.	[102]
	• Moderate peer feedback moments to enable students to listen and accept peer critique and feedback.	[90]
	• Provide emotional regulation support for students, especially during iterations.	[93]
Grouping	• Try to create a comfortable atmosphere within mixed-gender groups, especially in cases where they contain a gender minority.	[87,88]
	• Try to cultivate students' sense of responsibility and encourage them to volunteer to offer help to peers.	[92]
	• Involve various stakeholders (e.g., those with external businesses as clients, involving professionals as experts, and consulting intended users).	[96,100]
Time	• Carefully set a feasible project time constraint, considering the complexity of the design challenge and the checkpoints during the project.	[93]

It is important to note that this list of guidelines has only been discussed piecemeal in the studies reviewed and only partially covers the DBL components. 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.

2.6. Summary

Overall, this chapter provides an overview of 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. This review of students' 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.

[Section I]

Discovery: Initial Familiarization with the Field

Chapter

THREE

A Pilot Case Study: At a Dutch High School

Chapter 3: A Pilot Case Study: At a Dutch High School

Abstract: Design-based learning (DBL) is attracting increasing attention for its potential to support learning and as a way to enhance science and technology education at schools. However, related research has not yet considered the emotions students experience during DBL and how these affect the learning process. This chapter reports a case study to develop a deeper understanding of students' emotional experiences during DBL. In total, 9 students (12-13 years old) were involved in this case study. To assess students' emotions during DBL lessons, we used a self-reporting non-verbal instrument (the emotion card adapted from the Five Degrees of Happiness Smiley Face Likert scale) and a verbal instrument (the Geneva Emotion Wheel Questionnaire, which contains 16 emotions). Besides, a group interview with students probed into the role of their emotions during DBL. We discuss the methodological challenges exposed in this study, which will need to be addressed in future studies regarding measuring students' emotions in DBL.

This chapter is based on the paper: Zhang, F.; Markopoulos, P.; Bekker, T. (2018) The Role of Children's Emotions during Design-based Learning Activity - A Case Study at a Dutch High School. In Proceedings of the Proceedings of the 10th International Conference on Computer Supported Education; Vol. 2, pp. 198–205.

3.1. Introduction

Design-based Learning (DBL), Learning-by-Design, and Learning through Design are related learning approaches that apply the tenets of Design Thinking [23] in a problem or project-based learning context. In general, DBL involves open exploration, learning from trial and error, reflection, teamwork, and supportive tools. For instance, DBL increasingly employs technology-based tools (e.g., Scratch, Littlebits, LEGO education kits, and MakeyMakey, etc.) to support its design and learning process.

It is well known in education research that emotions play a vital role in the learning process. Firstly, emotions are known to affect a student's effort, motivation, and commitment to their academic works [80]. Secondly, emotions can trigger students' recall of memories and influence students' cognitive evaluation of events or memories [82]. Emotions are also deemed to modify the choice of learning strategies and the level of self-regulation in learning [143].

Accordingly, for DBL activities, emotions play a big part both as an outcome (e.g., in the case of successes or failures or group-based interactions) and as a factor that influences learning. Nevertheless, in contrast to traditional education, some DBL characteristics may lead to distinct emotions and consequent impacts on the learning process. For example, a student may frequently experience failure when building and testing their prototypes or design ideas. However, rather than resulting in negative emotions (e.g., disappointment or anxiety, etc.), such an episode may generate curiosity, excitement, or motivation to explore new design solutions. Consequently, the effect of such an episode on their learning process could turn out to be positive.

This chapter sets out to understand such emotional facets of DBL through a pilot case study at a Dutch high school. We engage in an exploratory case study where we aim to address the aspects as follows:

- What should be considered for designing a tool capturing students' emotions in DBL? (RQ1-b)
- How do DBL activities affect students' emotions? (RQ2)
- How do students' emotions influence their DBL activity? (RQ3-a)

The setup and methodologies used in this chapter aim to contribute to and inspire research on engaging students in DBL in the future. Furthermore, with the understanding of students' emotions in this context, this chapter will generate insights for developing interventions for the process and research on improving the DBL experience.

3.2. Related works

There is currently an increasing research interest in approaches to learning that are described as DBL [20], Learning-by-Design [34], or Learning through Design [15]. As a pedagogical approach, all these interchangeable terms have positively contributed to motivation and learning performance. Researches have been conducted to describe the main characteristics of DBL, including characteristics for organizing DBL in higher engineering education [62] and for teaching children digital literacy [25].

On the whole, related research demonstrated that DBL can positively affect students' learning activities. For instance, a study [75] indicates that enjoyment had no effect on students' intention to participate in similar DBL activities in the future. In contrast, happiness had a positive effect, and anxiety had a negative effect.

In the following sub-sections, we clarify the context of this research (see section 3.2.1), describe the groups of emotion in learning addressed by literature (see section 3.2.2), and summarize existing measurements for tracking emotions (see section 3.2.3).

3.2.1. DBL Characteristics

To deepen the multilayered understanding of a DBL activity and also ensure the external validity of the study, we settled on a list of criteria that DBL should match via synthesizing DBL characteristics from previous relevant studies. The below four characteristics will all run throughout the case study reported in this chapter. The structure of these criteria follows the framework of the curricular spider web [58]. These are detailed below:

The characteristic of *Learning Activity*, which is framed with four aspects:

- The activity should be open-ended, giving both teacher and students enough flexibility;
- The activity should be authentic, giving students a comprehensive context and real-life scenarios for positioning a design challenge and constructing a solution;
- The activity should be multidisciplinary activity enabling students to learn and connect knowledge and skills from different subjects;
- The activity should allow the student to learn knowledge and skills following a well-structured design process by using design skills.

The *Teacher Role* characteristic is that the teacher acts as a coach who enables the student to become an active learner.

The characteristic of *Grouping*, which is made up of two aspects:

- The student should have a sense of responsibility whenever they are individually performing their task or in a small group;
- The student should be involved in co-creation to learn to communicate and collaborate with peers and sometimes with stakeholders.

The characteristic of *Materials and Resource*, which is composed of two aspects:

- Involve hands-on materials and resources, equipping the student with practical techniques, tools, and materials for prototyping or testing;
- Involve minds-on materials and resources to document or visualize their minds-on outcomes during empathizing, defining, or ideating.

3.2.2. Emotions in Learning

In the introduction section, we already emphasized the importance of considering emotion under the learning context. But what emotions are frequently triggered in a general learning context? Previous research [143] has proposed four groups of academic emotions, especially relevant for students' learning:

- Achievement emotions refer to emotions related to achievement and the success or failure resulting from these activities.
- Epistemic emotions are triggered by cognitive problems toward non-routine tasks.
- Topic emotions pertain to the topics presented in lessons.
- Social emotions relate to teachers and peers in the classroom.

In short, this taxonomy of learning emotion provides macro guidance, which can be potentially used for qualitative analysis of emotion data in a DBL context.

3.2.3. Measuring Emotion

Measuring emotions during DBL brings theoretical and practical challenges because the nature of emotion is complex. The knowledge that guides the study of emotions will also influence data collection and interpretation [144]. But after all, tracking students' feelings as an approach to learning analytics offers educational stakeholders and researchers an opportunity to understand and improve the learning experience [144].

In the sub-sections below, we extract several emotion data gathering approaches from the literature, which may be applicable for measuring emotions in DBL.

Self-report Measures

In general, one advantage of self-reports is that they can help collect emotional data that cannot be observed directly. Researchers can obtain such data from respondents at relatively low cost, e.g., using paper-and-pen rating scale surveys, questionnaires, interviews, etc. The disadvantage of self-reports is also that sometimes data collected by them is biased or unreliable.

Rating scales are widely applied to obtain self-reports. Examples that could be completed by students are the verbal self-report instrument -- Geneva Emotion Wheel [119], and the non-verbal self-reports -- Self-Assessment Manikin [145], and Five Degrees of Happiness Smiley Face Likert [137]. With regard to the Geneva Emotion Wheel (GEW), it was developed to measure the respondent's experiences [146] in diverse contexts, which may include learning. The Self-Assessment Manikin, a pictorial assessment, is also applied to measure students' emotions. A Smiley Face Likert (SFL) scale named the Five Degrees of Happiness is a child-centered instrument mainly for measuring emotional reactions in child computer interaction.

On the other hand, Subtle Stone [64] is a technical and tangible instrument for students aged 12 to 13. It allows students to self-report seven emotions in the classroom in real-time.

Questionnaires are also a popular self-report measurement for a learning context, e.g., the Achievement Emotions Questionnaire (AEQ) [136] and its adopted version Achievement Emotions Questionnaire-Elementary School (AEQ-ES) [147]. AEQ was designed precisely for assessing adult students' achievement emotions, while AEQ-ES was intended for students in the early years.

Measures other than Self-report

Non-self-report measurements can be used instead of self-report measures where they are challenging to obtain or might introduce bias. They can be used together with self-reports for triangulation purposes to gain a multifaceted understanding of students' emotions or check the reliability of self-reports. However, these methods are more time-consuming than self-reports [148]. Such instruments may be various:

Language processing is a form of measurement for detecting a student's emotions in text. Linguistic Inquiry and Word Count [149] is one of the examples.

Computer recognition of facial expression is another form of measurement, e.g., using the Facial Action Coding System [150] and Facial Expression Analysis Tool [151].

3.3. Method

To ensure the external validity of this case study, we checked the main characteristics of DBL that should be included in the lesson plan. We constructed a DBL lesson plan spanning two weeks for a total of 100 minutes of classroom time. A total of 9 students (aged 12 to 13) were involved in this study. Some students were involved in the first DBL lesson, while some were involved in the second DBL). A team of two researchers acted as facilitators in the classroom and collected data through two emotion instruments (described in more detail in section 3.3.2), audio recordings, and video recordings.

3.3.1. Task

In this study, all students worked in pairs and were given the design challenge: “to design a school experience for your partner.” This learning activity was designed after a d.school (Hasso Plattner Institute of Design at Stanford) course assignment about redesigning the gift-giving experience for their partner and was embedded into our DBL framework. In this study, DBL materials and resources included the d.school crash course workbook and new (e.g., LEGO education kits, Littlebits.) and traditional (e.g., clay, color papers, tapes, etc.) materials.

The procedure of two sequential DBL lessons in our case study is adapted from the design thinking process proposed by d.school (see Figure 3.1; the colorful blocks are set up by d.school while the grey blocks are added in this case study). Apart from two warming-up sessions (i.e., team building and introduction), six main DBL sessions were carried out in order.

In addition to taking part in these DBL activities, students used two instruments to report their emotions during DBL. Then, we conducted a follow-up group interview at the end of the second lesson (see milestones of this activity in Figure 3.2). At the end of the study, we offered students a gift to thank them for their participation.

3.3.2. Measures (RQ1-b)

In this study, we focused on self-report instruments on account of the superiority in measuring students’ subjective experience of their own feelings and behaviors.

We devised an emotion card based on the Five Degrees of Happiness SFL, a simple non-verbal self-report instrument that they could complete efficiently during the DBL. We also used a follow-up verbal self-report instrument (i.e., GEW questionnaire, as seen in Appendix B), with which students can express their emotions freely. Although some previous studies already applied GEW in learning, it has not been applied in the DBL context before. Moreover, we also used for the first time emotion cards based on Five degrees of Happiness SFL under the context of DBL.

The data collection process includes the emotion card survey, the GEW questionnaires, interviews, observations, documents, and audio-visual materials. To ensure the anonymity of the materials the students would deliver, every student was assigned with an avatar, which they used to ‘sign’ their work and the emotion questionnaires they completed.

Emotion Card

To make the card looks attractive to fill and easy to understand, we adapted Five Degrees of Happiness SFL [137]. We used it for evaluating students' event emotions before the end of each session, as shown in Figure 3.1.

Figure 3.1. Example of Emotion Card in This Study.

At the end of each session, they were required to use a 5-point Likert scale to report their overall feeling. Researchers handed out and collected emotion cards after every single session. Emotion cards from all 6 sessions were collected (see Figure 3.2.): Empathize, Define, Ideate, Prototype, Test, and Present.

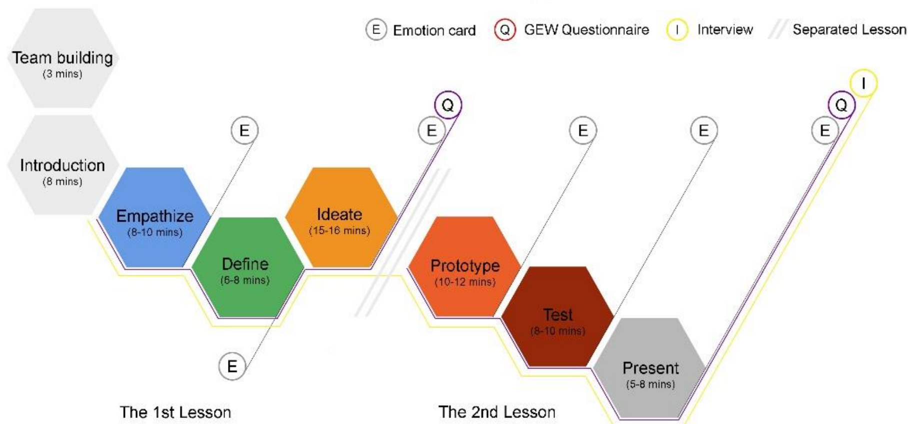


Figure 3.2. DBL Procedure in This Study (Adapted from the Design Thinking Process of d.school).

GEW Questionnaire

There are two reasons for embedding the Geneva Emotion Wheel (GEW) into our questionnaire: First, the emotion families in GEW cover most of the basic emotions, representing the dimensions of valence (on the horizontal axis) and control/power (on the vertical axis) respectively; Second, participants are not required to recall any vocabulary to describe their emotional experience, but only asked to identify an experienced or imagined emotion among the various options provided [146].

We made some adaptations for using this instrument with our young participants. We chose to decrease the number of intensity degrees from four in the GEW version 1.0 [119] into three levels (see Figure 3.3) to reduce the complexity of distinguishing intensity differences for them. Furthermore, we combined this adapted GEW version1.0 with an open-ended question as supplementary for examining students' emotions and experiences during DBL activities (as seen in Appendix B).

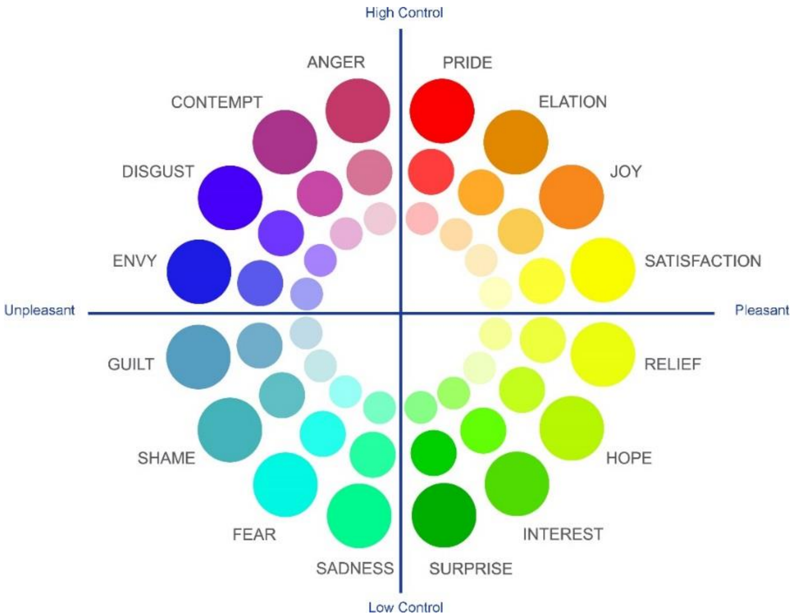


Figure 3.3. Adapted GEW Version 1.0 in This Study.

Group Interview with Students

In the end, after the second lesson, researchers used a face-to-face group interview. In the interview phase, questions concerning their answers on the emotion cards and questionnaires were asked. We held two group interviews in parallel under the guideline of a group interview protocol (as seen in Appendix C), with 3 and 2 students, respectively. Each group interview took about 15 minutes.

3.4. Results

We report the quantitative and qualitative results for research questions addressed in the following sub-sections. The answer to Q1-b is linked to the discussion and, Q2 can be found in sub-section 3.4.2. (i.e., Affective Elements in DBL), and Q3-c is explained in section 3.4.2. (i.e., Effect of Emotion on DBL). Sub-section 3.4.1 (how students' emotional states changed during DBL phases) is a supplementary part to Q2 and Q3-c.

3.4.1. Quantitative Results

The quantitative data sources come from the emotion card survey and the GEW part of the questionnaire.

Undergoing Emotions

Overall, each student selected between 1 and 5 emotions on the GEW questionnaire. Most of them reported that they undergo joy, and some of them undergo elation, pride, satisfaction, and a few students undergo surprise. In contrast, only one student experienced shame, and another student experienced anger during DBL. Most selected emotions (5/7) locate in the positive quadrant, except for the unpleasant feelings of shame and anger (in bold in Table 3.1). Meanwhile, most of these emotions (5/7) locate in the high control quadrant, except for the low control emotions of shame and surprise (in italic in Table 3.1).

Table 3.1. Thirteen Pieces of GEW Questionnaire in Two DBL Lessons. The abbreviations and marks in Table 3.1 are interpreted as Jo (Joy), Sh (Shame), Su (Surprise), Pr (Pride), El (Elation), An (Angry), Sa (Satisfaction); + (high intensity), * (medium intensity), - (low intensity).

Participant	In the first lesson	In the second lesson
Mickey	Jo+	Jo+
Minnie	Jo+	Jo+
Donald	Jo+, ***Sh***-	N/A
Daisy	Jo+, *Su*+	N/A
Winnie	Pr+, El*, ***An***+	N/A
Piglet	Jo+, Pr*, El+	N/A
Bambi	Jo+, Pr+, El+	Jo+, Pr+, El+, Sa+
Thumper	Jo+, Pr+, El+	Jo+, Pr+, El+, Sa+, *Su*+
Simba	N/A	Jo+, Pr+, El+, Sa+

Within two DBL lessons, a total of 13 valid responses (8 in the 1st lesson, 5 in the 2nd lesson) from the GEW questionnaire were collected. Since students selected between 1 and 5 emotions, these 13 pieces of valid responses amount to 33 'votes' in 7 different emotions. See details in Table 3.1. Students participating in both lessons are in shaded cells.

Changes of Emotion during DBL

Table 3.2 presents a descriptive statistic result of emotion card surveys. This result includes 24 responses from 8 participants who participated in the Empathize, Define, and Ideate sessions and 15 responses from 5 participants in Prototype, Test, and Present sessions.

Table 3.2. Descriptive Statistic Result: 39 Pieces of Emotion Card.

Session	mean	sd	IQR	n
Empathize	3.9	1.5	2.00	8
Define	4.6	0.5	1.00	8
Ideate	4.8	0.5	0.25	8
Prototype	5.0	0.0	0.00	5
Test	5.0	0.0	0.00	5
Present	5.0	0.0	0.00	5

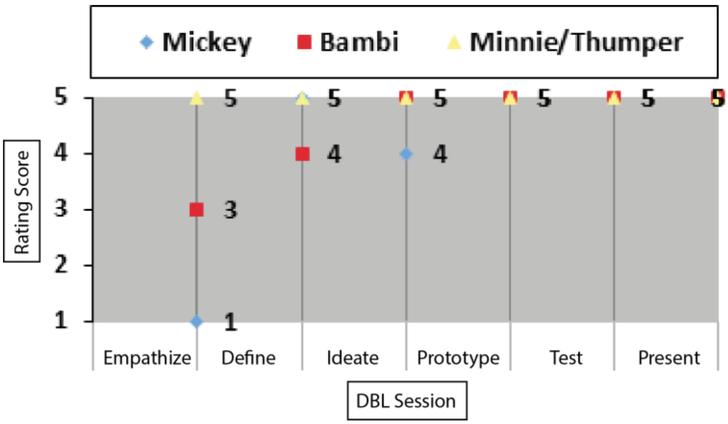


Figure 3.4. Emotion Scores from 4 Participants.

However, only 4 participants have taken part in the entire six DBL sessions, while the remaining participants were absent from some sessions for some personal reasons (e.g., sick leave). To probe the changes of their emotions during an entire DBL unit, we only analyzed emotion changes over six sessions from the 4 participants mentioned above. Figure 3.4 displays the changes in emotion intensity among the six DBL phases. As is seen, all participants reported the highest degree of happiness when taking part in the prototype session and all the sessions after the prototype session. These trends showed a broad tendency to rise.

3.4.2. Qualitative Results

The comments collected through the open questions and during the group interview were transcribed and analyzed thematically. Three following major themes emerged, which are discussed below.

Affective Elements in DBL (RQ2)

According to the curriculum components framework [58], our data suggest that some components positively affect students' emotions during DBL. For instance, students were affected by DBL *content*. Some students think the subject in the Empathize session was interesting, while others did not feel excited at all by it. Some students were less interested in the subject in the Ideation session. Second, DBL *learning activity* also affected students. Almost all students reported that the Prototyping session was their favorite one. Some students liked drawing their design idea, and some were fond of showing their design projects to others. Third, *the role of the facilitator/teacher* in DBL proved to have a positive effect. A supportive facilitator made students feel joy; this finding is in line with the expectation in [102] that students' enjoyment increases with the teacher's ability to connect lessons to the unit challenge in DBL. Fourth, the *grouping* component in DBL also affected them. Students considered working with friends makes them feel joy in line with earlier studies [74,85] that suggested that enjoyment is enhanced when working with peers. Fifth, the DBL *material and resources* had an influential impact. For instance, LEGO bricks, which some students used to build their prototype, made them feel good. This statement resonates with [59], who concluded that LEGO is a factor that brings students curious, as presented in the previous studies. Finally, the *time setting* caused a negative emotional response: one student found that starting at 4 p.m. as we did was too late, and she was not happy about it.

Emotions in DBL

Students reported several emotions using the verbal instrument: the emotion of joy, elation, pride, satisfaction, surprise, shame, and anger. Due to a lack of explanation about the experience of feeling shame and anger reported on the GEW questionnaire, we will not discuss the emotion of shame further in this paper. Hence, we only classified the rest of the 5 emotions into the taxonomy (see section 3.2.2) of academic emotions proposed by [143] for further discussion.

First, pride was a prominent achievement emotion. Most students were proud of their own ideas, their drawings, and prototypes. Some students felt pride in themselves and even their partners when receiving the design solution from their partner. Second, in the epistemic emotion theme, feelings of surprise were highlighted. Some students were surprised when they performed better than they had expected on tasks. One student expressed a surprising feeling that DBL was much more fun than she thought. Third, concerning the theme of topic emotions, the feelings of satisfaction, joy, and elation were prominent. Compared to an earlier study [98], which assessed the extent of student satisfaction and enjoyment while carrying out scientific tasks, this case study found that students not only feel satisfied with the DBL lessons but were in a state of elation towards DBL activities. Moreover, the materials and resources used in class also made them feel joy. Forth, in the social emotion theme, the feelings of joy were highlighted. Students tend to feel joy in working with friends, as was expected based on earlier research [75,85]. The supportiveness from their facilitator is another source of joy feelings, in line with [98].

Effect of Emotion on DBL (RQ3-a)

Two highlighted findings are derived from the interview. First, two students (i.e., Mickey and Minnie) state that joy facilitates their learning outcomes during the heads-in sessions, while it has no effect on their hands-on sessions. Second, three students (i.e., Bambi, Thumper, and Simba) mention that pride and elation positively influence their DBL activities. Similarly, an earlier study [24] found that enjoyment has no effect on students' intention to participate in similar future activities.

3.5. Discussion (RQ1-b)

Emotion plays a vital role in DBL activities, acting as a reciprocal linkage between antecedents (the affective elements in DBL) and effects (the effect of emotion on DBL). The content and process of each DBL session, the teacher's role, the social interaction with peers, and the learning materials are the physical or social antecedents of students' emotions during DBL. This case study highlighted seven emotions containing pride, elation, joy, satisfaction, surprise, shame, and anger. This finding is consistent with results presented in Chapter 2 [152] that students experience both positive and negative emotions during DBL. From the students' points of view, positive emotions such as pride and elation seem to have a positive effect on their engagement during DBL, while joy appears to facilitate their engagement before coming up with a design idea.

The findings reported are only tentative since this has been a small-scale study, and we experienced some severe methodological challenges in assessing students' emotions during DBL. First, data collected may suffer from a social desirability bias, where students tend to only report positive emotions to appear more appealing to researchers [137]. Second, it has not been possible to track emotions throughout the DBL activity using a self-reporting instrument. This would have interrupted the flow of their learning experience to some extent.

This study has derived valuable insights, which will guide our future research on measuring students' emotions during DBL activity: First, negative emotions need to be fully embedded into the emotion measurement instrument to detect the full range of emotions. Second, to ensure the credibility and reliability of emotion data, future study designs should ensure students do not share their emotional responses during the data collection process. Furthermore, due to the subjectivity of asking the subjects about their opinion on their own emotions, future studies could triangulate subjective report data with facial expression analysis and observation during the entire DBL activity. Last, a pre-and-post test of students' emotional states is necessary. Except for academic emotions, emotions originating from extraneous events and factors outside of school may also influence students' learning performance.

3.6. Summary

This chapter argues for the importance of considering emotions in DBL. An exploratory case study where students aged 12 to 13 engage in DBL in a classroom was conducted to assess their emotions. Our results show that from the students' point of view, positive emotions such as pride and elation seem to have a positive effect on their engagement during DBL, while joy appears to facilitate their engagement just before coming up with a design idea. Further research could replicate and extend these results to a broader range of situations where emotions could play a role in DBL (e.g., cases of failure, negotiation, and conflict), and at the same time especially pay attention to measuring students' emotion without interrupting the flow of DBL. Further research may also pay attention to adding the emotional angle of learning to existing computer-supported DBL tools.

[Section II]

Definition: Tool Design and Development

Chapter

FOUR

Tool for Capturing Emotions: EmoForm and other Possibilities

Chapter 4: Tool for Capturing Emotions: EmoForm and other Possibilities

Abstract: Emotions can greatly influence the learning process. So far, emotions have received little attention from the constructivist learning research community, which deals with approaches such as Design-Based Learning (DBL), Maker education, and project-based learning. To better understand the emotional aspects of DBL, there is a great need to develop an instrument for capturing emotions. This chapter presents the development and evaluation study of such an instrument called EmoForm, a lesson-based retrospective self-report tool for capturing students' emotional changes over time during DBL. We evaluated EmoForm during a three-month DBL project at a local school that involved 30 students aged 13-14. Data from 433 completed forms indicates that students can use this instrument to capture emotions associated with the DBL experiences they engaged in. Furthermore, this chapter briefly presents two initial concepts providing different means for capturing emotions in DBL: EmoLens (a working observation toolkit) and EmoWatch (a sensor-based wearable device). The chapter concludes with a discussion on the further development of tools to capture emotions during DBL.

Part of this chapter is based on the paper: Zhang, F., Markopoulos, P., Bekker, T., Schüll, M., & Paule-Ruíz, M. (2019). EmoForm: Capturing Children's Emotions during Design Based Learning. In Proceedings of FabLearn 2019 (pp. 18-25). ACM.

4.1. Introduction

Design has been argued to be a suitable catalyst for learning [16]. When students engage in the design process, they learn to identify needs, frame problems, work collaboratively, explore, and appreciate contextual dependencies [16]. Design-Based Learning (DBL) is a learning approach pivoted on design, which builds on constructivist learning tenets. Kolodner et al. defined DBL [19] as encountering a design challenge and attempting a solution individually and/or in small groups while using only prior knowledge.

Emotions affect students' ability to learn and remember [6,153] and be essential outcome indicators showing how learners feel and how they perceive their past experiences. Students can experience powerful emotions in academic settings. This can be even more so in the context of DBL due to students' social interactions in the classroom (e.g., working collaboratively in a team, interacting with the teacher), which are important factors for students' interest and emotional experiences [47–50]. Furthermore, DBL involves open exploration where students learn by trial and error, which can evoke emotions, when being in a self-directed exploration or engaging in a reflective self-evaluation on the performance outcomes (e.g., when faced with failure or a challenging situation).

However, considerable challenges beset research in students' emotions in the classroom setting, especially within a DBL context. For example, one difficulty could be in accounting for emotions and adequately incorporating an understanding of action as situated in a context that gives meaning [154]. The case becomes more vexing when doing research with students since the methods used to collect self-reported data need to be developmentally appropriate to match the students' level of understanding, knowledge, interests, and position in their social world [155]. Besides, a student's learning experience flow is easily distracted by reporting data during a class [26].

Motivated by these challenges and aiming to better understand the emotional aspects of DBL, we set out to develop a retrospective emotion-capturing tool called *EmoForm*. Furthermore, we explore two concepts: the *EmoLens* (a working observation toolkit) and the *EmoWatch* (a sensor-based wearable device), reflecting on insights for further developing related tools to capture students' emotions in DBL.

4.2. Measuring Emotions and Experience

4.2.1.Self-report Measures

Methods to assess emotions include psychophysiological, behavior measures, and self-report [4]. Self-report measures use various techniques to capture subjective data pertaining to emotions and experience, such as questionnaires, diaries, affective technology-enhanced survey tools, etc. For instance, the Achievement Emotions Questionnaire-Elementary School (AEQ-ES) is a paper-based questionnaire [147] developed to assess primary school students' enjoyment, anxiety, and boredom in school subjects such as maths. The emotion cards [26] and the Five Degrees of Happiness [137] are both based on the widely known Smileyometer [132]. All three are variations of

Likert scales with levels corresponding to different emoticons (smiley faces) to measure quantifiable overall experience.

Focusing on studying experience over time, the experience sampling method (ESM) [156] is a popular research technique that uses the repeated administration of a simple questionnaire to capture momentary or episodic representations of past experiences. Similarly, Colombo and Landoni [157] used a diary method to measure students' experiences of interacting with an ebook. Subtle Stone [64] embeds wireless and sensor technology in a tangible device that supports students (aged 12-13) in communicating their emotional experience to a teacher and enables understanding of their own emotional experience in the classroom and reflecting upon it.

4.2.2. Technology Supported Observational Measures

Psychophysiological measures that assess autonomic nervous system functioning (e.g., skin conductance, heart rate, blood pressure) [158] or central nervous system functioning (e.g., electroencephalography) are laboratory intensive for both participants and researchers [159]. Behavior measures include techniques such as the assessment of vocal and language characteristics (e.g., linguistic inquiry and word count [149]), behavioral observation, facial expression recognition (e.g., Facial Action Coding System [150]).

4.3. EmoForm: Paper-based Experience Sampling Form (RQ1-b)

4.3.1. Development Rationales

EmoForm is a paper-and-pencil-based questionnaire designed for repeated application at the end of each lesson throughout an entire DBL project. This questionnaire was designed to capture information regarding students (aged 13-14) achievement emotions [49], engagement, and the DBL activities [26] these emotions pertain to. Considering the challenges in measuring students' emotions in the context of DBL, we framed the following three considerations for the construction of the EmoForm; self-reporting, retrospection, and sampling strategy. These are discussed in the paragraphs below.

Self-reporting

Self-report was preferred over observation, as capturing emotions is inherently perceptual and self-referential [159]. Besides, current psychophysiological approaches are cumbersome to use in a natural context (i.e., the classroom) [159]. We decided to create a paper-and-pencil-based reporting journal rather than technology-enhanced non-wearable survey tools (e.g., the Subtle Stone [64]) considering that students physically and actively participate in DBL activities instead of passively sitting on the chair and listening to lectures as in other classroom contexts.

Retrospection

Although the pre-and-post test will bring insights into a respondent's preferences at two moments, we preferred to use retrospection to focus on the dynamic aspects of the learning experience focusing on students' emotional learning experience rather than their overall preference. Also, retrospection was seen as an approach to avoid repetitive self-reporting measures during the lesson, interrupting students' learning flow [26]. Further, it is known that self-reports of recent emotional experiences are likely to be more valid than are self-reports of emotion made somewhat distant in time from the relevant experience [160]. Thus, EmoForm is used on a lesson/daily basis.

Experience Sampling Strategy

To understand students' emotional experience during DBL rather than other aspects such as emotional expression, psychophysiological response, or emotional regulation [159], we adopted the experience sampling strategy. Our sampling approach targets specific experiences to filter out non-learning-related experiences (e.g., the noise brought from off-topic events outside the school). Note that the sequence of activities during DBL is not standardized given the nature of open exploration and iterative design; thus, learning activities in DBL vary from day to day and across groups or even individuals within the group. We adopted the approach used in the Experience Sampling Method (ESM) [156]. The same items are answered by participants repeatedly at selected moments during the study period to examine the relationships among activities, social context, and their psychological states.

4.3.2. Construction of EmoForm

By considering the advantages of self-reporting, retrospection, and experience sampling, we developed EmoForm, a paper-and-pencil-based questionnaire designed for repeated application at the end of each lesson throughout an entire DBL project. This questionnaire was designed to capture information regarding students' (aged 13-14) achievement emotions [49], engagement, and the DBL activities to which these emotions pertain. In this section, we introduce the EmoForm in more details to illustrate the multifaceted elements comprising the EmoForm:

Emotions Assessed by EmoForm

Emotions are outcome indicators and markers of quality regarding students' participation, which provide both fuel and guidance for students' behaviors [80]. More specifically, achievement emotions are particularly important to study in a learning activity since academic settings abound with achievement emotions are critically crucial for students' motivation, learning, performance, identity development, and health [52,161]. According to the control-value theory of achievement emotions, which addressed subjective control (i.e., expectancies and attributions) and value (i.e., intrinsic and extrinsic) appraisals, achievement emotions are defined as emotions tied directly to achievement activities or achievement outcomes [52]. Investigating achievement emotions helps understand students' engagement in learning activities and their emotional responses to learning outcomes. This EmoForm includes eight representative achievement emotions (in Table 4.1) from the three-dimensional taxonomy of achievement emotions [52] respectively, and some of them are addressed by previous studies [26,74,75].

Table 4.1. Representative Achievement Emotions [52]

Valence	**Arousal**	**Objective focus**	
		Activity	***Outcome***
Positive	***Activating***	Enjoyment	Pride
	Deactivating	Relaxation	Contentment
Negative	***Activating***	Frustration	Anxiety
	Deactivating	Boredom	Hopelessness

Defining the Affective Situational Context

According to the general model of curriculum development proposed by Akker [58], one of the main challenges for improving the curriculum is to balance the various components (e.g., learning activity, learning goal, and teacher role) of the curriculum. This current version of the EmoForm intends to measure some of the components suggested by this model (summarized in the theoretical source column in Table 4.2).

Table 4.2. Variables of DBL Experience in EmoForm

Theoretical source [58]	**EmoForm emphasized on**	**Code**	**Representative context**
Learning activity component	Empathize Design User	EDU	Design thinking process
	Define Design Problem	DDP	
	Ideate Design Solution	IDS	
	Make Prototype	MP	
	Test Prototype	TP	
	Prepare/ present Presentation	PP	Project management
	Multi-tasking involved activity	MT	Learning strategy
	Single-tasking involved activity	ST	
Grouping component	Collaboratively involved activity	CT	Learning strategy
	Individually involved activity	IT	
Assessment component	Get feedback from others	GFO	Social interaction & assessment
Teacher's role component	Get support from the teacher	GST	Social interaction
Time component	The time duration spending on diverse activities	n.a.	n.a.

Engagement Assessed by EmoForm

Engagement is an indicator of learning since it is related to essential academic and social-emotional outcomes [162]. Thus, it is vital to study students' emotions and experiences during DBL. According to the Flow Theory, concentration, interest, and enjoyment in an activity must be experienced simultaneously for flow to occur [163]. On the other hand, engagement is related to the associated outcomes [162], reflected within the Broaden and Build Theory [164], which hypothesized positive emotions broaden one's thought and action. Therefore, EmoForm also embeds two aspects of engagement, namely the culmination of concentration (i.e., how well were you concentrating) [156] and associated outcomes (i.e., were you learning anything or getting better at something) [156]. Further, we rephrased the statement about associated outcomes (for short described as "learn better" in the following paragraphs) into how much you learn to make it more understandable to students.

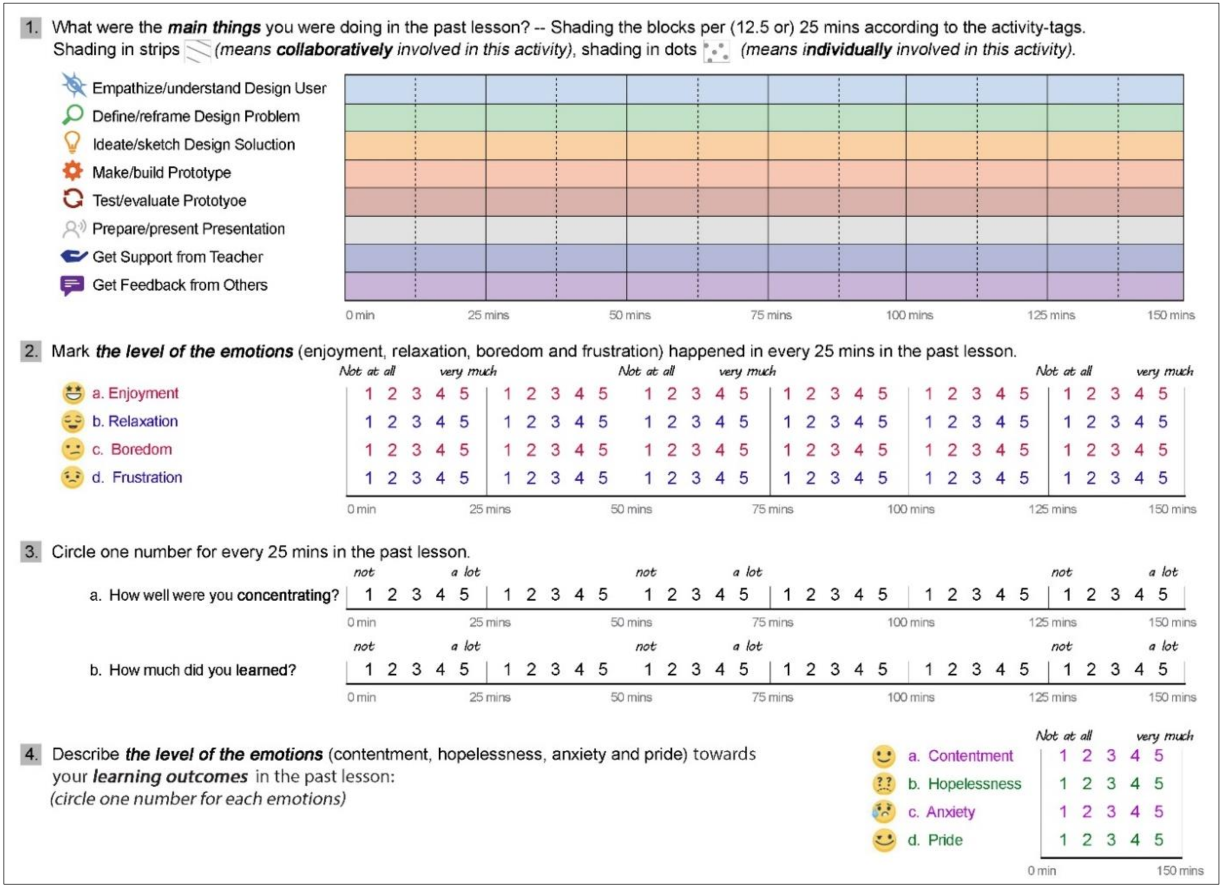
Defining Temporal Specificity

As highlighted in the literature, young students are unlikely to have developed memory retrieval strategies [139]. Considering a lesson usually lasts 50 minutes, it would be easy for students to recall half of the classroom time. Therefore, we set 25 minutes as a standard interval time to frame the timeline chronologically from the beginning until the end of the lesson on a single day. It is expected to reduce the memory burden for participants and stimulate retrospection on the momentary experience, and that its occurrence evokes achievement emotions accordingly. Meanwhile, we introduce a reference line in the midpoint of every slot of 25 minutes for stimulating retrospection on their experience. This temporal specificity enables EmoForm to be used either in a one-day workshop or in a regular lesson by adapting the total numbers of interval units on one page of the EmoForm.

Items and Scale Development

As mentioned above, this EmoForm (shown in Figure 4.1) considered the affective situational context for sampling a student's experience in DBL and the temporal specificity for scaffolding the timeline of retrospection on momentary experience. Note that the rating scales (on the x-axis) in all of the last three sections in EmoForm are 5-point Likert scale, which has been argued to be most suitable for students [137]. To be more specific, in the following paragraphs, we discuss how these considerations reflected on the items presenting by this EmoForm.

The first section of the EmoForm samples the DBL experiences. We follow a similar approach as the MemoLine [138,139] to ask students to recall their experiences. To do so, the y-axis includes eight DBL activities, respectively, identified by eight different colors. This section of EmoForm lists the main activities as recognition cues instead of asking students to color the periods corresponding to different types of experience as in the MemoLine [138,139]. In addition to the classification of DBL activities, EmoForm asks for an extra layer of information concerning the type of activity (i.e., individual vs. collaborative), which is indicated by shading (in the case of "collaborative") or doting (in the cases of "individual") the colorful blocks



1. What were the ***main things*** you were doing in the past lesson? -- Shading the blocks per (12.5 or) 25 mins according to the activity-tags. Shading in strips *(means **collaboratively** involved in this activity)*, shading in dots *(means **individually** involved in this activity)*.

	0 min	25 mins	50 mins	75 mins	100 mins	125 mins	150 mins
Empathize/understand Design User							
Define/reframe Design Problem							
Ideate/sketch Design Soluction							
Make/build Prototype							
Test/evaluate Prototyoe							
Prepare/present Presentation							
Get Support from Teacher							
Get Feedback from Others							

2. Mark ***the level of the emotions*** (enjoyment, relaxation, boredom and frustration) happened in every 25 mins in the past lesson.

Not at all … *very much*

	0–25 mins	25–50 mins	50–75 mins	75–100 mins	100–125 mins	125–150 mins
a. Enjoyment	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
b. Relaxation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
c. Boredom	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
d. Frustration	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

3. Circle one number for every 25 mins in the past lesson.

not … *a lot*

	0–25 mins	25–50 mins	50–75 mins	75–100 mins	100–125 mins	125–150 mins
a. How well were you **concentrating**?	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
b. How much did you **learned**?	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

4. Describe ***the level of the emotions*** (contentment, hopelessness, anxiety and pride) towards your ***learning outcomes*** in the past lesson:
(circle one number for each emotions)

Not at all … *very much* (0 min – 150 mins)

a. Contentment	1 2 3 4 5
b. Hopelessness	1 2 3 4 5
c. Anxiety	1 2 3 4 5
d. Pride	1 2 3 4 5

Figure 4.1. Example of the EmoForm. Note: our evaluation results suggest design documentation (DD), planning (PL), and off-task options should be added in improving EmoForm.

representing eight DBL activities, respectively.

The second section of EmoForm asks students to report feelings of enjoyment, relaxation, boredom, and frustration (i.e., four activity-focused achievement emotions) **during** DBL activities. To increase the attractiveness and avoid misunderstanding of verbalized emotion statements, EmoForm associates corresponding smiley emoticons to every emotion. The same principle is applied to the fourth part containing a question about their feelings of contentment, hopelessness, anxiety, and pride (i.e., four outcome-focused emotions). However, instead of repeatedly assessing the feelings of activity, the EmoForm only assesses the outcome-focused emotions once every lesson/day.

In its third section, the EmoForm reports students' perception of concentration and feeling of learning better (i.e., two aspects of engagement construction). EmoForm aims to enable researchers to check the potential relation between DBL activities, students' achievement emotions, and engagement.

4.3.3. Evaluation Study

We conducted a study to investigate the suitability of the EmoForm for assessing students' emotional experience during DBL. The aims of this evaluation are described below:

- Do the questions of EmoForm lead to varied answers, thus providing meaningful and differentiating information?
- Can the use of the form lead to an acceptable completion rate?
- Do the questions measure the concepts we are interested in -- achievement emotion and engagement relating to associated DBL activities?
- Do the questions of EmoForm have good internal consistency in responses?
- What expected results EmoForm can deliver (e.g., when students go through a longer-term DBL project)?

Study Context

The evaluation of EmoForm took place in a DBL project at a public secondary school in the Netherlands, which spanned three months. Students were given the challenge to design an escape room for the local fire department (see Figure 4.2) to acquaint them with fire safety in and around the house.

Figure 4.2. The Fire Department Design Case: Visiting Fire Department (L) and Building Prototype (R).

Participants

A total of 30 students (including 22 boys and 8 girls) aged 13 to 14 years old participated in this study. Based on the students' preferences, the teacher split the class into nine groups of 3-4 students each. Students were familiar with design thinking and had already practiced their design skills during design projects for one year. Consent forms were signed before the start of our study.

Procedure

The EmoForm was first pilot-tested with experts (i.e., three researchers and one teacher) and adult students majoring in industrial design. Afterward, we arranged one session before executing this evaluation study, introducing this research project, and offering instructions on using EmoForm to the participants in this study. Through all these trials, the EmoForm was used successfully, and it took participants about one to two minutes to complete once the students had become familiar with the routine.

Throughout this three-month DBL project, a total of 433 copies of the EmoForm were completed pertaining to 15 lessons/days except for three lessons where students were not required to complete the form (e.g., a temporarily canceled lesson or a lesson for visiting a design client). Every week students were given at most two lessons (on different days) for working on their projects as a group. The 15 lessons in this DBL project varied from 50 minutes, 100 minutes to 150 minutes, making the number of entries recorded from two to six per activity-focused emotion item and per engagement item. There is only one entry recorded in the EmoForm for each outcome-focused emotion.

4.3.4. Evaluation Results

Variability in Responses

Overall, there was sufficient variation of scores on all scales (sections 2, 3, and 4). As seen in Table 4.3, given the discriminating variability in responses, the EmoForm was useful for working with students aged 13 and 14.

The variability of students' responses to their DBL experience is beyond expectation. Except for the activities appearing on the template and the cases of doing off-task, two more activities were reported from their DBL experience – Design Documentation (DD) and Planning (PL). At this point, the researchers in the related field of DBL could adapt the EmoForm and use and evaluate it in more contexts.

Table 4.3. Percentage of Frequency Distribution on Scales of Sections 2, 3, and 4 on EmoForm

	1	2	3	4	5
Enjoyment	9%	15%	34%	26%	16%
Relaxation	15%	28%	28%	18%	11%
Boredom	30%	26%	21%	13%	10%
Frustration	65%	19%	9%	5%	2%
Concentration	4%	15%	29%	30%	22%
Learn better	27%	33%	27%	8%	5%
Contentment	6%	10%	31%	29%	24%
Hopelessness	73%	16%	6%	3%	2%
Anxiety	89%	8%	1%	1%	1%
Pride	11%	20%	26%	21%	22%

Completion Rates

During the 15 lessons/days from March until June, 30 students completed in total 433 EmoForms. The completion rate was satisfactorily reaching 96.2 (433/450); the few missing was due to some students being absent from school. However, the completion rate (i.e., the percentage of expected entries versus the actual entries) is around 81.6 to 91.9 percentage when considering off-task cases as missing entries.

Validity Analysis

To determine whether items in the questionnaire measure the concepts we are interested in, we examined construct validity and content validity by analyzing the component matrix and the interviews with the teacher and students.

To understand how engagement aspects (section 3) and achievement emotion (sections 2 and 4) aspects are interrelated in this instrument, we apply a Principle Component Analysis (PCA) for EmoForm reports in the response level (with 398 valid cases after list-wise deletion based on all variables). The Kaiser Meyer Olkin (KMO) value is 0.795 (and Bartlett's Test p=0.00), which indicates that the sampling is adequate and that the following factor analysis yields distinct and reliable underlying dimensions.

Table 4.4. Component Matrix

Items	**Component**		
	1	**2**	**3**
Enjoyment	**.789**		
Relaxation	.510		**.586**
Boredom	-.571		**.578**
Frustration	-.514	**.680**	
Concentration	**.659**	.351	
Learn better	**.457**	.473	-.347
Contentment	**.789**		
Hopelessness	-.515	**.673**	
Anxiety	-.456	**.618**	
Pride	**.667**	.414	

The Rotated component matrix (provided by the Varimax with Kaiser Normalization rotation method) indicates that the positive items, including four positive achievement emotions, concentration, and associated outcome (i.e., learn better in this case), are interrelated. Furthermore, most of the negative items included are also interrelated. Interestingly, the item of boredom is not highly interrelated with other negative emotions but loosely interrelated with the positive items. Besides, the PCA result indicates that the numbers of the components are between two and three. Hence, we applied one more time PCA by setting the number of factors as three. As shown in Table 4.4, the component matrix reveals the latent constructs of the EmoForm for capturing students' emotional experience, which is to some extent in line with the underlying constructs it is designed to measure.

To summarize, the cluster of bold items (in Table 4.4) in the first component, which turns to have the potential to measure the construct of a positive experience (with both positive emotions and high engagement) during DBL. While the cluster of bold items in the second component seems to measure the negative emotional learning experience. The bold items in the third component contain a mix of positive and negative deactivating achievement emotions (i.e., relaxation and boredom), which seem to measure more neutral emotional learning experiences in DBL.

Interviews were held with the teacher and students about how they understand the items presented by EmoForm and how they feel about filling in this questionnaire. The findings from synthesizing their feedback demonstrate that they could understand and answer the EmoForm. The content of the EmoForm adequately covers almost all representative activities in the DBL context when adding the DD, PL, and off-task options in the categories of sampled experience.

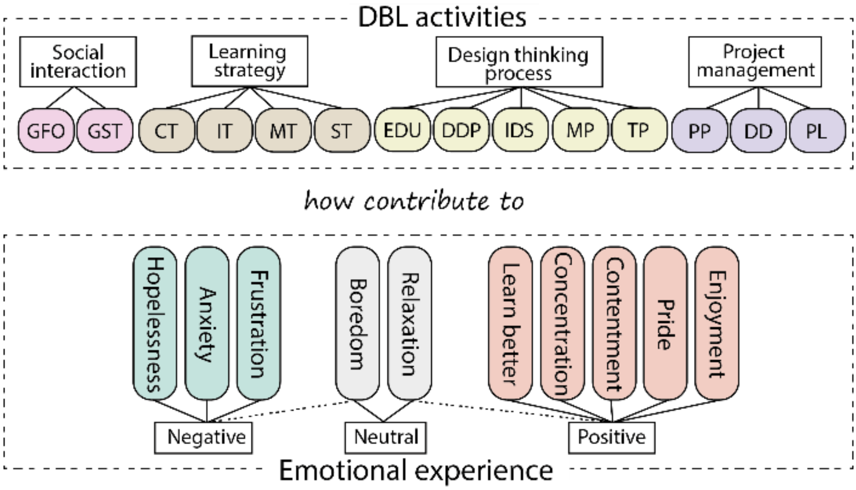


Figure 4.3. Mapping Framework Assessed by EmoForm.

In conclusion, the framework in Figure 4.3 illustrates how the EmoForm can map DBL activities to their emotional experience (mixing positive and negative items). The detailed analysis of the mapping relationship between DBL activities and emotional experience is out of the scope of this paper. Here we only give some examples of how and what results under this framework EmoForm can deliver in the following section.

Reliability Analysis

To determine whether the EmoForm has a good internal consistency in responses, we examined the reliability of the EmoForm by analyzing the Cronbach's alpha coefficient and stability reliability. We re-coded and transformed the negative response items (including boredom, frustration, hopelessness, and anxiety) into the same metrics as the positive response items (i.e., enjoyment, relaxation, concentration, learn better, contentment and pride) before running the reliability test. For instance, "5" (very much) in negative items (e.g., boredom) has been re-coded and transformed to "1," which in line with the metrics in other positive items (e.g., enjoyment) in "1" (not at all). Considering the different number of entries between the items in the fourth section (i.e., outcome-focused emotions) and rest sections, the overall reliability analysis of the EmoForm is at a response level (with 398 valid cases after list-wise deletion based on all variables) rather than in an individual level. Overall, the EmoForm has a Cronbach's alpha value of 0.798.

The Cronbach alpha coefficients among diverse contexts (i.e., all ten DBL activities sampled by EmoForm) are analyzed by the data provided by the EmoForm at the entry level. Refer to Table 4.2 for an explanation of the following abbreviations. As an illustration, the Cronbach's alpha in Design thinking process context (α=0.929), Project management context (α=0.987), Social interaction context (α=0.886), and Learning strategy context (α=0.939) are high. More specifically, the individual activity such as EDU (α=0.830), DDP (α=0.829), IDS (α=0.749), MP (α=0.863), TP (α=0.820), PP (α=0.876), GST (α=0.742), GFO (α=0.807), DD (α=0.846), PL (α=0.906), CT (α=0.836), IT (α=0.839), MT (α=0.802) and ST (α=0.840) are also acceptable. The Cronbach's alpha coefficients among the positive construct (α=0.798) and negative construct (α=0.766) of their emotional experience are also acceptable, except for the neutral construct (α=0.273). Alternatively, Cronbach's alpha value for the positive construct includes the item of relaxation (α=0.797) and the negative construct when it includes boredom (α=0.668). In all, Cronbach's alpha's acceptable values demonstrate the EmoForm has a good internal consistency in responses. Future research could especially focus on further develop the emotions in the neutral construct of emotional experience.

The stability reliability was determined by examining the correlation between different activities within a similar context. For example, various activities within a particular context (e.g., Project management, Design thinking process, Learning strategy, and Social interaction, respectively) are correlated with each other (all ρ *(rho)*>.4, *p-value*<.001). This finding indicates different activities have good consistency within the DBL context. To conclude, the results of Spearman's correlations demonstrated that these levels of stability of the EmoForm are high for a questionnaire administered with a classroom of students in a lively environment of the secondary school setting.

Deliverable Information by EmoForm

Evolution of DBL activities.

The information provided by the first section of EmoForm helps to gain an overview of how students go through DBL activities. Figure 4.4 visualizes the progress of different group's learning processes. Every numeric block chronologically stands for the lessons/days from the beginning until the end of this evolution map.

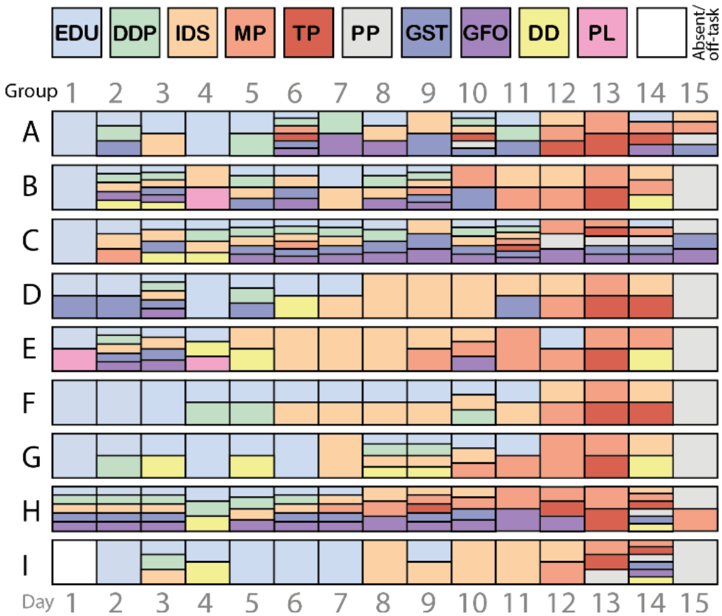


Figure 4.4. Evolution of DBL Activities (per group). Note: this is showing types of DBL activity and amount of dual tasking per day.

Due to the open-ended characteristics of DBL, students have autonomy in planning their learning paths to the same learning goal. Also, because of the individual difference in learning styles and personal abilities, their learning process's pace and path are always variant. Our findings indicate that empathizing and understanding design user (EDU) as a starting point happens mostly in the early days of their design project. All the groups involved EDU on the first day to a different extent. The activity of defining the design problem (DDP) sometimes happens together with or right after EDU. While the time range for ideating and sketching design solutions (IDS) varies from the early days until the last few days. Making a prototype (MP) and testing a prototype (TP) happens mainly towards the last days of this design project. The activity of preparing and presenting a presentation (PP) occurs mainly on the last day. In contrast, getting support from the teacher (GST) and getting feedback from others (GFO) happens randomly during this project.

In most cases, GST and GFO are more likely to occur in parallel with other activities. The activity of design documentation (DD) happens a few days after the opening of this project or before the closing of the project. The activity of planning (PL) occurs only in the early days of this project.

Single-tasking vs. Multi-tasking.

The results of EmoForm in the first section also show that when students experience DBL, they are sometimes in a single-tasking (ST) mode and sometimes in a multiple-tasking (MT) mode during the same time interval (i.e., 25 minutes timeslot on EmoForm). The total amount of lesson time reported by EmoForm is 1700 minutes. Overall, students spend more time on all types of ST in total rather than MT (M=266.85, SD=278.53). Turning to the details of single-tasking, for example, the top three of the highest mean scores for the time duration on ST are EDU (M=365.09, SD=275.17), MP (M=328.45, SD=213.05), and IDS (M=318.10, SD=205.49), while the lowest mean score is GST (M=43.75, SD= 9.18).

Overall, students tend to do 2-3 tasks in parallel simultaneously when they move into the multi-tasking mode. The results from EmoForm show that in our study, 23 types of activity combinations were identified when students were involved in two tasks of MT mode, while there were 15 types of activity combinations when they were involved in three tasks in parallel. As an illustration, ten students reported that they did the empathizing design user (EDU) parallel with defining design problem (DDP). More specifically, the students were involved in this EDU/DDP activity combination for varying lengths ranging from 12.5 mins to 375 mins.

Individual-tasking vs. Collaborative-tasking.

The information provided by the first section of EmoForm shows that overall, students spent more time on collaborative-tasking (CT) activities than individual-tasking (IT) activities. This difference is more minor at the beginning of the project, but the time spent on collaborative mode gradually dominates later.

Achievement emotion profile.

The data from the second and fourth sections (e.g., the mean scores of emotions, the frequency distribution of emotions relating to each activity) help derive an emotion profile towards corresponding DBL activities and their outcome in this study. As an illustration, students enjoy and relax when engaged in social interactions, and they are proud of their outcomes from these activities. However, they think getting support from a teacher is relatively more boring than getting feedback from peers. Besides, they are content with the outcomes of all DBL activities. Obviously, they have a strong feeling of contentment concerning the outcomes of making a prototype. Overall, students do not often feel frustrated or hopeless in DBL. Students feel less hopeless towards the outcomes from making prototypes than testing. Additionally, students almost experience no anxiety in DBL.

Engagement profile.

The information provided by the third section of EmoForm delivers students' perceptions of their own engagement. Concentration is one of the indicators of engagement in a learning activity. From the results of EmoForm, we found that students have the highest perceived concentration level while making a prototype. The activity of getting feedback from others and planning both require a relatively high degree of concentration. On the contrary, students have the highest degree of perception of learning better when getting feedback from others.

4.4. Discussion

To study students' emotions in DBL, a suitable measurement instrument is necessary. To this end, we have developed the EmoForm – a retrospective experience-sampling tool embedding a mix of negative and positive items for use in the constructive or creative learning context. To investigate the appropriateness of EmoForm for assessing students' emotional experience during DBL, we conducted a field study spanning 3 months. Analysis of the data collected using EmoForm shows that it is reliable and helps map how DBL activities contribute to students' emotional experience. In future studies, EmoForm needs to be extended with two more DBL activities – DD (Design Documentation), PL (Planning), and one more option for being off-task.

Further, it would be interesting to (a) validate EmoForm in different contexts, (b) with a diverse age group of students (e.g., middle school, junior high school students, or senior primary school students), or (c) in a longitudinal context. Future development could also enrich EmoForm with more items in each construct (e.g., adding items in the neutral experience construct). Finally, future research could digitize the EmoForm for improving its ease of use.

Emotions are complex things. One argues that measuring human beings' emotions is one of the most challenging affective science problems [158]. Scherer [165] has highlighted the multi-component nature of emotions, including the component of subjective feeling (emotional experience), cognitive (appraisal), neurophysiological (bodily symptoms), motivational (action tendencies), and motor expression (facial and vocal expression). Similarly, Hascher [5] has also argued that emotions experienced in learning are strongly interwoven with cognition and motivation. We would argue that future efforts should be made to measure and study the multifaceted emotions experienced in DBL. For example, future research could focus on developing multimodal tools with varied emphasis, e.g., the behavioral impact of emotions, or its intensity, duration, rapidity of change during the process.

Inspired by our primary motivation that triangulating emotional data in DBL by combining self-report with observational and psychophysiological measure, we also constructed other two possible tools for capturing emotions experienced in DBL. These two tools (namely EmoLens and EmoWatch) were based on the same theoretical underpin of emotion theory and DBL component framework described in EmoForm. The EmoLens toolkit was designed to effectively observe students' emotions when engaged in DBL activities as a supplementary source of self-reporting data (e.g., in EmoForm). On the other hand, we explored how technology could support the momentary ecological assessment of emotions during DBL. For this, we developed an experimental wearable device called EmoWatch, which aims to combine self-reporting with biometric measurement.

In the following, this chapter briefly presents these two potential tools for capturing emotions in DBL, including EmoLens (a working observation toolkit) and EmoWatch (a sensor-based wearable device), to spark insights for further development of related tools.

4.4.1. ***EmoLens***: *A Working Observation Toolkit*

Inspired by the multi-component nature of emotions and the need to avoid the subjectivity of only using self-reports, we propose an observation toolkit called EmoLens to effectively observe students' emotions when engaged in DBL activities as a supplementary source of self-reporting data, e.g., collected by EmoForm. Specifically, the EmoLens toolkit contains a working observation scheme (including codes of emotion, activity, and engagement; as seen in Table 4.5) and an associated observation note sheet, intended to provide a clear and operational description of students' emotions that aptly caters to DBL context. The underlying structure of this observation sheet is based on the continuous recording method [166]. Overall, the intended aim of EmoLens is to enable observers to record instances of emotional episodes following a recommended structure (i.e., activity events preceding > following emotions> following engagement and behaviors). In particular, EmoLens is designed to observe a group of students (e.g., 3-4 individuals from the same group) continuously throughout the observation period.

We conducted a pilot test with two users (i.e., observers) and evaluated using EmoLens in the DBL classroom. Before executing EmoLens, we provided these two observers with an orientation meeting and training exercises to reach an agreement on their understanding of the codes described in the scheme and the possible usage in practice. In total, we collected 68 copies of EmoLens, which contain 308 instances of various episodes in our evaluation study. The results from interviewing two observers show that they are positive about EmoLens enabling them to represent the situation they observed well. For example:

First, two observers thought EmoLens helped them observe three to four students in one group from the lens of emotion, activity, and engagement since students affect each other within a group. Some situations that are rarely observed made the observation challenging despite being scaffolded by EmoLens. For instance, some students were assigned different tasks having to work at various spots (e.g., one student is at the workshop space downstairs and another one works on the computer upstairs. Some students are around the working table in the corner). This finding suggests future efforts may pay attention to develop, e.g., wearables or portable self-tracking/reporting tools that can fill in situations rarely observed by classroom observation.

Second, observers reported the activities and engagement levels are easy to observe. However, some emotions might not be easily detected in some

Table 4.5. Observation Scheme of EmoLens Toolkit

Class	Behavior [Code]	Description
Emotion	Enjoyment [E]	Activating positive emotional response towards activities. For example, **verbal expression** (express willingness to continue learning or evaluate the situation in a positive way) [26,75,87], e.g., "having fun,"" liking tasks/activity," "enjoyable," "exciting," "cool"; **body activation** [168], e.g., "jumping," "dancing for joy," "clapping of hands," "stamping," "while laughing head nods to and fro," "during excessive laughter whole body is thrown backward and shakes or almost convulsed," "body held erect and head upright."
	Relaxation [R]	Deactivating positive emotional response towards DBL activities. For example, **verbal expression** [74,104], e.g., "relaxing," "comfortable"; **body activation** [169], e.g., "gestures are open and gentle, not sudden nor tense," "shoulders are not tensed up and generally hang loosely down," "asymmetrical arm positions, sideways lean," "asymmetrical leg positions, hand relaxation, backward leans."
	Frustration [F]	Activating negative emotional response towards DBL activities. For example, **verbal expression,** e.g., "frustrated," "I messed that up," "I can't get it done"; **body activation** [170]**,** e.g., "tapping fingers," "scratching the back of the head," "rubbing the back of the neck," "nervously shaking of the foot."
	Boredom [B]	Deactivating negative emotional response towards DBL activities. For example, **verbal expression,** e.g., "boring," "would be better, if…", "I find

		this class fairly dull," "slow tempo, moderate pitch variation," "down pitch contour and low pitch level"; **body activation,** e.g., "upper body collapsed [168]", "head backward not facing the interlocutor."
	Pride [P]	Activating positive emotional response towards their outcomes. For example, **verbal expression** (related to actively seeking feedback or be motivated to tell others how well they did) [171], e.g., "proud of," "accomplished," "confident," "productive"; **body activation,** e.g., "expanded posture with head tilted slightly back and arms out [172]", "symmetrical vertical arm movement [171]", "symmetrical up-down repetitive arm action [173]".
	Contentment [C]	Deactivating positive emotional response towards their outcomes. For example: **verbal expression** [74,174] e.g., "satisfied", "pleased with", "vocalizations of long duration"; **body activation** [175] e.g., "small nod".
	Anxiety [A]	Activating negative emotional response towards their outcomes. For example: **verbal expression** e.g., "feel tense", "makes me nervous", "scares me", "sighing", "inappropriate laughter", "expresses numerous concerns, worries, complaints, inability to focus on"; **body activation** e.g., "continual non-purposeful activity or inactivity [176]", "backward body lean or movement with upward gaze and lateral trunk lean [173]", "touching or pulling the hair [177]", "wriggling or interlocking the hands [177]", "aimless fidgeting [177]", "hiding the face [177]".
	Hopelessness [H]	Deactivating negative emotional responses toward their outcomes. For example, **verbal expression,** e.g., "no one can help me," "I feel like giving up," "I don't have the energy to something," "I have lost all hope," "I

		don't understand," **body activation,** e.g., "drooping," "listless," "immobile."
	Other emotions [O]	Any other emotions that are tied to learning activity or learning outcome.
Activity	Empathize Design User [EDU]	A stage of a design thinking process [178] aims to create meaningful innovations after understanding users. It represents a specific episode of the Learning Activity Component [58].
	Define Design Problem [DDP]	A stage of a design thinking process [178], aiming for bringing clarity and focus to the design challenge based on what learned about user and context. It represents a specific episode of the Learning Activity Component [58].
	Ideate Design Solution [IDS]	A stage of a design thinking process [178] aims for idea generation, which provides source materials for building prototypes and getting innovative solutions into the hands. It represents a specific episode of the Learning Activity Component [58].
	Make Prototype [MP]	A stage of a design thinking process [178], aiming for the iterative generation of artifacts intended to answer questions that get closer to the final solution. It represents a specific episode of the Learning Activity Component [58].
	Test Prototype [TP]	A stage of a design thinking process [178], aiming to gain another opportunity to understand the user and learn about this solution when soliciting feedback. It represents a specific episode of the Learning Activity Component [58].

	Prepare or present presentation [PP]	A stage of the (design thinking) process aims to represent the story of the solutions to others. It means a specific episode of the Learning Activity Component [58].
	Get Support from Teacher [GST]	A specific social interaction is between teacher and students [98]. It represents the Teacher's Role Component [58].
	Get Feedback from Others [GFO]	It frequently happened during the learning process [86], e.g., receiving comments on the work from peers, design users, etc. It represents the collective feedback part of the Assessment Component [58].
	Use Hands-on Materials & Resources [UHMR]	Using hands-on materials & resources for building or testing prototypes. It represents the Materials & Resources Component [58].
	Use Minds-on Materials & Resources [UMMR]	Using minds-on materials & resources for design documentation, visualization, or ideation. It represents the Materials & Resources Component [58].
	Other activities [OTHER]	Any other activities that are related to the DBL project.
Engagement	On Task Involved [OTI]	One observable engagement cue [176] representing the highest level of engagement among the rest.
	On Task Uninvolved [OUT]	One observable engagement cue [176] representing the second-highest level of engagement.
	OFF Task Quite [FTQ]	One observable engagement cue [176] representing the third-highest level of engagement.
	OFF Task Disruptive [FTD]	One observable engagement cue [176] representing the least high level of engagement.

students due to distinguished personal motivations, which is not surprising. Some students may invest more in the DBL project driven by their high intrinsic motivation and therefore exhibited more emotions [167], while some are generally not into this subject. This would suggest a need to supplement observation with self-report measures.

Third, observers said that the observation training and exercises help make the cognitive load for field observation less intense. Future research could focus on refining the training guidelines of using a related observation tool in DBL, especially when it comes to upscale the field observation in a larger sample.

*4.4.2. **EmoWatch**: A Working Wristband*

Given the apparent advantage of self-reporting on accounting for subjective feelings and the disadvantage of retrospective reporting in increasing memory loss, we explored how technology could support the momentary ecological assessment of emotions during DBL. For this, we developed an experimental wearable device called EmoWatch, which aims to combine self-reporting with biometric measurement. Specifically, EmoWatch is designed to detect students' fluctuating arousal changes in real-time by using the Galvanic Skin Response (GSR) sensor. We assume that several (though not all) such fluctuations could be related to emotions experienced by the student. A student is then informed by the vibration notification from the EmoWatch to self-repot the corresponding emotion once a fluctuating change of arousal state was detected. EmoWatch is expected to capture academic emotions similar to the EmoForm, but in a less obtrusive way, based on the naturally sampled fluctuation of the participant's arousal state. A corresponding platform is designed to visualize and display data collected by EmoWatch for both students and teachers.

We collaborated on the development of EmoWatch with two industrial design students during the year 2018. The early prototype of EmoWatch (as shown in Figure 4.5-a) is based on the design in the final bachelor project of Leenders [179] and further developed (as shown in Figure 4.5-b) in the final master project of Wang [180].

Yet, we did not conduct a rigorous evaluation study of EmoWatch with students in the DBL classroom due to more time needed for manufacturing multiple stable devices. It would be interesting for future work to further develop this technology and assess its comparative benefits compared to a paper-based tool like EmoForm capturing students' emotions.

Figure 4.5-a. A Prototype of Button-Based EmoWatch [179]. In this version, eight representative achievement emotions are assigned as eight different colorful buttons, respectively. Once notified by this device, students need to click one colorful button to self-report one emotion and turn around the potentiometer to adjust the intensity of the selected emotion. (Photo credit: Ward Leenders)

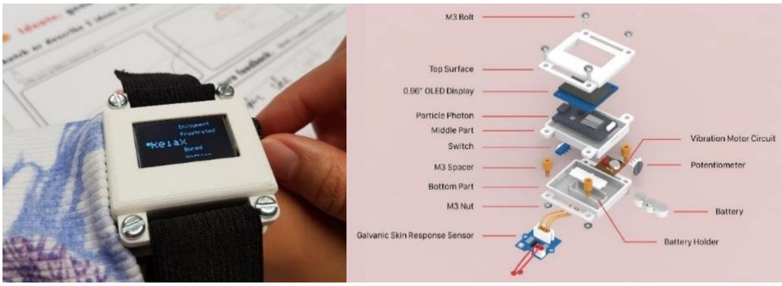


Figure 4.5-b. A Prototype of Digital Screen-Based EmoWatch [180]. In this version, we simplified the actions required for students to self-report their emotions while learning to make it less interruptive. They just need to turn around the potentiometer to self-report one of the eight representative achievement emotions pre-registered in the digital screen display. (Photo credit: Hongyu Wang)

4.5. Summary

To capture and assess students' emotions in DBL, we developed and tested EmoForm extensively. Motivated by the insights from Chapters 2 and 3, we believe that there is a need to triangulate DBL emotion research findings by combining self-reporting with other sources, e.g., observational or psychophysiological measurement. To this end, we developed EmoLens and EmoWatch. These three concepts refer to a consistent DBL framework and emotion concept that is not well-represented in current DBL studies. These concepts illustrate different possibilities for capturing emotions in the DBL context, but EmoLens and EmoWatch were not further developed or used later on in this research, considering the limited usage with participants in a field study setting. Overall, this chapter advocates three different approaches to measuring emotions in DBL and contributes to a methodological insight showing how to design tools for capturing emotions in DBL.

[Section III]

Development: Case Studies of Emotions in DBL in-and post-Secondary Education

Chapter

FIVE

Emotional Experience in DBL: A Three-month Field Study

Chapter 5: Emotional Experience in DBL: A Three-month Field Study

Abstract: Educational settings are places where students experience diverse emotions in relation to academic activities and their outcomes. Emotions, in turn, greatly influence students' learning process and engagement. Research on emotions in Design-Based Learning (DBL) has so far been coarse-grained, examining how students evaluate their overall feelings towards the DBL project. As yet, little is known regarding how specific DBL activities influence students' emotional experience. Therefore, we report a three-month field study of a DBL project involving 30 high school students (aged 13-14) addressing dual research purposes: (1) to faithfully reconstruct the manner and sequence of activities during DBL from a fine-grained perspective; and (2) to examine the relationship between these activities and students' emotional experiences. This study used a mixed research method and collected multiple data sources, including experience sampling surveys, classroom observations, and interviews. The research outcomes in this study are multiple. First, this chapter reveals a detailed investigation regarding the types of task students performed, the strategies of shifting and executing tasks during the process students experienced. Second, this chapter identifies specific types of activities that have a significant positive or negative relationship with students' emotional experiences. Derived from reported empirical evidence in the present study, this chapter proposes an Activity-and-Affect model of DBL. This model provides a fine-grained description of DBL activity as continuous along three dimensions: task (design thinking process, project management, social interaction), task strategy (single-tasking vs. multitasking), and collaboration strategy (individual or group). Our analysis highlights the diversity in how different DBL activities can be associated with different emotions.

This chapter is based on the paper: Zhang, F., Markopoulos, P., Bekker, T., Paule-Ruíz, M., & Schüll, M. (2020) Understanding Design-Based Learning Context and the Associated Emotional Experience. International Journal of Technology and Design Education. https://doi.org/10.1007/s10798-020-09630-w

5.1. Introduction

Design can be seen as a valid form of inquiry, given the general goal of design activities is typically to develop or improve artifacts and services [181]. Consequently, the design process can be easily transferred to a process of problem-solving in the learning of many subjects in the K-12 classroom [16]. Driven by the mechanism of design, the learning approach called Design-Based Learning applies Design Thinking [23] in a problem-based or project-based learning context. Design thinking is built upon fundamental mindsets (e.g., human-centeredness, empathy, a culture of prototyping, and radical collaboration) that frame a student's orientation to learning [182]. The application of design thinking in education allows students to develop designerly ways of doing and knowing [24] from moving back and forth of a sequence of design phases (e.g., insights, investigation, ideation, and implementation). In this way, students experience and acquire the concept and knowledge presented in the design project. Related research has provided ample evidence of the potential benefits of DBL: gain in self-confidence [60], become more tolerant of errors [38], and increase students' interest in the subject topic [29]. Consequently, DBL as a learning approach is attracting increasing attention by relevant communities, e.g., for Science, Technology, Engineering, and Mathematics (STEM) education [17–22,28] and design education [16].

One of the featured characteristics of DBL is engaging students in complex and sometimes interleaved processes of inquiry and designing. Specifically, the inquiry process in DBL forces students to carry out the design process in a flexible and highly opportunistic manner [63], which involves frequently switching between different tasks and sub-problems. As a result, students often are expected to go through the design process iteratively rather than adhere to some strictly defined stepwise process [183]. The opportunities for learning in DBL may precisely occur during this active interleaving and switching between different roles in individual work or teamwork and between various sub-tasks amidst the process. For instance, interleaving sub-tasks such as investigative activities with attempts to take on a design challenge is expected to enable students to refine their understanding of concepts, ideate solutions to design problems, communicate, and collaborate at the same time [184]. However, such a complex and dynamic process makes positioning or orchestrating specific activities within the overall DBL process challenging for researchers and practitioners. Perhaps, for this reason, there has been little rigorous empirical analysis of how DBL activities unfold and the emotions students experienced during these.

Research has shown that emotions can influence students' attention, engagement, and choice of learning strategies [6,80,82]. It has been argued already that emotions are essential in DBL [26,152]. However, research on young students' emotions in DBL has so far been coarse-grained [152]. For example, emotion research in DBL may pertain to how students evaluate their interest in the subjects covered [60,99] or their willingness to participate in similar DBL activities in the future [73,75]. Existing research seems not yet to provide a fine-grained consideration of how emotions are associated with specific DBL activities.

To address this apparent gap in related research, we carried out a three-month field study in a DBL classroom with 30 high school students (aged 13-14). Overall, the dual aims of this study are: (1) to develop a fine-grained understanding of how DBL activities unfold in the classroom, and (2) to examine students' associated emotional experience during these. To reconstruct the dynamic processes of DBL activity, we refine DBL activity from several aspects such as learning activity, grouping strategy, social interaction, and temporal of the learning task. To conceptualize emotional experience, we refer to eight representative achievement emotions (as seen in Table 5.1) and two aspects of engagement (in Table 5.2) in the present study. These rationales are detailed further in the Background section.

Specifically, this chapter addresses the following two aspects: (1) a detailed understanding of *how DBL activities unfold during the process?* (e.g., in which manners and sequence DBL activities reveal by students?) (2) *What relationships exist with students' emotional experience when engaged in different DBL activities?* (e.g., which DBL activities have a positive and negative association with students' emotional experience?) (RQ2)

This chapter makes the following contributions to the field: (1) an empirical understanding of how students go through the DBL process, including the types of task students performed, the strategies of shifting and executing tasks during the process student experienced; (2) developing an understanding of the relationships between students' emotional experience and different DBL activities; (3) a theoretical model which highlights the complex and reciprocal relationships between DBL activities and associated emotional experience; and (4) implications for informing further practice and research for carrying out DBL activities.

5.2. Background

5.2.1. Design-Based Learning

Learning can be addressed from a variety of perspectives. A constructivist learning perspective asserts learning is affected by the context, namely, in which an idea is taught, as well as by the students' beliefs and attitudes [185]. In line with the constructivist learning tradition, DBL has been introduced as a learning approach in which the typical setup has students encountering a design challenge and attempting a solution individually and/or in small groups using only prior knowledge [19]. Other definitions of DBL are quite comparable, e.g. [20,22,27]. In general, DBL at a general level is akin to other terms, such as Learning-by-Design (LBD; e.g., [19]), Learning through Design [15], Design-based Science (DBS; e.g., [18,32,186]), T/E Design-based Learning (T/E DBL; e.g., [35,187]) or maker education (learning by making; e.g., [37,38,188]).

Prior attempts in relation to characterizing DBL activities fall into the following two categories: (1) *The requisite phases of the design process and/or related inherent knowledge construction*; Related works include the conceptualization of a five-stage design thinking process [189], the learning by design cycle [19], the design-based science learning cycle [186], the activity model for the process of scientific inquiry [190], and PIRPOSAL phases of integrative STEM education [36]. These works illustrate the designing and inquiry processes through stages of constructing design concepts and alternatives. (2) *The critical instructional elements for implementing a successful DBL curriculum in practice*; For instance, some studies have pointed out the iterative design process as a vital element in orchestrating DBL activity [1,25,33,62,191,192]. Other elements include the teacher's role of coach [62,193], reflection [25,194], the open-ended and authentic project feature [25,62], and collaboration in teamwork [18,25]. These works help develop successful instructional strategies for a DBL environment and contribute to a theoretically grounded understanding of DBL. Literature in the second category characterizes DBL in a relatively broader sense from an instructional design perspective, while the first category addresses the design and inquiry nature of DBL that has been widely agreed as the core of such a learning approach.

However, given the dynamic practices of designing and inquiry processes in DBL, current studies will not suffice in providing detailed accounts of how students approach and unfold tasks amidst DBL. For instance, they do not consider in detail how DBL unfolds in action from a student-centered perspective and whether or how students interleave the aforementioned prescribed DBL elements while the learning activity takes place. In this chapter, we refer to these mentioned critical aspects, especially regarding the designing and inquiry process of DBL, to reconstruct how DBL activities can be unfolded and approached by students; and to understand how DBL activities can be conceptualized and represented.

To understand the DBL activity at a systemic level, we adopted the curriculum development components [58] as a theoretical foundation. This curriculum development framework proposed by van den Akker et al. includes ten components: *learning activity* (i.e., how are students learning?), *teacher role* (i.e., how is the teacher facilitating their learning?), *grouping* (i.e., with whom are students learning?), *time* (i.e., when are students learning?), *content* (i.e., what are students learning?), *location* (i.e., where are students learning), *aims and objective* (i.e., what learning goals do student pursue?), *assessment* (i.e., how is their learning assessed), *materials and resources* (i.e., with what are students learning) and *rationale* (i.e., why are students learning). Theoretically, learning in DBL may take place in a student's construction of the object and interaction with the people around, according to the notion of "constructionism" [14]. Therefore, we mainly refer to some components of the curriculum development framework [58], which helps construct the student's dynamic engagement and interaction with the tasks and people during DBL. In this chapter, we refine the DBL activity as situational information on four interdependent aspects.

- The learning activity (e.g., the sequence and ritual of design and learning process: how tasks are unfolded and how students are learning);
- The grouping strategy (e.g., the allocation of learning tasks: student learning individually or in small groups);
- The social interaction (e.g., peer-to-peer communication and student-teacher interaction);
- The temporal aspects of the learning task (e.g., the duration and sequence of learning tasks).

For example, one possible DBL instance could be described along these dimensions as follows: a student works individually (*grouping strategy aspect*) on interleaving between ideating design concepts and empathizing with design users (*learning activity aspect*), and the teacher provides support to this student (*social interaction aspect*) when this student is interleaving between these two tasks for a long time (*temporal aspect*).

5.2.2. DBL, Emotion, and Engagement: An Extended Perspective

Emotional experiences are ubiquitous and greatly influence the learning process. Some researchers consider emotional experiences as a "way of being" and study them as holistic episodes [9]. Others argue that the emotional experience is characterized by at least two levels of consciousness [195,196]. The first order of emotional experience is characterized by total involvement [9], e.g., being in a state of "flow" in tasks or immersed in a feeling. The second order adds awareness [195,196], which adds specificity and direction of attention [9]. For instance, being conscious of the situation where the potential for emotional regulation during the experience occurs. A third-order refers to the quality of emotional experience [196], which can be thought of as a motivational tendency that helps to define how emotional expression should look and feel in a particular situation [9].

In the field of DBL, increasing attention has been placed on studying or measuring emotion as a part of the evaluation of DBL activities [26,29,59–61,197]. This body of emotion research in the DBL field often treats emotions as an independent outcome indicator for the students' experience of a DBL intervention, becoming separated from the holistic multi-faceted nature of the emotional experience itself. The present study used eight representative achievement emotions (as seen in Table 5.1, reflecting on the first-order of involvement) and two aspects of engagement (in Table 5.2, reflecting on the second-order of awareness) in framing emotional experience. The general conceptualization of emotional experience in DBL is further detailed in the following sections.

Achievement Emotion

In emotion research, some models and theories use a limited set of categories to classify emotions [198], echoing the idea that emotion is information [199]. The Control-Value theory [52] defines achievement emotions as emotions tied directly to achievement activities or achievement outcomes. More specifically, this theory treats achievement emotions as three-dimensional constructs [52] defined along the dimensions of *object focus* (i.e., activity-focus vs. outcome-focus), *valence* (i.e., positive vs. negative), and *activation* (i.e., activating vs. deactivating). Accordingly, activity-focus emotions can be either positive activating (e.g., enjoyment), positive deactivating (e.g., relaxation), negative activating (e.g., anger, frustration), or negative deactivating (e.g., boredom). Likewise, outcome-focus emotions can be positive activating (e.g., joy, hope, pride, and gratitude), positive deactivating (e.g. contentment, relief), negative activating (e.g. anxiety, shame, and anger) and negative deactivating (e.g. sadness, disappointment, and hopelessness).

Few studies have directly examined achievement emotions in different learning contexts. For instance, one study [147] assessed elementary school students' enjoyment, anxiety, and boredom about the situations of attending class, doing homework, and taking tests and exams. Another study [136] examined enjoyment, anxiety, boredom, and six other emotions (including hope, pride, relief, anger, shame, and hopelessness) in these similar situations but with university students. More recently, a study [93] examined frustration, confusion, excitement, and curiosity, specifically during an elementary school DBL course. These studies represent the different range of contexts for studying achievement emotions. However, the achievement emotions examined in these studies differ. The study by Pekrun et al. [136] with university students covers all three dimensions of achievement emotions resulting in broader coverage of achievement emotions than the other two studies involving elementary school students [93,147], which only address one or two dimensions. However, that study only considers emotions at a macroscopic level without making precise the relation of emotions to specific DBL activities.

Table 5.1. The Achievement Emotions in the Present Study

	Positive		Negative	
	Activating	Deactivating	Activating	Deactivating
Activity	Enjoyment	Relaxation	Frustration	Boredom
Outcome	Pride	Contentment	Anxiety	Hopelessness

As argued in a study conducted by Linnenbrink-Garcia and Pekrun [200], more research is needed to consider how different contexts shape students' emotions. The present study focuses on a wide variety of students' achievement emotions, especially concerning a DBL course in a middle school. The focus of achievement emotions in the present study is elucidated in Table 5.1, including eight representative achievement emotions, to ensure a more balanced coverage compared with the studies mentioned above. There are two considerations for selecting achievement emotions in the present study. First, the emotions chosen are according to the three-dimensional taxonomy in an equally representative way. Second, the emotions chosen echo the ones that have been addressed with K-12 students, e.g., pride, enjoyment, relaxation, boredom, anxiety, and hopelessness in prior studies [26,74,75,85].

Engagement

Students' engagement that reflects psychological investment and effort is necessary for learning [201,202] and highly associated with emotions. Related works on the definition of engagement have different foci. For instance, the Flow theory [203] conceptualizes student engagement based on the culmination of concentration, interest, and enjoyment (i.e., flow). Besides, the Broaden-and-Build theory [164] hypothesized that positive emotions broaden one's thoughts and actions, defining student engagement as a multidimensional construct including academic, behavioral, cognitive, and psychological subtypes, and considering engagement as conducive to meaningful academic and social-emotional outcomes [204].

The notion of engagement in the DBL has been addressed using different theoretical perspectives. For instance, one recent study in a maker space [201] considers engagement as a component of flow, while another study [205] has measured the influence of gender on students' cognitive, behavioral and emotional engagement in a high school DBL course. Furthermore, one study [28] focused on one aspect of engagement, which, to some extent, amounts to students' participation to analyze the close association between engagement and achievement. In summary, a consistent manner of assessing engagement seems lacking in the body of DBL research.

Table 5.2. Engagement Aspects of Emotional Experience

Aspect	Description	Measurement
Concentration	How well are you concentrating?	-EmoForm (i.e., From the cognitive aspect, ask the student to self-rate perceived concentration) -Observation sheet (i.e., From behavior aspect, ask the researcher to observe the degree of being on-and-off task)
Learn better	Were you learning anything or getting better at something?	-EmoForm (i.e., Ask the student to self-rate perceived learning outcomes)

Therefore, we put forward our conceptualization of engagement in the present study. This conceptualization is built on an integrated understanding of engagement according to the Flow theory and Broaden-and-Build theory. Table 5.2 illustrates this engagement conception, including the degree of concentration (i.e., how well you are concentrating?) and its perceived associated outcomes (i.e., were you learning anything or getting better at something?).

5.3. Method

We report on a three-month case study of a class with 30 students (aged 13-14) engaging in DBL activities carried out as part of the standard Dutch school curriculum in design and research. The study had a dual purpose of studying the activities in the DBL context and the students' associated emotional experience. A triangulated mixed-methods approach [206] was adopted to collect both quantitative and qualitative data regarding the emotions experienced during the DBL activities, using a combination of naturalistic observation, interview, and experience sampling survey.

5.3.1. Study Context

The present study was embedded in a Design & Research subject (i.e., O&O; the Dutch abbreviation for "Onderzoeken en Ontwerpen") at a Dutch public school so-called "Technasium." Students at Technasium develop STEM-related competencies and design skills (e.g., creativity, collaboration, communication, planning, and project-based work). Overall, the Design & Research (O&O) subject in Technasium education is closely related to STEM contexts [207], which typically combines science content-related research projects (e.g., DBS [18] or LBD [19]) and technological and engineering-related design projects (e.g., T/E DBL; [35]). For example, the Research & Design projects can be done with different STEM-related contexts, such as relating to architecture, industrial design, or biology [207].

The design challenge of this DBL project was to design an escape room for the local fire department to allow participants to playfully and interactively improve awareness of fire safety in and around the house. In this Escape Room project in the present study (more details can be found in Appendix D and E), the design challenge students have to address is more related to the technological and engineering content and knowledge about design and inquiry. The learning goal in this Escape Room design project is open-ended and depending on the student-oriented personal learning objective. In general, the typical learning goal in this project is to learn design and inquiry skills (e.g., empathize with the client's need, inventing, model, use, and value information) and collaboration skills (e.g., communicate and cooperate with peer students and stakeholders).

Before the study was initiated, we ascertained that the planned learning activities match four DBL characteristics that have been used in prior studies [26,152] to ensure external validity. The following four DBL characteristics are built upon the features of DBL that have been addressed in the literature, e.g., [16,19,25,27,28,54–57].

(a) The *learning activity* should be open-ended, followed by a design process involving multidisciplinary knowledge and skills. Furthermore, the challenge and problem introduced in this learning activity should be embedded in an authentic context.

(b) The *teacher's role* should be that of a coach enabling the students to become active learners.

(c) The *grouping* should enable students to share a sense of responsibility and be able to communicate and collaborate with peers and stakeholders.

(d) *Materials and resources* should support hands-on activities, e.g., prototyping or testing, and minds-on activities, e.g., empathizing, defining, or ideating.

5.3.2. Participants

Participants were a class of 30 students aged 13-14 who are at the level of HAVO2 (equivalent to the grade 7-8 in a secondary education system). In the Dutch education system, the HAVO stream gives access to polytechnic level tertiary education, which in the Netherlands is considered an applied science university. Participants in this study already had one year of experience with STEM and DBL. Before participating in the Escape room design project, they were already involved in two design projects (e.g., designing a working toy for pigs in an organic form and designing a system encouraging students to classify garbage). Besides, they have also participated in several skill training modules, such as technical drawing and sketching, making video presentations, and working with workspace tools and materials (e.g., wood, acrylic, cardboard, etc.). The guardians of participating students provided informed consent before the start of the study.

5.3.3. Measures

To overcome the challenges involved in obtaining reliable data about young students' emotions in the DBL classroom [26], e.g., a social- desirability bias for self-reporting internal states, data collection in this study involved multiple sources of information, including an experience sampling survey – EmoForm [90], observation, and interview. The data collection was carried out by two researchers who conducted an after-project interview and two research assistants (students in a design department with more than two-year experience in DBL in higher education) who attended field observations and conducted after-lesson interviews during the project.

Experience Sampling Survey – EmoForm

EmoForm [90] is a retrospective experience-sampling questionnaire (see Figure 5.1) for use in the constructive or creative learning context that combines negative and positive items. An earlier validation study has shown EmoForm has an acceptable internal consistency and is a helpful self-report tool for capturing students' emotional experience in DBL [90].

The content of EmoForm consists of four sections of questions: (1) what activities were a student involved in sequence in the past lesson? (2) How a student felt (precisely about four activity-focused achievement emotions, e.g., enjoyment, relaxation, boredom, and frustration) every 25 minutes during the last lesson? (3) How well was a student concentrating, and how much did a student learn in every 25 minutes in the previous lesson? ; (4) How a student felt about four outcome-focused achievement emotions, e.g., contentment, hopelessness, anxiety, and pride in the past lesson? In the present study, students were required to fill in the EmoForm at the end of each DBL daily based lesson.

Observation

Combined with students' self-reporting with EmoForm, we used an observation note sheet which applies continuous recording [166] where observers record: (a) instances of the episodes following our recommended structure (i.e., activity events preceding, following emotions, following engagement level, or behaviors); (b) the episodes of three to four students who are in the same team; (c) the episodes in every 25 minutes (the same as the timeframe in EmoForm) which allows triangulating self-reporting responses and observation notes within the same period.

We've involved two participating observers (i.e., research assistants) who were trained before the start of the study. They observed one team using the observation note sheet during every lesson. Every group in the class is observed in a pre-determined order over time.

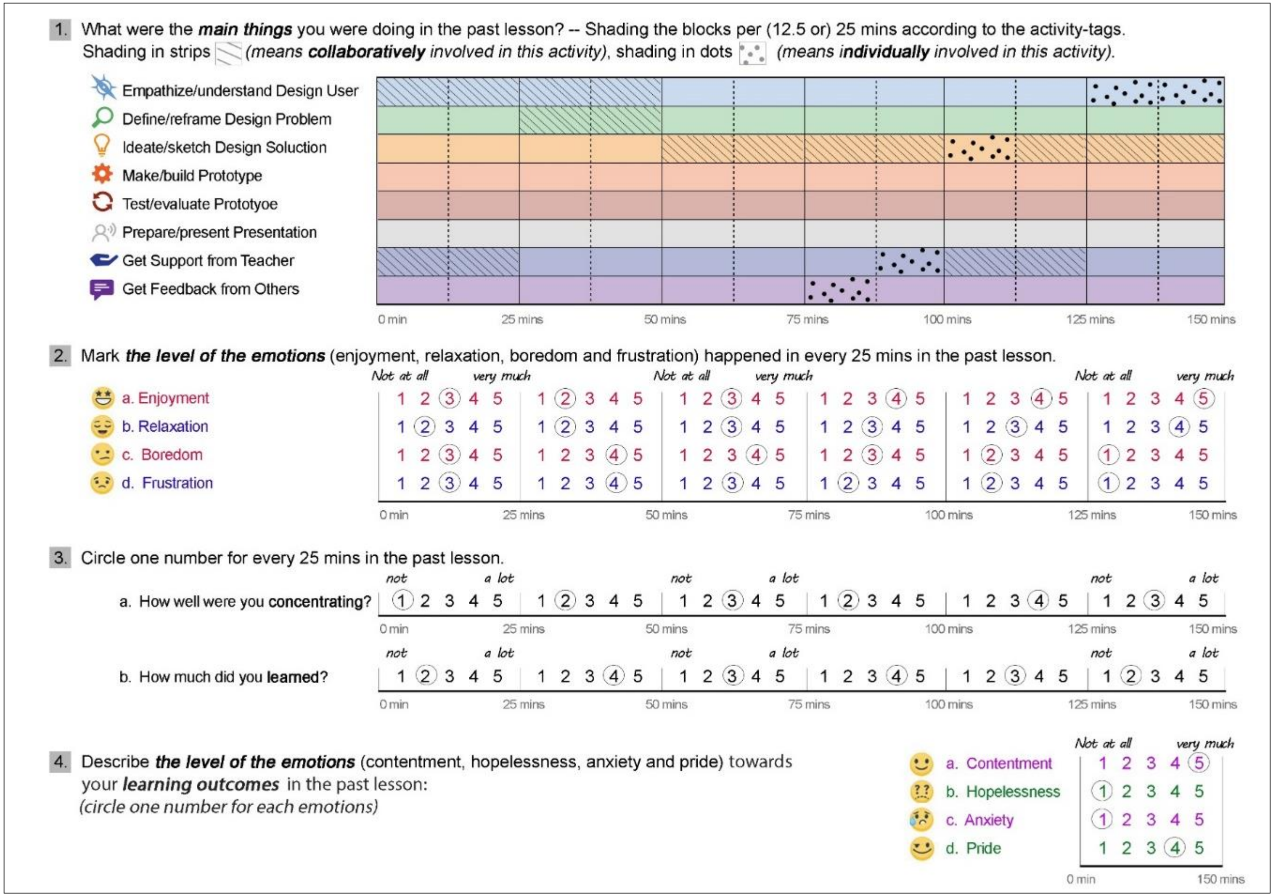


Figure 5.1. Example of a Filled EmoForm (A Made-Up Example Based on Actual Reports)

Interviews

Two types of the interview were conducted during and after the DBL project. (a) *a semi-structured interview* following a predetermined protocol was conducted during the project. Specifically, one observer observed a specific team (following a predetermined order) at every lesson. Before the daily lesson ended, the observer interviewed the same group of students one by one. The questions during the interview revolved around one or two episodes the observer has recorded. (b) After the end of this project, *a structured in-depth interview* was conducted with the students who have reported multi-tasking activities to get a deeper understanding of reported cases.

5.3.4. Procedure

Seventeen lessons were scheduled during this DBL course lasting three months. The lesson duration varied: three sessions of 50 minutes, eight sessions of 100 minutes, and six sessions of 150 minutes. As shown in Table 5.3, all seventeen lessons/sessions were observed using our observation note sheets. However, semi-structured after-lesson interviews and EmoForm were completed only in fourteen and fifteen sessions, respectively. The exceptions, where data was not collected from both measurements, concern some unexpected situations (a canceled lesson and a visit to the local fire department where it was not possible to distribute questionnaires nor interview). Besides, one structured in-depth group interview was conducted after the end of this project.

Table 5.3. The Procedure of Scheduled Lessons and Data Collection

Lesson date (Year 2017)	Lesson duration (mins)	Data collection			
		EmoForm	Observation	Interview (a)	Interview (b)
March 29	100		√		-
April 11	100	√	√	√	-
April 12	150	√	√	√	-
April 18	100	√	√	√	-
April 19	50	√	√		-
April 25	100	√	√	√	-
April 26	50		√		-

May 16	100	√	√	√	-
May 17	150	√	√	√	-
May 23	100	√	√	√	-
May 24	150	√	√	√	-
May 31	150	√	√	√	-
June 07	150	√	√	√	-
June 13	100	√	√	√	-
June 14	150	√	√	√	-
June 20	100	√	√	√	-
June 21	50	√	√	√	-
Post project	-	-	-	-	√

Annotation: - not applicable; interview (a) semi-structured after-lesson interview; interview (b) after-project structured think-aloud group interview.

Note: The exceptions of missed sessions concerned some unexpected situations (i.e., a canceled lesson and a lesson was scheduled to visit the local fire department where it was not possible to distribute questionnaires), where data was not collected from EmoForm and interview (a).

5.3.5. Analyses

In this chapter, we analyzed the data collected from EmoForm as the primary source, while observations and interview recordings as supplementary sources. The quantitative analyses are made with IBM SPSS statistics 25 [208].

To address the first aspect (*How do the DBL activities unfold?*), we first qualitatively analyzed the data collected by observations and EmoFoms following a thematic analysis approach [209]. We transcribed EmoForm recordings and observation notes following the predefined episode structure and inductively coded the transcripts into categories. For instance, we first transcribed and marked all newly emerged activities on EmoForm recordings (e.g., off-tasking events, design documentation, and planning, etc.) and observation notes (e.g., off-tasking activities, asking and/or offering help, reviewing other's tasks, and chatting with peers). We then performed a follow-up thematic analysis to find the featured categories of all reported DBL tasks (as seen in Table 5.4). Detailed results in terms of DBL tasks can be found in the task dimension of section 5.4.1.

Additionally, we descriptively reported sequences of switching tasks based on data from both EmoForm and observation notes. We portrayed the overall evolution of participating DBL tasks per student over days (as seen in Figure 5.2). Likewise, we reported the manner of combining tasks based on EmoForm data, and we then validated these results through interviews. More detailed results can be found in the task strategy (single-tasking vs. multi-tasking) Result section. We also analyzed the highlighted types of combined tasks based on the frequency of reported students (as shown in Table 5.5), and we portrayed the relationship between combined tasks during DBL (as seen in Figure 5.3). For executing tasks in the manner of groups or individually, we analyzed the types of tasks favored in teamwork and individual work based on the reported time spent. Besides, we also calculated students' average time spent on tasks when utilizing specific collaboration strategies (as shown in Table 5.6 and 5.7). Detailed results can be found in the collaboration strategy (collaborative-tasking vs. individual-tasking) Result section.

Based on the qualitative results relating to *how the DBL activities unfold*, we synthesized a three-dimensional perspective of DBL activities (task, task strategy, and collaboration strategy dimension). Based on these results, we proposed the Activity-and-Affect model of DBL (as seen in Figure 5.4) to establish the nuanced channels between DBL activities and students' emotional experiences. To assess the goodness of fit of the model, we fitted the data repeatedly collected by EmoForm into the taxonomy of this proposed model and then performed a linear regression using a hierarchical data structure (as shown in Table 5.8). Detailed analysis procedures and results can be found in the subsection of 5.4.1 section -- A conceptual framework: the Activity-and-Affect model of DBL.

Finally, to answer the research question, *how are emotional experiences related to different DBL activities?* (RQ2), we performed multiple linear regressions using a stepwise method to measure which DBL activities significantly contribute to students' emotional experience (see Tables 5.9 in Appendix F). Specifically, this analysis investigates DBL activities from the dimensions of the task, task strategy, and collaboration strategy, respectively. All the multiple regression analyses were calculated on a group level rather than distinguish individual differences. A detailed explanation of the analysis procedure and results are presented in the Results section.

5.4. Results

5.4.1. Uncover DBL Activities From A Three-Dimensional Perspective

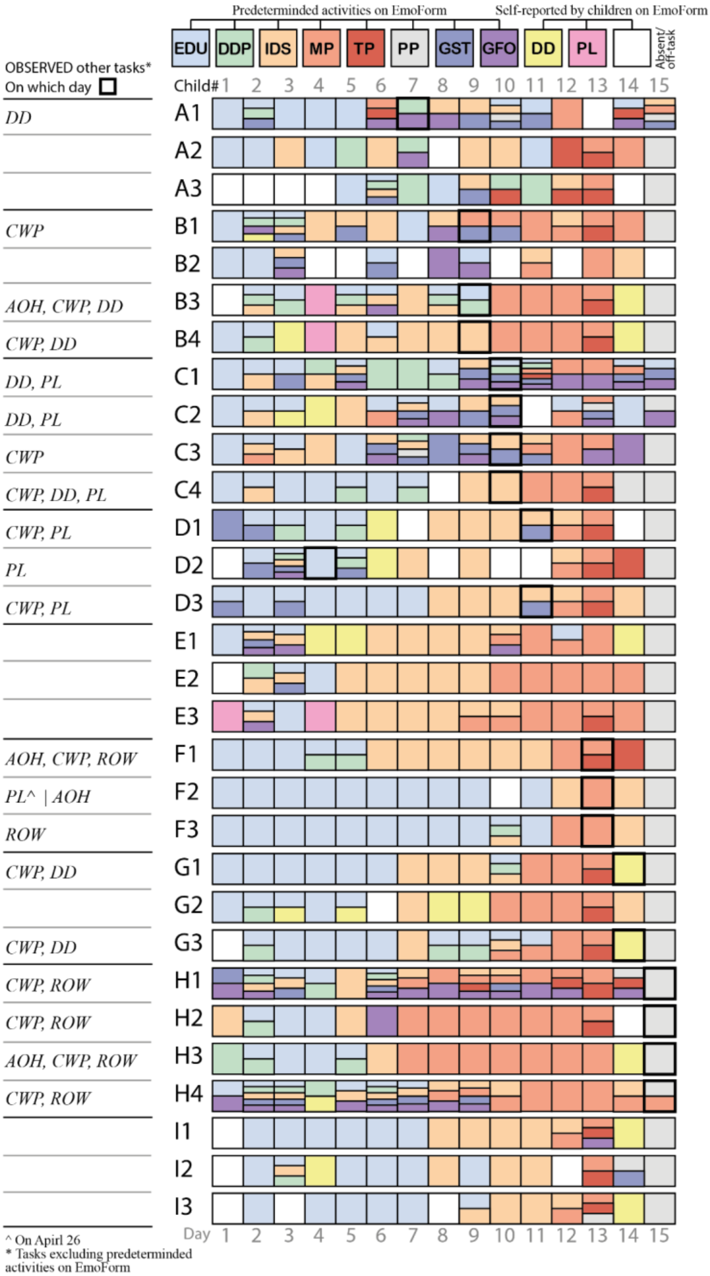
We report the findings relating to *how the DBL activities unfold* from the following three aspects: (a) task dimension: various tasks and varied paths of the process, (b) task strategy dimension: multi-tasking versus single-tasking strategy, and (c) collaboration strategy dimension: collaborative-tasking versus individual-tasking used in the process. For each aspect, we first report the empirical findings derived from the present study and then discuss the theoretical implications relating to the literature. Finally, we propose a conceptual framework called the Activity-and-Affect model of DBL to construct a three-dimensional perspective of DBL activities and describe a flexible view of how different DBL activities could be associated with mixed emotions.

Task Dimension: Various Tasks and Varied Paths of the Process

In general, investigating how the process unfolds is essential for a proper understanding of context and its influence on behavior [210]. In this section, we report how the DBL process unfolds by illustrating the various tasks and varied paths of the process that students followed (see Figure 5.2), which was derived from the data collected with the observation (left side of Figure 5.2) and EmoForm (the colorful square block of Figure 5.2).

On the top legend of this figure, each color represents one type of task documented in EmoForm. Each square block in the table of Figure 5.2 represents one day. The colorful stripes in the square block represent the tasks a student has completed within a day. For instance, the data described in Figure 5.1 from a student can be compressed into a single square block filled with five differentiating colored strips (resembling the block of student H4 on day-2 in Figure 5.2). The whole colorful square table describes all participated students involved in activities in this DBL project. Nine teams were denoted in this figure alphabetically, ranging from "A to I," and each group (containing three to four individual students) was denoted by a number, e.g., A1, A2 A3. The left side of this figure illustrates the observation data and primarily lists types of activities that were identified by observations rather than predetermined by EmoForm.

Due to the open-end nature of DBL, students have autonomy in planning and implementing tasks. As a consequence, how they went through a sequence of DBL activities varied across teams. For example, only teams B and



Abbreviations: EDU *Empathize Design User*; DDP *Define Design Problem*; IDS *Ideate Design Solution*; MP *Make Prototype*;TP *Test Prototype*;
DD *Design Documentation*; PL *Planning*; PP *Prepare/present Presentation*;GST *Get Support from Teacher*, GFO *Get Feedback from Others*; AOH *Ask or Offer Help*; ROW *Review Other's Work*; CWP *Chat With Peers*.

Figure 5.2. Evolution of Participating DBL Activities (per child) over Days.

E experienced all predetermined task-focused activities foreseen in the design of the EmoForm (refer to the top legend in Figure 5.2). It is because some teams missed reporting some activities. Indeed, we observed that some teams (e.g., team A) participated in the design documentation, and others (e.g., C, D, and F) participated in the planning despite that participants did not report on this. There is also quite some variation in how teams experienced the DBL process: e.g., two teams (F and G) did not report social interactions (getting support from a teacher or giving feedback to others). Moreover, the degree of iteration in the process also varied substantially between teams. For example, team H went through activities iteratively most times, whereas teams F or G the least times.

Students seemed to follow a relatively consistent activity pattern over time. As one might expect, the activity of empathizing and understanding users (EDU) was reported mostly at the initial steps of their design process (almost all students report this on the first day and slightly fewer on the second). Continuing on the general pattern, we see that the activity of defining a design problem (DDP) very often happens together with or right after the event of empathizing with the design user (EDU). There were more variations with regards to ideating design solutions (IDS), which took place early on or even only in the last few days of the project. Despite that all teams participated in defining the designing problem (DDP), only a small number of individual students did so: eighteen students in total on the ninth day of this project. The activity of making prototypes (MP) and testing prototypes (TP) was left for the later phases of this design project. On the 13th day, all teams were involved in making and testing. The project ended uniformly for all groups and individuals as they were all engaged in preparing and presenting (PP) their work. Getting support from the teacher (GST) and getting feedback from others (GFO) happened at various times during the project with no apparent pattern, most often in parallel with other activities. Too few instances relating to design documentation (DD) and planning (PL) were recorded to allow discerning a common pattern.

Observation data shows some patterns in the learning process. Some off-task cases were indicated in classroom observations, such as dealing with a computer problem, searching for lost documents, looking at the phone while waiting for the teacher's support, and goofing around. Apart from these non-task-related activities, the most commonly reported events were documenting their designs and planning. Besides, the field observations in this study also discerned another three frequent activities relating to students' task-related social interaction amidst DBL. (a) *Asking or offering help* (AOH). It can be expressed by answering peer's questions and asking for instructions on the task, or students sometimes would help a team member with a task when they were doing some other tasks. Besides, we found offering help was often concerning trying out another team's prototype. (b) *Reviewing other's work* (ROW). It often occurred through testing prototypes and when following the presentation of another group. (c) *Chatting with peers* (CWP). It often happened in idle moments while waiting for other tasks, such as presentation, getting the teacher's support, and sometimes during an off-topic conversation.

In general, characterizing and categorizing DBL activities is a fundamental step in identifying the most likely DBL elements and supporting learning and teaching in practice. Based on the results derived from this study, we outlined a list of project-related tasks in Table 5.4, which comprises the three most likely categories: Design Thinking Process (DTP), Project Management (PM), and Task-related Social Interaction (TSI). The mixed steps and tasks in parallel (see the last four rows of Table 5.4) will be reported and discussed in the following sub-section regarding the multitasking strategy.

Design thinking is a general theory of design [211] that has been used to characterize what individual designers know and how they approach and make sense of their work [212]. The design thinking process category we proposed in this table is consistent with the widely adopted design process recommended by Stanford d.school [189], which consists of five main steps: Empathize, Define, Ideate, Make and Test.

Furthermore, this table identifies the category of project management to refer collectively to some auxiliary activities relating to the DBL context, e.g., presentation, design documentation, planning. Notably, an earlier study [133] has regarded design documentation as an additional essential design skill in the high school classroom. In another study [28], presentation in DBL is where teacher assessment and peer assessment occur. Besides, planning is regarded as a critical skill or practice for learning science [33].

The final category pertains to social interaction, including getting support from the teacher or getting feedback from others. The importance of social context has already been emphasized in earlier works, e.g., the teacher's supportive coach role on students' tasks and processes in DBL [25,27]. While earlier studies have argued that it is more enjoyable to do tasks with peers, e.g., see [85], little empirical evidence of such collaboration can be found in DBL literature. Table 5.4 explicitly emphasizes project-related social interaction and de-emphasizes off-topic social interactions, e.g., goofing around making jokes. Besides, task-related social interactions are further

Table 5.4. The Categorized Activities in the Task Dimension

Category	Activity	Theoretical source
Design Thinking Process (DTP)	Empathize Design User (EDU)	Design element
	Define Design Problem (DDP)	Design element
	Ideate Design Solution (IDS)	Design element
	Make Prototype (MP)	Design element
	Test Prototype (TP)	Design element
	Combined the above steps (DTP)	
Project Management (PM)	Design Documentation (DD)	Design element & project characteristics
	Planning (PL)	Project characteristics
	Prepare/present Presentation (PP)	Design element & project characteristics
	Combined the above steps (PM)	
Task-related Social Interaction (TSI)	Get Support from Teacher (GST)	Teacher's role
	Get Feedback from Others (GFO)	Assessment & social context
	Ask or Offer Help (AOH)	Social context
	Review Other's Work (ROW)	Social context
	Chat With Peers (CWP)	Social context

	Combined the above steps (TSI)
Mixed design process steps and task-related social interaction (DTP-TSI)	e.g., EDU-GST, IDS-GFO, etc.
Mixed design thinking process steps and project management (DTP-PM)	e.g., DDP-DD, IDS-PP, etc.
Mixed project management and task-related social interaction (PM-TSI)	e.g., PP-GST
All categorized tasks in parallel (DTP-PM-TSI)	e.g., MP-PP-GST

classified as asking or offering help, reviewing other's work, and chatting with peers (e.g., casually discussing with peers).

Task Strategy Dimension (Multi-Tasking Versus Single-Tasking Strategy)

During the DBL process, students sometimes engaged in one singular task after the other, and at other times carried out multiple tasks in parallel. Single-tasking refers to a single activity (e.g., one specific stage of the design thinking process, or separate action of receiving help from the teacher, etc.) on which students dedicated a sustained period before interleaving and switching to other tasks. For instance, the EmoForm in Figure 5.1 illustrates a single task from the timeframe of 50 minutes until 75 minutes. On the contrary, multi-tasking refers to two to three project-related tasks in parallel within the same timeslot. Note that the term multi-tasking here does not apply to non-project-related tasks (such as working while listening to music, or goofing around, etc.).

From the data collected from the first section of EmoForm, students reported working on a single task more often than in multi-tasking. For single tasks, students tend to spend the most time on empathizing design users (M=365 mins, SD=275 mins), making a prototype (M=328 mins, SD=213 mins), and ideating design solutions (M=318 mins, SD=205 mins). Overall, students worked on at most two to three tasks within any single time interval (25 minutes), and six types of task co-occurrences can be discerned that are detailed below. Notably, the first and third types of task co-occurrences stand more robust than the rest types based on the frequency of involved students.

(1) Combining different design process steps;
(2) Combing task-related social interaction;
(3) Mixing design process steps and task-related social interaction;
(4) Combining design thinking process steps and project management;
(5) Mixing project management and task-related social interaction; and
(6) All categorized tasks in parallel.

When interviewed about their multi-tasking behavior, most students did not mention any motivation or purpose for starting to multi-task. During the interviews, students reported multi-tasking activities when they were involved in different successive tasks (or, in other words, sequential tasking) in a single time interval (e.g., 25 minutes). Furthermore, analysis of the interview data (which were also consistent with the results obtained from the observations and the EmoForm) helped identify the following two particular situations which appear to be related to multi-tasking:

Table 5.5. Highlighted Task Co-occurrence during Multi-tasking

Type of task co-occurrence	Co-occurrences	Students (N)	Total duration (mins)			
			mean	sd	Max	Min
(1) Combining design process steps	EDU-DDP	10	118.75	120.37	375	12.5
	EDU-IDS	8	51.56	43.01	125	12.5
	IDS-MP	5	80	68.81	175	12.5
	MP-TP	5	117.5	59.69	150	12.5
(2) Combining task-related interaction	GST-GFO	4	18.75	7.22	25	12.5
(3) Mixing design process steps and task-related social interaction	EDU-GST	6	58.33	73.60	200	12.5
	EDU-GFO	5	30	11.18	50	25
	IDS-GST	8	50	62.32	200	12.5
	IDS-GFO	7	42.86	37.40	100	12.5
	DDP-GFO	4	62.5	53.03	125	12.5
	EDU-IDS-GFO	4	53.13	41.30	100	12.5
	IDS-GST-GFO	4	15.63	6.25	25	12.5

Note: some task co-occurrences are selected and represented in this table when reported on the EmoForm by more than four students (N≥4) to have some ideas on frequently reported types of multi-tasking,

Abbreviations: EDU *Empathize Design User*; DDP *Define Design Problem*; IDS *Ideate Design Solution*; MP *Make Prototype*; TP *Test Prototype*; GST *Get Support from Teacher*; GFO *Get Feedback from Others* *(a) When helping out a team member working on a different task than them*; this was confirmed by our observation in the classroom where we could notice, e.g., one student making a prototype while helping other with painting their work.

(b) When tasks are inherently interdependent, in which case they discover new insights for one task while working on a different task (reflecting the opportunistic nature of the design process [213]). For example, students explained that making the prototype in parallel with ideating for the cases in which they would come up with new ideas (minor changes or additional features) when they were building their prototype. Moreover, tasks (e.g., empathizing and ideating) were done in parallel in some cases, in which the team was searching for design inspiration. The combined task of defining the design problem and ideating design solutions happened when students discovered a new aspect of design problems when designing their solutions, which was also in line with the observation findings.

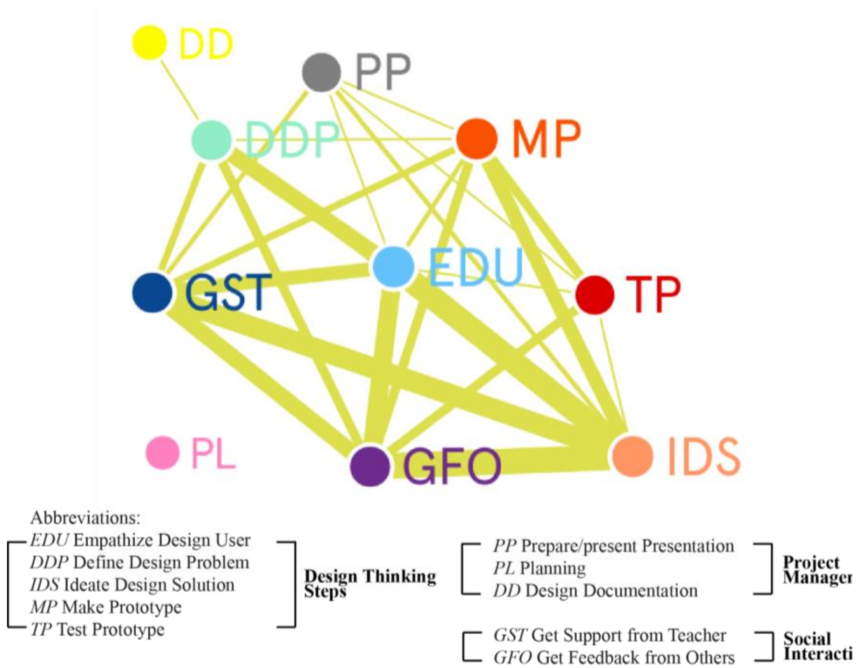


Figure 5.3. Relationship between DBL Activities in Multi-tasking.

Figure 5.3 visualizes all the co-occurrence relationships between different DBL tasks, which are extracted from EmoForm data. This figure shows how

DBL activities were all be combined to some extent, except for planning. Nodes in the graph represent different types of activities, while lines in the figure represent by their thickness how often the specific activities are combined in multi-tasking. How often here means how many students have reported such a co-occurrence relationship between DBL tasks.

Overall, there is a stronger co-occurrence between empathizing design user (EDU), ideating design solution (IDS), getting support from the teacher (GST), and getting feedback from others (GFO). Additionally, the task of empathizing with the design user (EDU) was carried out throughout the entire design process and often in parallel with other minds-on activities (e.g., DDP, IDS) and also in parallel with other's input such as teacher's support (GST) and other's feedback (GFO). Interestingly, identifying the design problem (DDP) and testing prototype (TP) were not combined. Defining the design problem (DDP) is often combined with empathizing with users (EDU), which is a good example of the first type of task co-occurrence (i.e., connecting different design process steps) as described in the bullet lists above. This combination is understandable, as it provides a springboard for an in-depth understanding of the design challenge. Interestingly, as an example of the fourth type of task co-occurrence (i.e., combining design thinking process steps and project management), one child reported combining the activity of defining the design problem (DDP) with design documentation (DD).

The open-ended nature of DBL, on the one hand, gives students freedom in task implementation to encourage diversity in design approaches [27]. On the other hand, the opportunistic nature of the inquiry process inherited from the design thinking notion encourages students to move among tasks [63]. Such an opportunistic approach is well known and may include, for example, immediate recognition of a partial solution in another part of the problem, immediate handling of inferred or added requirements, drifting through partial solutions, and interleaving problem specification with solution development [213]. This may be the reason why students combine different DBL tasks to varying extents. To theoretically describe this manner of executing tasks in DBL, we introduce the task strategy dimension includes a dichotomy of strategies – Single-tasking (ST) and Multi-tasking (MT). The distinction of multi-tasking from single-tasking in this chapter pertains to how and whether tasks are inherently interdependent or may reflect an opportunistic approach to solution development. Specifically, we refine this task strategy dimension of DBL activity as follow:

Single-tasking refers to students spending a continuous time interval on a single task before interleaving and/or switching to others. For example, as seen in Figure 5.1, the student applied the single-tasking on ideation between minute 50 and minute 75.

Multi-tasking is defined by [214] as a mode of doing multiple activities simultaneously in an interleaved manner. Defined by Salvucci et al. [215], multi-tasking is represented along a continuum in terms of the time spent on one task before switching to another. However, the emphasis on multi-tasking representing such phenomenon was largely lacking and underrepresented in prior DBL works. Multi-tasking in this chapter refers to performing two to three project-related tasks contrary to how multi-tasking is often defined in earlier works, i.e., including off-topic tasks done either concurrently or sequentially in a particular time interval. For example, in the case of Figure 5.1, the student applies multi-tasking on empathizing with the design user and getting support from the teacher during the first 25 minutes.

Collaboration Strategy Dimension (Collaborative-Tasking Versus Individual-Tasking)

Students sometimes worked in small groups or individually during this project. Initially, students seemed to spend similar amounts of time on collaborative versus individual tasks. Different students exhibited different patterns in using collaborative or individual tasking strategies. For instance, the data reported in the EmoForm indicates that student H4 did almost all of the tasks collaboratively, except for a short moment of individual tasking on the fourth day. On the contrary, student A1 spent most time single-tasking except for the first two days of collaborative tasking and a few moments of collaborative-tasking on the 9th day. Overall, we found that all students followed both of these strategies, and most of them worked increasingly in collaboration as the project progressed.

Students seemed to spend more time on collaborative tasks than individual tasks based on data collected from the first section of EmoForm, as seen in Tables 5.6 and 5.7. Note in both Table 5.6 and Table 5.7: Tasks with a number in boldface are the ones with the majority proportion of time spent. The total column represents the total accumulative time spent (by all participants) on collaborative-tasking and individual-tasking, respectively.

Table 5.6 shows how students relatively spent relatively more time on collaborative tasks (see activities with boldface numbers) such as empathizing design user (EDU), ideating design solution (IDS), making prototype (MP), and design documentation (DD). Besides, students often engaged with multi-tasking activities collaboratively. Likewise, for individual tasks, as shown in Table 5.7, students tend to spend more time empathizing with design users

Table 5.6. Average Time (in mins.) on Collaborative-Tasking (CT)

	Collaboratively involved in a single task (CT*ST)										CT*MT	Total
	EDU	DDP	IDS	MP	TP	PP	GST	GFO	DD	PL		
mean	**238**	66	**242**	**318**	69	51	45	58	**108**	50	**188**	925
sd	276	94	182	222	43	10	35	48	24	0	217	408
Max	1075	262.5	587.5	750	175	87.5	112.5	112.5	175	50	737.5	1537.5
Min	25	12.5	12.5	50	25	25	12.5	12.5	100	50	12.5	25

Table 5.7. Average Time (in mins.) on Individual-Tasking (IT)

	Individually involved in a single task (IT*ST)										IT*MT	Total
	EDU	DDP	IDS	MP	TP	PP	GST	GFO	DD	PL		
mean	**185**	**84**	**168**	**118**	63	**75**	31	44	82	**75**	**114**	449
sd	121	70	160	74	32	35	22	27	43	n.a.	180	338
Max	462.5	225	550	275	100	100	50	62.5	150	n.a	662.5	1250
Min	12.5	12.5	12.5	37.5	25	50	12.5	25	25	n.a	12.5	25

Abbreviation in both Table 5.6 and Table 5.7: ST *single-tasking*; MT *multi-tasking* (all combination of multitasking activities); CT*MT all collaboratively involved multi-tasking tasks; IT*MT all individually involved multi-tasking tasks; EDU *empathize design user*; DDP *define design problem*; IDS *ideate design solution*; MP *make prototype*; TP *test prototype*; PP *prepare/present presentation*; GST *get support from the teacher*; GFO *get feedback from others*; DD *design documentation*; PL *planning*.

(EDU), ideating design solutions (IDS), and making prototypes (MP). Comparing the time spent on individual versus collaborative tasks (Table 5.6 versus Table 5.7), it seems that some tasks favored individual works, such as defining the design problem (DDP), presentation (PP), and planning (PL). In some rare instances, students were involved in interleaved collaborative and individual work within a single 25-minute timeslot. For example, a student spent half of the time collaboratively getting feedback from others collaboratively and individually for the remaining time.

These findings above are related to the social environment of DBL, which are driven by the peer learning process within and across teams when they share resources, engaging in debate, and exercise freedom in task implementation [27]. In this chapter, we address the collaboration strategy dimension of DBL activity distinguishing between three strategies; Collaborative task (CT), Individual task (IT), and intertwined IT and CT (intT) in this chapter.

Specifically, we refine that the *collaborative task* refers to small groups of students working together to achieve the same task goal or working together to finish assigned tasks. In contrast, *individual tasks* are situations when students work on tasks alone. In *intertwined individual and collaborative tasks*, students interleave individual and collaborative tasks frequently. As shown in the example of Figure 5.1, the student is intertwining individual and collaborative tasks regarding empathizing design user and ideating design solution between minute 125 and minute 150.

A Conceptual Framework: The Activity-and-Affect Model of DBL

The Activity-and-Affect Model of DBL (as shown in Figure 5.4) was synthesized from the results in this study to capture how students experience emotions during DBL activities (to understand RQ2 synthetically). It is intended as a conceptual model, and it expands upon earlier descriptions of the DBL process, such as the DBL framework [62], the Reflective DBL framework [25], and the Learning-by-Design framework [1]. Additionally, the Activity-and-Affect Model of DBL is proposed to address the following two intentions that are underrepresented in the existing literature:

(1) *Describing the DBL activities from a multi-dimensional perspective*. More specifically, all these vital elements of DBL are mapped along the task dimension, task strategy dimension, and collaboration strategy dimension, respectively.

(2) *Having a nuanced view of how a specific activity could be associated with an emotional experience.* This model establishes the nuanced channels between DBL activities and students' emotional experiences.

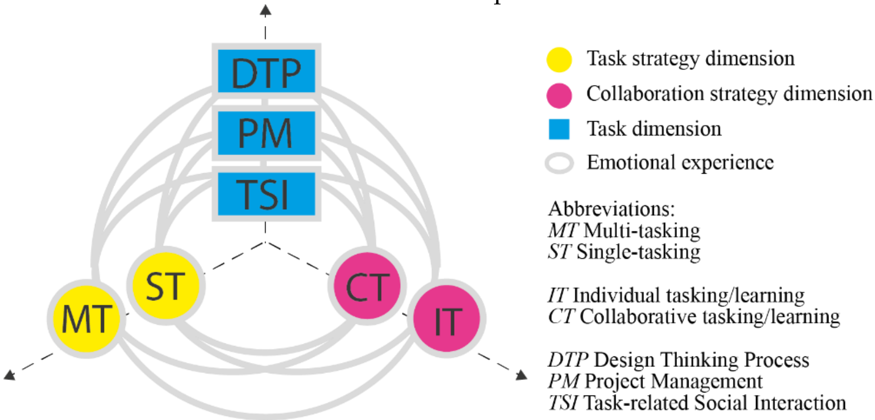


Figure 5.4. The Conceptual Activity-and-Affect Model of DBL

As shown in Figure 5.4, this model introduces three dimensions of DBL activities using three identified colors. The blue rectangle block represents the task dimension, including three categorized tasks (see Table 5.4); the yellow circle and red circle represent the task strategy dimension and collaboration strategy dimension. These circles and rectangles presented with identified abbreviations and colors function as the foundations for constructing DBL activities from three dimensions. Further, every loop (connecting three nodes from each of the three dimensions, respectively) in this model represents a possible type of activity in DBL. For example, the loop on edge stringing with the nodes of "IT-MT-DTP" stands for the activity that individually involved multiple tasks parallel to a design thinking process. In general, the arc connecting nodes represent one indicator of the emotional experience (e.g., enjoyment, frustration, etc.; see Tables 5.1 and 5.2 for the indicators of students' emotional experience). For example, the feeling of enjoyment when mixing multiple (task strategy dimension: MT) design stages (task dimension: DTP) in teamwork (collaboration strategy dimension: CT) is a part of a student's emotional experience of DBL. Likewise, the feeling of boredom when mixing multiple (task strategy dimension: MT) design stages (task dimension: DTP) alone (task strategy dimension: IT) is also a possible part of a student's emotional experience of DBL.

The discussion above introduced the Activity-and-Affect model of DBL to describe students' emotional experiences of DBL activities. Potentially this model is intended to explain students' emotional experience in DBL. For this purpose, we fitted a linear regression model to the data collected by EmoForms from a sample of 30 students on a repeated basis adhering to the taxonomy of our proposed Activity-and-Affect model of DBL. Specifically, we performed a linear regression using a hierarchical data structure (i.e., a linear regression-based analysis that takes the hierarchical structure of the data into account) to explain individual student's emotional experiences from DBL activities. Therefore, we sorted the data set collected by EmoForms into a three-level nested structure:

(1) **Level 1 (activity level)**: measurement occasions, i.e., DBL activities (where is coded as the dimension of ***task***, ***task strategy,*** and ***collaboration strategy*** according to the structure of Activity-and-Affect model of DBL) nested within-day within-person.

(2) **Level 2 (day level)**: repeated measurement nested within-day (which is measured as fifteen different lessons/days) within-person.

(3) **Level 3 (student level)**: repeated measurements nested within-person (which is measured as 30 students).

The three-level multilevel multiple linear regression was calculated to explain six dependent variables of emotional experience (including enjoyment, relaxation, frustration, boredom, concentration, and learning better, respectively) based on DBL activities within days within-person. It is important to note that only one-time measurement rather than repeated measurement is designed within an occasion for this set of outcome-focused emotions (as seen in the last section of EmoForm in Figure 5.1). Therefore, the two-level regression was calculated to explain four dependent variables of emotional experience (including contentment, pride, anxiety, and hopelessness). Overall, the results indicate that a regression model using a multilevel nested structure was a significant predictor of an individual student's emotional experience within a day (as seen in Table 5.8, all outcome variables of emotional experience having the value of $R^2 > 0.5$).

For example, the results (as seen in Table 5.8) indicate that a three-level structured regression model can significantly explain 84.8% of enjoyment variance (F (571, 1114) = 10.904. The enjoyment level is significantly dependent on an individual student (level 3), $\eta^2_p = 0.695$, and a student's enjoyment is dependent on the day (level 2) on which the activity took place, $\eta^2_p = 0.723$.

Table 5.8. Coefficient Regression Using a Hierarchical Data Structure

Emotional experience	Model		Level 3: Students		Level 2: Days (student)		Level 1: Task (days(student))		Level 1: Task strategy (days(student))		Level 1: Collaboration strategy (days(student))	
	R^2	p	η^2_p	p	η^2_p	p	η^2_p	p	η^2_p	p	η^2_p	p
Enjoyment	.848	**.000**	.659	**.000**	.723	**.000**	.047	**.000**	.024	.754	.129	**.000**
Relaxation	.876	**.000**	.736	**.000**	.746	**.000**	.033	**.002**	.045	**.021**	.085	**.007**
Boredom	.852	**.000**	.629	**.000**	.754	**.000**	.033	**.002**	.044	**.028**	.109	**.000**
Frustration	.846	**.000**	.616	**.000**	.749	**.000**	.044	**.000**	.031	.385	.082	**.009**
Concentration	.799	**.000**	.555	**.000**	.672	**.000**	.029	**.007**	.039	.082	.086	**.007**
Learn better	.836	**.000**	.595	**.000**	.718	**.000**	.069	**.000**	.063	**.000**	.093	**.001**
Contentment	.609	**.000**	.301	**.000**	-	-	.184	.377	.115	.202	.203	.057
Pride	.640	**.000**	.342	**.000**	-	-	.139	.891	.106	.307	.149	.542
Anxiety	.529	**.000**	.196	**,001**	-	-	.228	.053	.069	.853	.190	.112
Hopelessness	.612	**.000**	.289	**.000**	-	-	.152	.778	.100	.402	.160	.398

Note: (1) Bold numbers are p <.05. (2) Outcome variables of contentment, pride, anxiety, and hopelessness only measured once a day, therefore no repeated measurement can be calculated at level 2. (3) To have an idea of each variable's effect size, we use this following criteria proposed by Cohen (1988) for cross-referencing, $\eta^2_p = 0.01$ (d = 0.20) is a small effect size, $\eta^2_p = 0.059$ (d = 0.50) is a medium effect size, and $\eta^2_p = 0.138$ (d = 0.80) is a large effect size accordingly.

Specifically, the level of student's enjoyment is dependent on both the task (level 1) and collaboration strategy (level 1) of activity within a day, η^2_p =0.047, and 0.129, respectively.

This three-level structured regression model can significantly explain 87.6% of relaxation variance, F (566, 1099) = 13.714. The level of relaxation was found to be dependent on individual students (level 3), η^2_p = 0.736, and student's relaxation is dependent on the day (level 2) the activity took place, η^2_p = 0.746. More specifically, student's relaxation within a day was greatly influenced by the three elements of an activity: task (level 1), task strategy (level 1), and collaboration strategy (level 3), η^2_p = 0.033, 0.045 and 0.085 respectively.

Likewise, the three-level structured regression model can significantly explain 85.2% of boredom variance, F (563, 1100) = 11.239. The level of boredom is significantly dependent on individual students (level 3), η^2_p = 0.629, and student's boredom is dependent on the day (level 2) the activity participated in, η^2_p = 0.754. Moreover, all three aspects of the activity, including task (level 1), task strategy (level 1), and collaboration strategy (level 1), greatly influenced student's boredom within a day, η^2_p = 0.033, 0.044, and 0.109 respectively.

With regard to frustration, results indicate that the three-level structured regression model can significantly explain 84.6% of frustration variance, F (562, 1101) = 10.767. The level of frustration is significantly dependent on individual students (level 3), η^2_p = 0.616, and student's frustration is also dependent on which day the activity occurred, η^2_p = 0.749. More specifically, the task (level 1) and collaboration strategy significantly account for student's frustration within a day, η^2_p = 0.044 and 0.082, respectively.

Our three-level structured regression model significantly explains 79.9% of concentration variance, F (572, 1117) = 7.750. The student's self-perception of concentration was significantly dependent on individual students (level 3), η2p = 0.555, and student's concentration depends on the day on which activity took place, η^2_p = 0.672. Additionally, both the task (level 1) and collaboration strategy (level 1) of activity significantly account for student's self-perception of concentration within a day, η^2_p = 0.029, and 0.086, respectively.

Similarly, the three-level structured model significantly explains 83.6% of learning better variance, F (570, 1100) = 9.893. The level of perception of learning better is significantly dependent on individual students (level 3), η^2_p = 0.595, and student's perception of learning better is significantly dependent on the day that an activity took place, η^2_p = 0.718. Specifically, student's perception of learning better within a day was greatly influenced by the three elements of an activity: task (level 1), task strategy (level 1), and collaboration strategy (level 1), η^2_p = 0.069, 0.063 and 0.093 respectively.

In terms of four outcome-related achievement emotions (e.g., contentment, pride, anxiety and hopelessness), the two-level structured regression model significantly explains 60.9% of contentment variance, F (161,248) = 2.403; 64.0% of pride variance (F (161,248) = 2.740); 52.9% of anxiety variance (F (161,248) = 1.728); and 61.2% of hopelessness variance (F (161,247) = 2.419) respectively. Furthermore, the level of contentment, pride, anxiety and hopelessness are significantly dependent on individual student (level 3), η^2_p = 0.301, 0.342, 0.196 and 0.289 respectively.

5.4.2. Relationship Between Students' Emotional Experience and DBL Activities (RQ2)

In the previous section, our results suggest emotional experience (including a total of ten dependent variables as summarized in Table 5.1 and Table 5.2) in DBL is significantly dependent on individual students (level 3). Student's enjoyment, relaxation, frustration, boredom, concentration, and self-perception of learning better are dependent on the day when students took part in an activity (level 2). At the activity level (level 1), the multilevel regression results only indicate the general type of activity (from the dimensions of the ***task***, ***task strategy***, and ***collaboration strategy,*** respectively) in DBL.

To answer how specific DBL activities are related to the emotional experience (RQ2), we conducted multiple linear regression using a stepwise method to measure which DBL activities significantly contribute to students' emotional experience. Specifically, this analysis investigates the fine-grained types of DBL activities from the task, task strategy, and collaboration strategy dimensions, respectively. For instance, the ***task*** dimension is coded as the different sub-tasks (as summarized in Table 5.4). The ***task strategy*** dimension is coded as single-tasking and multi-tasking. Besides, the ***collaboration strategy*** dimension is coded as individual tasking, collaborative tasking, and intertwined individual and collaborative tasking. All the multiple regression analyses were calculated on a group level rather than distinguish individual differences. The detailed results regarding multiple linear regressions are displayed in Appendix F (see Table 5.9 a-j).

Overall, the descriptive results of each variable showed that students had a positive experience in DBL according to the low scored negative emotions and high scored positive emotions. For instance, the mean scores for anxiety (M=1.16, SD=0.56; N.B. scores "1" as "not at all" and "5" as "very much"), hopelessness (*M*=1.47, *SD*=0.92), and frustration (*M*=1.61, *SD*=0.99) are low. The positive indicators of emotional experience, e.g., enjoyment (*M*=3.24, *SD*=1.16), contentment (*M*=3.56, *SD*=1.13), pride (*M*=3.18, *SD*=1.28) and self-perception of concentration (*M*=3.50, *SD*=1.11) had a relatively high scores. The remaining three indicators of emotional experience are to different extents near the middle point of the scale, including boredom (*M*=2.47, *SD*=1.31), relaxation (*M*=2.82, *SD*=1.21), and self-perception of learning better (*M*=2.32, *SD*=1.11).

Getting feedback from others (GST) has a positive effect on student's relaxation (β=.101). Additionally, students who were busy with making prototype (MP) report a higher level of enjoyment (β=.129), relaxation (β=.086), pride (β=.133) and self-perception of concentration (β=.201) but also a lower level of boredom (β=-.198) and hopelessness (β=-.130). A mixed design thinking steps and project management (%DTP-PM) is a specific type of task where applying a multi-tasking strategy was found to have a positive effect on student's self-perception of learning better (β=.050) but a negative impact on student's boredom (β=-.054). Likewise, students using the collaborative-tasking strategy (CT) report a higher enjoyment level (β=.112).

During the design thinking process, some other tasks seem to negatively affect students' emotional experience. For example, students who were involved in the task of empathizing design user (EDU) report a lower level of relaxation (β=-.062), contentment (β=-.197), and in the meanwhile report a higher level of frustration (β=.157) and boredom (β=.148). Students working on the task of defining design problems (DDP) indicate a lower level of enjoyment (β=-.122) and a higher level of boredom (β=.075) and hopelessness (β=.109). Students, when busy with testing a prototype (TP), report a lower level of contentment (β=-.132) and a higher level of frustration (β=.070). Similarly, presentation (PP) and design documentation (DD) are the two project management tasks that both seem to be positively related to frustration (β=.082; β=.049, respectively). Besides, when working on design documentation (DD), students report a lower level of relaxation (β=-.064). In comparison, when busy with presentation (PP), students indicate a lower level of enjoyment (β=-.049) and a higher level of anxiety (β=.148).

The combined design thinking process and task-related social interaction (%DTP-TSI) is another specific type of task in which, particularly applying a multi-tasking strategy was found to make students feel a higher level of anxiety (β=.170). Moreover, the single-tasking strategy (ST) seems to have a negative effect on student's enjoyment (β=-.138), pride (β=-.339), self-perception of concentration (β=-.163), and self-perception of learning better

(β=-.158). Students using the individual-tasking strategy (IT) report a lower level of self-perception of concentration (β=-.074).

Interestingly, students involved in the task of planning (PL) report a lower level of boredom (β=-.061) and a lower level of self-perception of learning better (β=-.058). The combined design thinking steps (%DTP) seemed to be negatively related to both boredom (β=-.071) and pride (β=-.127). Similarly, students, when getting support from the teacher (GST) and involving a particular task of mixed design thinking steps and task-related social interaction (%DTP-TSI), report a higher level of relaxation (β=.075, β=.090 respectively) and also higher level of frustration (β=.049, β=.231 respectively). Furthermore, getting support from the teacher (GST) seemed to be positively related to boredom (β=.059).

5.5. Discussion

In summary, our results suggest (i) future work should seek a more fine-grained understanding of the dynamic DBL process since some potential issues need to be clearly articulated, such as the level of iteration and multi-tasking. Besides, our results also suggest (ii) that students and educators should have a flexible approach towards the student's emotional experience. It is because there is a subtle relationship between students' emotional experience and different DBL activities that emotion may change along with moving among tasks or strategies. Based on the results in this study and the two mentioned implications, we suggest that (iii) using the Activity-and-Affect model of DBL could provide a means for understanding individual student's involved activities and associated emotions.

5.5.1. A More Nuanced Understanding of DBL Context, More Insights

This chapter presents empirical evidence of the variety of ways in which students go through a sequence of DBL tasks. For example, as shown in Figure 5.2, students made several transitions between empathizing (EDU) and ideating (IDS); however, not every student spent time reframing design problems (DDP). Few students interleaved making (MP) and testing (TP), while a few students seldom interleaved ideating (IDS) and building (MP). They mostly followed up with making (MP) and testing (TP) for the later parts of the project and uniformly ended the project by preparing and presenting (PP) their work, which consistently with the teacher's plan for the class and to enable assessment. Getting support from the teacher (GST) and getting feedback from others (GFO) occur at different times during the project with no apparent pattern, most often in parallel with other activities. This can be because different teams and individuals do not follow a strict synchronized process, so interactions happen serendipitously. Also, individuals may need help at very different moments depending on their abilities, task, and learning. Students in our case spent more time on design thinking steps such as empathizing (EDU), ideating (IDS), and prototyping (MP).

Even though they went through the design process relatively consistently, some individuals do more iterations than others over time. It has been argued before [216] that the most crucial element for successful learning in DBL is to have multiple iterations towards a solution, as iteratively generating solutions help understand the aspects of the problem that need to be considered [217]. However, no clear criterion has been provided for the early iterations in DBL [192], partly due to the ambiguous nature of ill-defined design problems and partially because the reframed problem and its solution are developed concurrently [218]. This raises questions about how DBL educators can encourage iteration to ensure effective learning. One may argue that the process of frequently switching tasks when applying a multi-tasking strategy in DBL would potentially motivate students' iterative inquiry. This would suggest further investigation of the correlation between multi-tasking and iteration in DBL.

Despite that multi-tasking is not a new phenomenon as such, there has not been an earlier attempt to describe how students multi-task during DBL. Task switching has been recognized as a critical element of multitasking [219]. The present study explicitly mapped students' frequent task-switching in DBL and particularly discerned six ways in which students worked on at most two to three tasks within 25 minutes interval period. Among these six ways were the two most frequent: (a) combining different design process steps and (b) mixing design process steps and task-related social interaction. Zooming in on how these tasks were related, we note that empathizing design user (EDU), ideating design solution (IDS), getting support from the teacher (GST), and getting feedback from others (GFO) were often combined. We would suggest researchers interested in multi-tasking in DBL carefully examine the trade-offs involved in multi-tasking. Future research could pay closer attention to whether and how different multi-tasking activities (e.g., the co-occurrence of EDU and IDS, or IDS and GFO) influence the learning process. Besides, future research could investigate the correlation between the level of experience in DBL and multi-tasking strategy.

Our findings suggest that specific tasks may invite individual work, e.g., empathizing (EDU), ideating (IDS), and prototyping (MP). However, other tasks may favor collaboration, e.g., defining (DDP), presentation (PP), and planning (PL). Students sometimes work individually or in small teams, and this case allowed us to observe how different individuals use different collaborative or individual tasking strategies. A general pattern across individual participants was that as the project progressed, students worked increasingly in collaboration. Future research could attempt to derive guidelines for DBL teachers regarding how to steer students in allocating their effort in individual or joint tasks.

5.5.2. The Variable Impact of Emotions

Overall, DBL activities across the project were rated positively. Especially, prototyping is an appealing and enjoyable task in DBL. We found a positive relationship between prototyping and positive emotions, e.g., enjoyment and pride, which also is consistent with earlier findings [26]. Besides, our results indicate that prototyping is positively related to students' self-perceived concentration levels. Reflecting on the positive impact of prototyping on students' emotional experience, this would suggest DBL educators could orchestrate the session of prototyping as a moment for students to engage and enjoy. On the other hand, getting feedback from others, as a way of receiving summative assessment in DBL [220], was found to be positively related to relaxation feelings, which can also facilitate learning evaluation. Future design considerations in DBL classroom management may foster students' relaxation and reflection by facilitating feedback moments in groups.

Individual work seemed to be negatively related to students' self-perceived concentration levels. On the contrary, teamwork was consistently rated positively, in line with other earlier research, e.g., [85]. However, the collaborative aspect of teamwork is still challenging for some students in DBL, as argued in one study [61]. This would suggest that DBL teachers should facilitate the classroom culture of teamwork [105] and also encourage the transition to teamwork when individual tasks appear to be experienced negatively.

Mixing design thinking steps with project management is a type of task as a multi-tasking strategy, which seemed to increase students' self-perception of learning better and decreased boredom. This justifies investing some effort in tracking progress to take charge of the project and move back and forward in the design process. Therefore, future design research in DBL could focus on developing tools for scaffolding students' planning and task management.

Earlier research provides no clear answer as to whether learning is more effective while students are in a positive or in a negative emotional state, as the answer largely depends on the nature of the learning task [141]. Specifically, confusion or frustration may be beneficial for learning [221], especially in DBL (as opposed to traditional learning environments involving passive listening lectures, take examinations and individual assignments, etc.). One notes that the frustration by the failure of testing and building design ideas may motivate students to find new solutions [167], which argues for flexibility in dealing with students' negative emotions in DBL. Moreover, the same task could have utterly different effects depending on the collaboration strategy adopted.

One limitation of this study concerns the potential inconsistencies in students' recording of data. Although we've used mixed methods of data collection (self-reporting surveys, classroom observations, and interviews) to triangulate the results, the risk of inconsistencies in data recording still may exist. It is due to the observation measurement in this study was conducted at a group level while the self-reporting survey was at an individual level. The strategy we applied to fix the inconsistency is to focus more on the self-reported data while using observations to get more insights on the contextual information and using the interviews to verify the data collected in field observations and self-reporting surveys. We would suggest future work to resolve the potential inconsistency issue by testing the trustworthiness of data collected, which is equally important as using multimodal data collection to triangulate results. Another limitation concerns that the participants in this study already had experience with DBL for one year. This may have affected the results. Specifically, we could expect that for students experiencing DBL for the first time, there could be a novelty effect that could potentially result in more positive experiences and a different execution of the design process. In contrast, one strength of the present study is that such a novelty effect does not confound the results. Future research could examine how activities affect participants' emotions for groups at varying levels of experiencing DBL (e.g., novices or experts to DBL).

5.5.3. Implications on Further Use of the Model

A challenge for DBL is to help teachers orchestrate activities in the classroom so that they could assess the progress of individuals [1]. The Activity-and-Affect model of DBL was found to have a good fit in accounting for individual student's emotional experience within a lesson/day. This study's results suggest using the Activity-and-Affect model of DBL could help understand students' involved activities and associated emotions. By tracking individual student's involved activities and associated emotion, one could assess students' progress and provide the necessary support. Future research is needed to examine and validate the efficacy of this model for understanding students' progress and associated emotional experiences in diverse learning environments.

For educators, we envision this model could (1) help explicate the process of students' learning, (2) structure how educators reflect on ways to support or instruct students, and (3) reflect on how it is going during the DBL process. For example, a DBL educator could check:

*What kinds of activity students engage in, and what kinds of activity they need to engage in (**task** dimension)* to support or intervene or adjust the classroom instructions. For example, during a one-to-one evaluation meeting with students, the educator could use it to evaluate their activities so far.

*How and whether students conduct multi-tasking activities by examining the **task strategy** dimension*. By doing so, the educator could prevent or advise against less effective multi-tasking (referring to the capacity of multi-tasking within 25 minutes we reported is at most 2-3 tasks).

*How and whether students are involved in an activity individually or collaboratively by examining the **collaboration strategy** dimension*. By doing so, the educator could have an equitable assessment of students' personal effort and teamwork when noticing student's approach DBL activities;

*How students approach activities by integrated examining **task strategy** and **collaboration strategy** dimensions*. For example, the educator could evaluate the student's combined task and collaboration strategy and suggest learning strategies. E.g., to boost the progress, the educator could identify opportunities for encouraging collaborative multi-tasking.

How students feel about a specific activity by examining the three dimensions together. For example, the educator could support a certain form of collaborative strategy if a certain activity is better done individually than collaboratively (vice versa). Consequently, to prevent frustration from building up in a small group, the educator could advise students to work individually for a while.

For students, we envision this model could potentially inspire them to explore various project-related tasks and use diverse learning strategies according to different situations. For example, students participating in a DBL project could check:

*What kinds of activity they are involved in and what kinds of activity they need to be involved in by examining the **task** dimension* to reflect what they have done so far and brainstorm what they could do next during a peer-to-peer discussion.

How they can approach activities by integrated examining ***task strategy*** *and* ***collaboration strategy*** *dimension*. For instance, students could find their ways to sequence and interleave activities inspired by the structured information delivered by this model (e.g., using it as an instructing template to reflect on and better understand their learning habits) during a session of planning and managing a project.

How they feel towards specific activity by examining the three-dimension together. For instance, using the emotion layer of this model could help students be conscious of their emotional state and facilitate their further emotion regulation.

5.6. Summary

To investigate how specific DBL activities influence students' emotional experience. We report a three-month field study of a DBL project with 30 students that examined (a) the type and complexity of activities students performed, (b) the nature of the collaborative learning students experienced, and (c) the nature of shifting and executing tasks during the process. This chapter proposes an Activity-and-Affect model of DBL, which (a) highlights a three-dimensional perspective of DBL activities and (b) describes a flexible perspective that taking account of how different DBL activities (from the three-dimensional view) could be associated with different emotions. Furthermore, this chapter identifies specific activities that have a significant positive or negative relationship with students' emotional experience. The results in this study suggest (a) it's essential to seek a more fine-grained understanding of DBL context from the view of students, (b) students and educators should have a flexible perspective towards the student's emotional experience, and (c) using the Activity-and-Affect model of DBL could provide a means for understanding individual student's involved activities and associated emotions.

[Section III]

Development: Case Studies of Emotions in DBL in-and post-Secondary Education

Chapter

SIX

Emotions and Learning in DBL: In a University Environment

Chapter 6: Emotions and Learning in DBL: In a University Environment

Abstract: There is a growing interest in, Design-Based Learning (DBL), a constructivist learning approach where students learn through design activities. Past research has examined extensively how this theoretically motivated learning approach can be implemented in practice. Earlier empirical studies have examined the effectiveness of DBL and have surveyed the attitudes of participating students towards DBL. However, related evidence lacks detail and does not account for how different aspects of DBL support students' learning and how students experience DBL. We report a case study of a DBL course involving 110 undergraduate students working in multi-disciplinary teams engaging in technology design to support innovation. This chapter contributes to the following three aspects: (a) an empirical understanding of students' perception and attitude of learning in DBL; (b) our awareness of emotions' impact in DBL-related experience; and (c) implications for educators steering DBL activities taking into account the students' feelings.

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6.1. Introduction

Design is a powerful tool for transforming the curriculum and accommodating various ways in which students learn [16]. Accordingly, there has been growing advocacy and interest in incorporating design activities into education, especially in STEM education, e.g., [17–22]. With this backdrop, Design-Based Learning (DBL) has emerged as a learning approach where students learn what they need to learn through project-based or problem-based design activities. Furthermore, there are several related learning approaches, such as design-based science (DBS; e.g. [18,32]), learning by design (LBD; [1]), learning through design [15], and maker education (e.g. [37,38]). All these approaches apply design thinking and expand on the theoretical notions of case-based reasoning [43,222] and problem-based learning [76] in diverse settings such as the classroom, maker spaces, workshops, museums, or camps, etc.

DBL is seen as a way to help students acquire knowledge, skills, and attitudes in diverse scientific disciplines [16]. For instance, early design-based education programs at the secondary school level were intended to promote science learning through design, e.g. [1,22,186], or to help students understand the content in various disciplines, e.g., [16,20]. Pedagogical practice in higher education shows some similarities with the design thinking process [23] as a method for facilitating student-centered learning in design education and engineering education [223]. Related research has demonstrated a positive influence of DBL on students' experience, e.g., pertaining to stimulating interests [72] and enjoyment [105].

Furthermore, a growing body of research has examined teaching strategies and instructional design to optimally put DBL into practice, e.g., [1,223,224]. While considerable attention has been paid to the theoretical underpinning of DBL and its practical implementation in different contexts, there is little known regarding how students value and experience DBL. In particular, our understanding of what aspects of DBL students perceive as most effective for learning and of the emotions that these DBL aspects evoke are lacking [26,152]. Such an understanding would be valuable for two reasons. First, students' perceptions of their learning and emotions experienced in a learning setting reflect how they subjectively perceive the learning environment. This understanding has fruitful implications for the design of curricula and classroom instructional practices. Second, previous research [225] has noted that students' subjective perceptions of the learning environment are associated with their achievement and emotional outcomes. Therefore, understanding students' perception of learning and their emotions experienced during the process is meaningful also for facilitating students' learning and fostering their positive emotional development.

Addressing this apparent gap in the field of DBL, we carried out a case study that examined how students learn and experience emotions in relation to different DBL activities. Our case in this chapter concerned a semester-long DBL program of a 3rd-year undergraduate program at a Dutch applied sciences university. This switch changed the age group of students presented in previous chapters. This is because there was an opportunity that teachers were also interested in exploring the same questions as the questions in this research, and the general principles of DBL are not different from one age group to the next. We also considered the difficulty of fitting school curricula is low, and there are great opportunities to interact directly with young adult students and conduct in-depth interviews with them. Below, we report on in-depth interviews conducted in the last week of the program with fourteen participants. The interview questions were aimed at answering the following research questions:

- What aspects of DBL do students perceive as conducive for learning?
- How do different aspects of DBL influence student's emotions? (RQ2)
- How do student's emotions influence learning in DBL? (RQ3-a)

Our results contribute to (a) an empirical understanding of students' perception of how learning takes place in DBL, (b) insights on the impact of student's emotions in DBL, and (c) implications for educators facilitating DBL activities for how to address students' emotions.

6.2. Method

We used a single case study [226] as the methodology to understand how undergraduate students value learning and experience emotions in a DBL program at the applied university level.

6.2.1. Context of Study Set-Up

Our case was a DBL program called Embrace TEC at Fontys PULSED (a University of applied science in the Netherlands) that aims to support learning by design in multi-disciplinary teams taking on a technology innovation challenge. In the past, this program has been run six times and has involved a total of 415 students, 41 nationalities, from 27 different major programs. In this program, the DBL environment is featured in the following aspects: (a) the design and inquiry process is composed of several iterations; (b) the learning outcome is delivered by a portfolio filled with evidence students collect for their learning progress when working on design challenges and (c) the learning outcome is assessed focusing on the development of student's learning process.

The entire DBL program consists of four challenges that are spread over 20 weeks (with a one-week break between the third and fourth challenges). The purpose of the first challenge, lasting three weeks, is to expose the student to new visions, developments, and trends in technology and the corresponding impact upon society. The second challenge, lasting two weeks, aims to let students discover potentially meaningful connections between the insights from the first challenge and value in design. The third challenge, spanning over three weeks, aims to train students to experience the entire design process under considerable time pressure and train them to work collaboratively in a team. The fourth challenge, entitled "Future Solution," lasts ten weeks in which students work on a more advanced design topic addressing a real-life challenge through an iterative design process. Students enrolled in this program are free to determine what they want to learn. Furthermore, students in this DBL program are given training on required skills, e.g., process management, stakeholder involvement, and prototyping.

Table 6.1. The Disciplinary Background of Participated Students

Disciplinary background	Student's reference number
ICT and software engineering	S1, S6, S8, S14
Computer science	S7
Civil engineering	S13
Mechanical engineering	S3, S9
Mechatronics	S4, S10, S12
International business	S5, S11
Industrial product design	S2

A total of one hundred ten students with different disciplinary backgrounds have enrolled in this DBL program. Fourteen of them participated voluntarily in the study. This sample of participants covered a diversity of disciplinary backgrounds, as seen in Table 6.1.

The teachers involved in this program come from different disciplines, including Technology, Design, Entrepreneurship, Creativity, and Research. Besides, diverse pedagogical approaches are used in this program, including workshops, lectures, inspiration sessions, consultancy hours (with expert support), field trips, and self-study (with blended materials).

6.2.2. Data Collection

All participants signed consent forms before data collection. Multiple sources of data were collected in this study: (a) Emoform, an experience sampling questionnaire specifically designed to study the student's emotions and experience in DBL [90], and (b) a one-on-one semi-structured interview with the student participants. Students used the EmoForm during the last challenge of the DBL program, and they were free to choose when and on which days of this last project to fill it in. The purpose of EmoForm was to help students self-record and self-reflect on their own learning experiences and associated emotions. The interviews lasted about half an hour and took place towards the end of the last challenge (interview questions can be found in Appendix G). The interviews aimed at collecting a detailed, qualitative description of students' experience of learning and an account of the feelings they experienced during the DBL program.

Below we present the results of the systematic analysis of a total of fourteen audio-recorded and verbatim transcribed interviews, while the EmoForm data was used as a supplementary source for understanding the interview responses.

6.2.3. Thematic Analysis of Interview Data

Our data analysis followed the thematic analysis approach [209]. We iteratively developed a codebook following the protocol described in [227] before the start of the coding process. This codebook contains themes that emerged respectively from a data-driven perspective (i.e., the theme of influential elements) and a research-driven perspective (i.e., the theme of phenomenon and consequence), as shown in Table 6.2.

We involved two researchers (acting as two independent coders) in the analysis process in ensuring the trustworthiness of coded data. Before coding, we have held a session to understand the codebook and coding strategy to establish a consistent way of mapping the interview texts. After coding each sample of interviews, we had a discussion correspondingly to identify disagreements and discuss explicit inclusion or exclusion reasons for each disagreed instance. We calculated inter-coder reliability using as in [228]:

$$intercoder\ reliability\ = \frac{number\ of\ agreements}{number\ of\ agreements + disagreements}$$

The overall percentage of agreement of our coding was found to be 95%, showing excellent inter-coder agreement. More specifically, the overall rate of agreement was calculated separately at three moments and was found to improve over time: 90% (after coding two out of fourteen interviews), 92% (after coding five more interviews), and 98% (after coding seven more interviews). Besides, Table 6.2 describes the percentage of agreement over each theme (see the numbers in italic in the column of Description).

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Table 6.2. Themes and Sub-Themes Derived from the Interview

Themes	Sub-theme	Description (*percentage of agreement*)
Influential elements	Novelty versus uncertainty	The degree of novelty or uncertainty when experiencing something familiar versus something new, e.g., (a) too little novelty during ritualized routine tasks; (b) too much uncertainty over less structured tasks; and (c) novelty during new or different ways of doing. *(92%)*
	Relevance	How tasks are related or unrelated to personal interest, goal, preference, and ambition. *(95%)*
	Feedback	Giving or receiving feedback, judgment, or comments about works, e.g., (a) positive feedback such as others being impressed by work impressed or complimenting it, and (b) negative feedback such as work being doubted or criticized by others. *(84%)*
	Progress assessing	Assessing the progress or outcome of learning, e.g., (a) reflecting on developing progress; (b) detecting a challenge or failing in something; and (c) achieving some goals or succeeding in something. *(89%)*
	Social interaction	The task-related social interaction includes (a) student-to-student interaction, e.g., help-seeking or help-offering among peers, communication among peers, (b) teacher-to-student interaction, e.g., coaching by the teacher. *(93%)*

	Collaboration strategy	The strategy of working individually or collaboratively, e.g., (a) individual work such as implementing tasks alone based on a separate project, and (b) work in a team such as sharing a sense of responsibility in task implementation, negotiating with members, or leading the team. *(93%)*
	Task strategy	Strategy on (a) how to approach the tasks, e.g., problem-solving strategy; (b) how to interleave tasks, e.g., organizing tasks in a specific sequence. *(69%)*
	Design process	Actions or trials related to a particular stage of the design process. *(97%)*
	Time management	Actions considering time constraints, e.g., (a) setting plans, (b) noticing or dealing with a deadline, and (c) trying to finish a task on time or just rushing. *(100%)*
Phenomenon	Learning	Situations and opportunities for learning in the DBL project. *(100%)*
	Emotion	All emotions and internal states are evoked by DBL. *(99%)*
	Favorite	Personal preference on aspects of DBL. *(100%)*
Consequence	Positive consequence	A positive consequence of emotions, e.g., (a) increasing motivation in doing something; (b) increasing confidence in doing something; and (c) easing tasks or enhancing memory. *(94%)*
	Negative consequence	A negative consequence of emotions, e.g., (a) disengaging or demotivating in doing something; (b) lowering the quality of work or triggering errors; and (c) being not open to learning. *(100%)*

6.3. Results

Based on thematic analysis of interviews, we found the nine essential elements listed in Table 6.2 that shape students' learning and emotions. In the following sections, we present findings with selected interview quotes to illustrate the following three aspects: (1) the situations in which learning can be achieved; (2) situations where positive and negative emotions can be evoked (RQ2); and (3) the impact of emotions in DBL (RQ3-a).

Given the intended role of the active learner of students in DBL, they are the ones who decide what to learn and what learning is for. To provide some idea of the individual differences among all participating students, we present a summative visualization of interview results in Figure 6.1, featuring (a) the extent to which how these essential elements (as described in Table 6.2) shape individual students' learning and emotions; (b) the reported impact and consequences of emotions; and (c) the favorite part of DBL from the perspective of different students.

6.3.1. Students' Perception of Learning in Various Ways

Students' perceived learning in DBL seemed to be influenced by multiple aspects. Unsurprisingly, ***social interaction*** in the DBL environment provided opportunities for learning. Specifically, interaction with the teacher was noted as providing opportunities to learn, e.g., receiving coaching on setting personal learning goals from the teacher and interacting with peer students, e.g., learning from each other, especially when working on similar problems. Previous research has already indicated that a core element of DBL is the role of the teacher in coaching students' tasks, design process, and self-development rather than lecturing as in traditional teaching [25,26,62]. Our results indicate that students are aware of the value of the teacher's role and a peer community in shaping their learning.

Learning for some students was perceived through exploring ***novice*** approaches and ideas in DBL, e.g., interviewing users amidst the inquiry process, which they had not experienced before in their non-design-based education. This resulted from the majority of participating students having little experience in design prior to this DBL program. The ill-defined problems force students to seek an in-depth understanding of the context and come up with many open-ended alternatives. In addition to the improvement in terms of design skills, experienced DBL students may also view the knowledge underlying the new problem context as integral to learning.

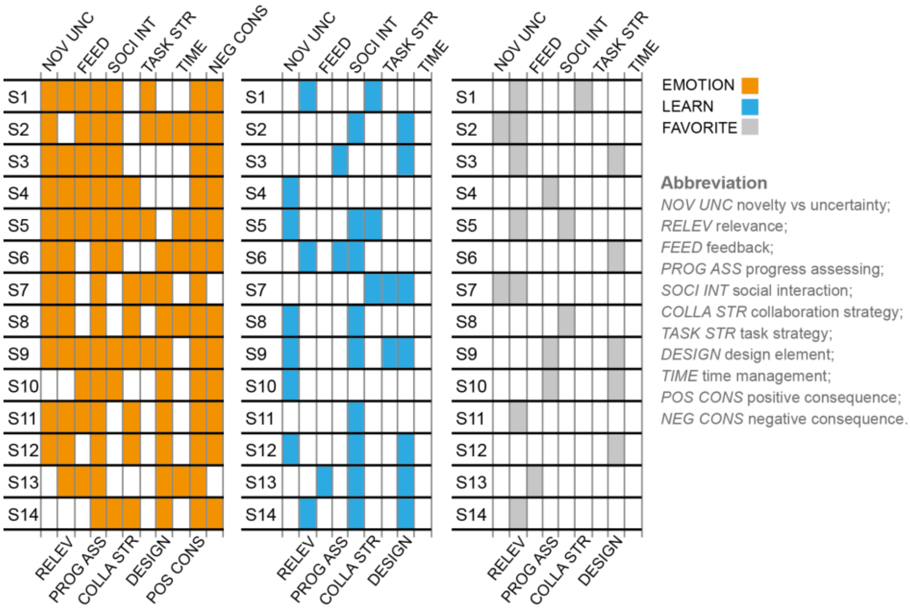

Figure 6.1. Overview of Student Perceptions of Whether DBL Elements (Horizontal Axis) Shape Their Learning And Emotions.

Furthermore, the following three more specific situations were found to allow learning to occur in DBL:

Perceived Learning from the Design Process

Learning was perceived to result from iterations or trials during the design process. As suggested in previous work [16], instruction needs to integrate design problem solving as a natural component of learning. One may argue that recognizing the importance of iteration and trial and error in the design process could be one of the ways to integrate design problem solving into learning [191]. It is through iteratively digging into diverse alternatives and weighing these different outcomes that students are driven to solve problems in a "designerly" way. Our findings demonstrate that students have recognized the core value of design activities in acquiring knowledge and expertise that respond to a specific problem.

"I'm still learning new things in that way but also the certain design processes and having to try and make something and revise it to make it again, revise in that way to optimize the product" (S3). "For me, it is really a lot of trying your ideas instead of just only diving into the theory and then, in the end, making it on time and

expecting it to be successful immediately. Now, we are doing way more prototyping and just doing something, and even if it fails, change something and then do it again to see if it works" (S9).

Perceived Learning from Progress Tracking

Interestingly, tracking project progress appears to help students learn. Such progress tracking involves self-evaluation, which helps students learn from their failures and build on their successes. Failure recognition when tracking the progress of learning is a specific opportunity for learning in DBL. This finding particularly echoes the underlying theoretical rationale of DBL that failure promotes a need to explain, adjust, and redirect in response to the progress, thus promoting learning [19]. On the other hand, previous research has shown that DBL increased the self-confidence of low-achieving students [72,105]. A relevant open question is whether there is a relationship between reviewing failures as a way of learning in DBL and improving confidence.

"I feel like I failed many times; it must have taught me something. I am trying to learn from my mistakes. Now I printed new prototypes today, and they look about right" (S6). "I mostly look at failure as an opportunity to learn, especially for the design that I am working in and the process I am in right now; there are a few cases that I thought would work, did not. I just took that as an opportunity to see, okay, what else will work?" (S3).

Perceived Learning from Making a Personally-Meaningful Connection

From the students' perspective, they learned to learn from relating personal interests or ambition to their design projects. The design inherently encourages students to make connections among different facts and subjects [16]. Having freedom in reframing the design challenge, students could have a more meaningful inquiry based on their interests, goals, and ambition, making them feel positive. Such freedom, therefore, can provide a motivational boost for learning and may even more opportunities for discovering personally meaningful relevance [229]. The finding in this study elaborates on how a seamless integration among personal interest and design activities enables the student to figure out how things work in a self-directed way.

"Everyone is encouraging us to use it, and that is why I chose to use 3D printing as a part of my future solutions to teach myself this technology without the trauma that I went through [in my last project]" (S6). "You can choose your projects so you can just decide what you want to learn and then base your project on that" (S14).

6.3.2. Students' Emotions Evoked throughout the Entire DBL (RQ2)

All participating students experienced some positive emotions, e.g., enjoyment, relaxation, enthusiasm, pride, satisfaction, curiosity, etc. The majority of students felt more positive about DBL in comparison with their majors. The only exception is one student who felt less favorable towards DBL compared with the project in their major because of the less structured instruction in DBL. On the other hand, not all students experienced negative emotions like boredom, disappointment, frustration, or anxiety. A few students claimed that they did not experience any negative emotions at all. Remarkably, there are also substantial individual differences in the experience of negative emotions. Some thought they experienced less negative emotions in DBL than in their major, while one student attributed feeling stronger negative emotions in DBL to being more conscious of them as a result of the diary self-report.

Overall, various aspects of DBL can evoke students' emotions. First, the ***collaboration strategy*** in DBL provides plentiful opportunities for working individually and collaboratively but inevitably also involves situations of negotiations, disagreement, or group conflicts during collaboration. Having to figure out the problem alone frustrated students (e.g., S7). More specifically, this student S7 recorded on the EmoForm about a high level of frustration when individually making a prototype and when preparing a presentation alone. On the other hand, sharing responsibility in the team evoked some students' (e.g., S9, 14) negative feelings such as frustration. Moreover, one student (S5) mentioned a specific case in teamwork when tracking and coping with team members' emotions brought negative emotions.

Second, students' ***social interaction*** with peers and with the teacher was found to bring positive feelings since students (e.g., S4, 14) favored the interactive way of working and communicating in DBL. Some students (e.g., S3, 6) also mentioned that offering help in DBL evoked strong positive feelings. The EmoForm data also confirmed this finding, showing that many students reported intense enjoyment when chatting with others, particularly when asking or offering help in DBL.

Third, ***time management,*** e.g., being aware of or dealing with deadlines, was found to cause stress. However, students (e.g., S2, 8) thought that pressure could be regulated and decreased by setting their deadlines.

Fourth, emotions towards receiving positive and negative ***feedback*** are straightforward. Positive feedback is associated with positive emotions; negative feedback, e.g., *"you did not do that well"* or *"others did not think it is* *going to work,"* activated negative feelings such as frustration or disappointment.

Fifth, students (e.g., S1, 7) mentioned that developing their ***task strategy*** made them feel positive, such as creatively solving a problem or spending a long time on a task.

Finally, different students did not experience ***uncertainty or novelty*** in the same way. Some students (e.g., S5, 8, 9) were excited about experiencing new things, such as a creative problem-solving approach in DBL. Another student (e.g., S6) felt negative about the new design approach in DBL, such as making or sketching a prototype on paper compared with the familiar experience of prototyping on the computer. Other students (e.g., S3, 6) felt bored about routine things such as documentation in DBL, while other students (e.g., S2, 4, 11) mentioned they felt less uncomfortable and more neutral about routine tasks such as researching in DBL compared with the projects in their majors. In the following paragraphs, we discuss three other highlighted DBL aspects.

Making a Personal Connection Intensified both Positive and Negative Emotions

Interestingly, the personal relevance of the design challenge seemed to have mixed results, intensifying both positive and negative emotions. For instance, it made some students more passionate about their projects when working on something they are interested in. On the other hand, it made students value the outcome of their projects more, increasing the pressure they experienced.

"At the major, they expect me to be able to do something, and here you can impress people by what you can do" (S1). "That is something I am very passionate about, and because I had so many positive emotions about photography, it gave me the motivation just to go and start doing things and experimenting" (S6).

"There are always emotions throughout this project because I am so invested in it" (S5). "It is really frustrating that I cannot come up with something, and it is more negative than in my major because then I just think, 'Okay, I come up with something [for my own project], but now I want to do it perfectly.' It takes more time, and it is more frustrating. That is why I also sometimes get negative about that because I just want to do it perfectly" (S11).

Progress Tracking is an Emotional Situation

Experimental and iterative design activities enable the students to continually track their project progress, e.g., evaluate their outcomes, reassess their goals, explore new paths, imagine new possibilities, and weigh different outcomes [230]. Such progress tracking and assessing action occurs naturally within the design and learning process. We found that project tracking is a situation in which emotions are frequently activated. However, individual students may have different feelings, even during a similar experience. For instance, the student's retrospection on his/her development was a source of positive emotions for some students. Whereas other students had both intense positive and negative emotions from tracking their goals, evaluating outcomes, and redirecting actions. Given the importance of progress critique in reshaping the processes and final product of learning [16], our finding would suggest educators need to encourage students to self-track progress. Meanwhile, educators could monitor the students' self-tracking taking account of the potential individual difference in its corresponding emotions.

"My favorite part is, I would say, just see your own progress. In the beginning, you have nothing, and you slowly see more and more come up, and it starts working better and better, and it is just good to see" (S4).

"In the minor [DBL program], they constantly say, 'What are your goals?" and, "What do you think about this? How do you feel about that?' Definitely, the minor brings more emotions, both negatives, and positives" (S10).

Emotions towards the Design Process Changed over Time

We found that students' emotions seemed to fluctuate over time during the design process. Even during one task, e.g., sketching or researching, the associated emotions changed over time. Emotion changes in DBL may, to some extent, reflect how students deal with tasks and regulate emotions. Research has shown that the patterns of emotion change contribute to our psychological well-being [231]. Future research should examine more closely how emotions change over time in DBL and what aspects of the patterns of change are essential for learning. Our findings suggest that emotion tracking associated with task progress would be useful to provide well-orchestrated classroom instruction and take care of students' learning and well-being.

"I was initially doing a sketch it was like okay I am not really feeling anything, then eventually I got onto some design that I thought would work and I just started working more and trying to develop it more, really started enjoying more" (S2).

"In the beginning, I was really motivated because I was learning a lot. I was happy with the answers I got and the information I got. I was motivated to keep researching. To keep going and learning even more about it. At the end of the researching phase, I was not learning as much. I got demotivated, like stressed or bored by the research" (S12).

6.3.3. The Impact of Emotions in (De)Motivating Learning (RQ3-a)

With regard to the impact of emotions, this study discerns three general types of positive consequences and another three general types of negative consequences, as briefly described in Table 6.2. More specifically, students (namely S2, 4, 8, 11-13) mentioned the effect of some positive emotions (e.g., happiness, excitement, or satisfaction, especially after achieving success) on increasing their motivation. One student (S6) mentioned that the good feeling of having a successful trial was a rewarding moment, which increased her confidence. Another student (S1) explained that relaxation enhanced his memory, and others (S1, 6, 9) mentioned the impact of positive emotions (e.g., relaxation, passion, or happiness) on easing tasks.

The negative effects of negative emotions (e.g., stress and boredom) include being disengaged or demotivated students (e.g., S12, 14); making students rush and thus hampering the quality of their work (e.g., S6, 8) or causing errors (S4); and, more generally, made student (S3) be less open to learning.

Frustration, in particular, was thought to have a complex impact. For instance, students' frustration about tasks in DBL fueled their motivation. On the contrary, frustration about a group conflict was found to demotivate learning in DBL. One may argue that the positive consequence (e.g., motivating learning) may be related to whether students are more likely to consider failure as a way to learn or as defeat. A relevant question that arises is whether the consequence of frustration in DBL could be managed by cultivating students' optimistic attitude towards failure in the early phase of the design process. However, frustration in different types of DBL tasks needs to have a subtle consideration. For instance, frustration towards group issues may need regulation or intervention to avoid demotivation in the task.

"I learned about when I started with the database. If I do not get frustrated, it will be so easy for me. Maybe I do not like it because it is not challenging for me. And it is like… okay, it is so easy, I do not get anything" (S7).

"Frustration will not influence my motivation to do things; it will influence my ability to learn. My brain basically goes to neutral, and I am just away, so I will do it, and I am motivated to do it, but I will not be able to comprehend any learning, doing that same routine" (S3).

"If the peers and the friends with my group members arrive late, I get frustrated that they arrive late and do not say where they are or something. Let us say we meet up at 9:00, and then they call up to 10:00, then they show up, and I am already there for 45 minutes, really frustrated. I am already doing something; I feel like I do not

really want to do anything anymore because they obviously also do not want to. Then I do not want to do anything anymore" (S9).

6.4. Discussion

Our findings show that overall, some DBL aspects which students perceived as conducive for learning seem to overlap with aspects evoking their emotions. This can be seen in the theme of emotions and learning in Figure 6.1. For example, novelty and uncertainty create opportunities for learning and trigger their emotions as well. Likewise, the aspect of progress assessment and that of the design process in DBL both trigger students' emotions and are perceived by students as learning opportunities. This empirical finding is consistent with the theoretical perspective in the control-value theory [51,52] of achievement emotion that the perceived learning environment is among the antecedents of students' emotions. According to the control-value theory [51,52], the subjective *control appraisal* (i.e., feeling in control of or out of control over achievement activities and their outcomes) and *value appraisal* (i.e., the perceived importance) of the learning environment are the proximal determinants of individual students' emotions.

Some findings in this study can be explained by individual differences in students' appraisals of subjective control and values. For example, some students perceived that the new and self-directed way of exploring and researching in DBL allows them to learn while evoking positive feelings. Whereas one student liked learning new things in DBL but experienced negative emotions about the uncertainty and the lack of structure in DBL instruction. Different students may have distinct perceived internal *control* over experiencing new things and their associated outcomes. For some students, a low sense of controllability over the loose curricular structure in DBL compared with their non-DBL education may result in a negative emotion towards learning new things. Equally important, all students perceived a positive intrinsic or extrinsic *value* about the new experience in DBL, as they all believed that learning from this new experience is important for them. This result suggests the importance of taking students' perceptions of learning and DBL into account for the future development of emotional regulation support in DBL.

Furthermore, from a more integrative theoretical view, the three parts presented in the result section are intrinsically interwoven. This point aligns, to some extent, with the theoretical assumption of the control-value theory [51,52] that there is a dynamic feedback loop of emotions, their antecedents, and their effects over time within individuals. That is to say, learning and achievement outcomes are among the antecedents of students' appraisals and emotions, and in the meanwhile, emotions reciprocally affect these appraisals and learning.

This linked loop appears to be explainable, especially in the case of failure recognition during DBL. In this study, students believed failures and mistakes are learning opportunities and experienced emotional feelings from their failures. One student (S3) mentioned that her curiosity came into play soon after feeling a bit down about her failure. As a result of feeling curious about failure, one student (S3) was motivated to search for other alternatives. Another student (S6) felt frustrated when continually adjusting to a task that still did not meet her expectations. The motivation of student S6 slipped away at the start as a result of feeling frustrated about her repeated failures. Soon after, she was motivated again because she felt anxious about the approaching deadline and realized that these failures must teach her something. Both these examples (S3 and S6) can be seen as linked feedback loops of emotions, their antecedents, and their effects. The failure triggered different emotions in them. As a consequence, these emotions had different effects on the motivation to learn. This cycle was followed by another one, which starts with restructuring control and value appraisals about failure. Consequently, both students became motivated to learn again, driven by a perception of failure as an opportunity to learn. This finding (potential interplay between students' emotions and DBL) is preliminary as it is based on limited empirical evidence. Future work could examine in detail how this dynamic loop can be manifested within learning episodes, and it can evolve over days, weeks, or years within a DBL context.

6.5. Summary

We reported a case study that explored how students value learning and how they experience emotions in a DBL environment. In particular, our study revealed students' perceptions of nine DBL aspects, which enabled learning to occur and impacted students' emotions. These aspects are the iterations or trials during the design process, making a personally meaningful connection in a design project, tracking project progress, etc. These findings recognized specific elements that affect students (as presented in Chapters 2-3 and 5) and add two more aspects (i.e., novelty versus uncertainty and relevance) that are influential in students' DBL experiences. In addition to these DBL aspects, our study shows that emotions are essential to consider for the following three reasons: (a) various aspects of DBL can yield students' emotions, and these emotions can change during the design process; (b) there are substantial individual differences in how negative emotions affect students; and (c) in particular, the role of emotions, e.g., frustration in DBL, needs to be considered in depth.

Overall, our results suggest that researchers and practitioners should pay attention to monitoring students' emotions in relation to the associated DBL progress. Further research can seek to replicate this result and extend it to a broader range of DBL programs. Especially we may consider differences between formal and informal learning environments. Besides, future research can also consider the influence of age and the disciplinary background of the students on their learning and emotions.

[Section IV]

Demonstration: Application of Self-awareness and Social Sharing of Emotions

Chapter

SEVEN

Emotion Awareness: An Intervention Study

Chapter 7: Emotion Awareness: An Intervention Study

Abstract: This chapter presents a case study where university students (N=13) use a paper diary called EmoForm to self-track their emotions over a ten-week-long design-based learning course. Design-Based Learning (DBL) is a learning approach that enables students to learn through a sequence of design activities in a project-based learning or problem-based learning environment. Student's emotions are known to play an essential role in learning settings. We argue that students engaging in DBL will benefit from the self-tracking of emotions. Such self-tracking will enable students to identify and control their emotions during the DBL process. The results of this study confirm that self-tracking with EmoForm enabled students' emotion awareness in DBL. In particular, our results illustrate how self-tracking with EmoForm impacted students' DBL with regard to three main aspects. We discuss design challenges regarding tools to support emotion awareness in DBL, and we present a summary of strategies conducive towards emotion awareness in DBL and implications for future research.

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7.1. Introduction

Design-Based Learning (DBL) is a pedagogical approach that enables students to learn through a sequence of design activities. DBL has been applied in diverse subject-oriented contexts; the core of DBL stands consistent across subjects that students actively engage in their learning driven by the process of design and inquiry. Given that design is a core element in engineering, DBL has been particularly regarded as a promising educational concept for engineering education [223]. The motivation for applying design activities in engineering and science education is to enhance students' engagement in learning, considering that traditional courses often fail to engage students' interest and make meaningful connections to their everyday lives [1]. Besides, previous research has noted a positive effect of DBL on students' interest and awareness of engineering [30] and their intention to pursue an engineering career [29].

Emotions, in general, can reveal students' underlying cognitive processes, commitments, and concerns in learning [232]. In the context of DBL, our previous research (as presented in chapters 2 and 3) has already argued that students' emotions play a big part in their participation in DBL activities [26,152]. In the current chapter, we argue that it is essential for students to be self-aware of their emotions experienced during DBL for two reasons. First, DBL is an emotional place where situations such as collaboration, negotiation with peers, or conflicts in teamwork may frequently evoke students' emotions [26,152]. Consequently, students need to develop the ability to identify their emotions timely during the process. Second, students following such an active learning approach have to take responsibility for their projects [62] and develop skills to control their own emotions. However, little is known yet on how to facilitate emotion awareness during DBL. Resolving this deficit became the motivation of the inquiry in the present study. The contribution of this chapter is to show how emotion awareness can be supported in DBL and demonstrate how it influences a DBL activity.

In the following sections, we present our theoretical framework and review related works on emotion awareness. The subsequent section describes the methodology used in the present study in terms of exploring and evaluating EmoForm [90] as an emotion awareness tool in DBL. Finally, we report the findings and discuss the implications for future research.

7.2. Related works

7.2.1. A Theoretical View of Emotion Awareness

Emotion awareness refers to the ability to perceive, identify, and understand emotions [233]. Emotion awareness occurs in an attentional process in which emotions become the center of a person's attention [5]. During this process, the awareness of emotions is interconnected with interpretative and evaluative functions [234]. Previous research has explained some functions of emotion awareness in this attentional process [234]. For instance, these functions contain (a) differentiating between various emotions; (b) locating the antecedents of emotions; (c) monitoring emotions; (d) appraising the value of emotions; and (e) acknowledging the physiological correlates of the emotional experience.

Emotion awareness is a necessary step for the self-regulation of learning [235], which can play an essential role in students' learning process. Specifically, the information provided by emotion awareness influences the usage of adaptive emotion regulation strategies [195,233,236]. Some have argued that improving students' emotional awareness helps their self-regulation, which can, in turn, have a positive implication on their learning performance and outcomes [235].

The Control-Value theory [51] proposes the concept of achievement emotions that point to the emotions directly related to achievement situations and their outcomes. According to the Control-Value theory [51], three types of students' awareness are identified as helpful for emotion regulation:

A1: Emotion-oriented awareness

Emotion-oriented awareness pertains to information for differentiating students' emotions. This theory defines the achievement emotion along three dimensions, including *valence* (i.e., positive or negative), *arousal* (i.e., activating or deactivating), and *object* (i.e., activity-related or outcome-related). According to this theory, students' emotion-oriented regulation can be enhanced by being aware of various emotions, e.g., whether they are positive or negative (valence and arousal dimension) and whether they relate to the activity or its outcomes (objective dimension).

A2: Appraisal-oriented awareness

Appraisal-oriented awareness pertains to information for appraising and locating the antecedents of emotions that students aware of. An appraisal is crucial in educational processes, as it can mediate the impact of situational factors and foster positive emotional development [51]. The Control-Value theory highlights two types of antecedents relating to students' achievement emotions. For example, the *individual personality* antecedent, which refers to the control and value beliefs underlying students' situational appraisal, and the *environment* antecedents that may influence students' own control and value beliefs in a broader social-historical context. The environment includes the classroom elements, e.g., feedback and consequences of achievement, quality of instruction, anatomy support, and goal structures and expectation [52]. In this sense, students' appraisal-oriented regulation can be enhanced by, e.g., being aware of how their learning environment affects emotions. It can also be enhanced by their sense of control over learning tasks as well as task value.

A3: Problem-oriented awareness

Problem-oriented awareness relates to being aware of the information about the effect of students' emotions on their academic learning and achievement, which can be reflected as students' cognitive resources, motivation to learn, learning strategies, or learning performance. Correspondingly, according to the control-value theory, students' problem-oriented regulation can be enhanced by, e.g., being aware of their learning and achievement.

7.2.2. Tools for Emotion Awareness

Emotion awareness tools can capture information about student's emotions and associated environmental and situational cues. Emotion awareness tools in learning situations differ in terms of what emotion-related information is recognized and correspondingly what technique is used. Overall, they have used several techniques that include:

Emotional Behavior Recognition

This type of technique identifies the patterns of emotional behavior by observing motor-behavioral activity [237]. These observable behaviors can be varied, e.g., from facial expressions, voice intonation to sentiment analysis. Related tools include, e.g., Emodash [238] and affective AutoTutor [239]. Emodash is an interactive dashboard designed to support teachers' retrospective awareness of students' emotions in an online language learning setting. The mechanism of Emodash is based on Microsoft Emotion Recognition API to interpret and analyze students' facial expressions in video recordings, which enables teachers to explore their past teaching sessions from the lens of students' emotions. While affective AutoTutor is a dialog-based intelligent tutoring system that detects and responds to students' emotional states.

Subjective Self-report

This type of technique requires students to self-report their subjective feeling on either a mobile application, web platform application or paper-based questionnaire. Related tools include app-based and paper-based self-reporting tools.

For instance, the Live Interest Meter App [240] is a mobile application tool designed to quantify students' emotions and provide teacher insights on fostering learning. The meter component of this tool enables students to vote on their interest level in a topic. Similar to Live Interest Meter, ClassMood App [142] is a web-based application tool that provides teachers with data of students' emotions and helps them guide students to emotions that are more conducive to learning. Both of these tools can provide nearly real-time insight and feedback on students' feelings and thoughts in the classroom. The Emotion Awareness Scale [234,241] and the Levels of Emotional Awareness Scale [242] are retrospective paper-based questionnaires containing questioning items describing how students feel and think about their feelings.

Although the tools above are well suited to evaluate students' emotion awareness and regulation strategies in traditional learning situations, they are not well suited for the context of DBL. Ensuring emotion awareness in the DBL classroom is challenging. As an illustration, given the opportunistic nature of the design process [213], DBL engages students in an opportunistic sequence of tasks rather than a standardized sequential learning process. Consequently, emotion awareness in DBL demands extra effort to locate the antecedents of their emotions from the intricate design and inquiry process.

7.3. Method

It is a widely held contention that self-tracking and its ensuing data-based insights foster positive behavioral change [243]. Inspired by experience sampling approaches [244], we have developed EmoForm [90] (see Chapter 4), a paper-based self-reporting tool, to capture students' emotions and learning experiences in DBL. However, our understanding of whether and how a self-tracking tool facilitates emotion awareness in DBL is still lacking. This chapter reports on a case study evaluating students' self-tracking experience with EmoForm in a DBL program in an applied science university. Specifically, this study intends to address the following three aspects:

- How did students experience using EmoForm for self-tracking emotions in DBL?
- Whether and how does the EmoForm facilitate students' emotional awareness during DBL? (RQ3-b and RQ4-b)
- What are strategies perceived by students for facilitating emotion awareness in DBL?

7.3.1. EmoForm in DBL (RQ4-b)

The original version of EmoForm [90] was developed for application in secondary education, so it had to be adapted for the university context. The adjustments the current version has made include four aspects. First, the modified version of EmoForm uses a 7-point Likert scale instead of a 5-point

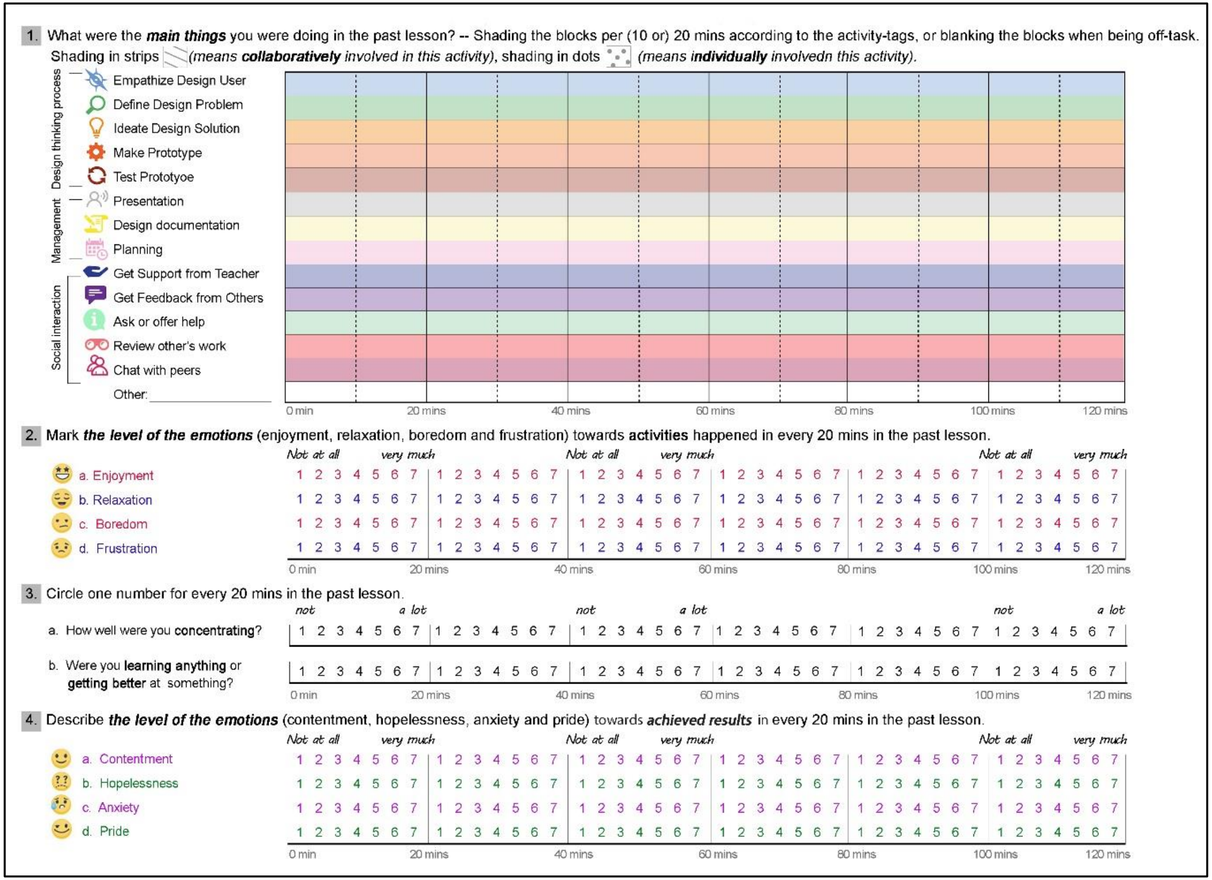

Figure 7.1. The Current Version of EmoForm for Adult Students in the Present Study. (Adapted from the Original Version of EmoForm [90])

Likert scale to enable university students to have a finer grain expression on the intensity of their emotions. Second, the original version of EmoForm presents ten DBL activities in the first section: empathize with design user, define design problem, ideate design solution, make prototype, test prototype, presentation, get support from the teacher, and get feedback from others. Based on the implications on the further development of EmoForm suggested in [90] (see Chapter 4), the modified version adds five more activities to the first section of EmoForm, including design documentation, planning, ask or offer help, review other's task, and chat with peers. Besides, the current version adds one open-ended option in the first section of EmoForm to encourage students to fill in any project-related activities other than the thirteen stated in the form. Third, the current version categorized DBL activities in the first section of EmoForm into three groups, namely, (a) design thinking process, (b) management, and (c) social interaction. This adjustment is to ease students' cognitive load for recalling and retrieving their involved activities. Four, the current version asks students to rate their achievement emotions (in sections 2 & 4), learning performance and concentration (in section 3), and involved activities (in section 1) every 20 minutes.

The underlying design principles (**P1-3**) of EmoForm adhere to the information intended for emotion regulation (**A1-3**) in the control-value theory. In this study, we hypothesize these three design principles of EmoForm formulated as follows (**P1-3**) can support students' emotional awareness in DBL. We aim to explore these design principles in the case of EmoForm to inform future development of tools for supporting emotion awareness in DBL.

P1: Support emotion-oriented awareness by differentiating and quantifying emotions

As seen in Figure 7.1, EmoForm asks students to differentiate their achievement emotions. For example, students need to differentiate and rate (a) their positive feelings (e.g., enjoyment, relaxation, contentment, and pride) from negative feelings (e.g., boredom, frustration, anxiety, and hopelessness). (b) their activity-focused achievement emotions (in section 2) and outcome-focused achievement emotions (in section 4); and (c) the level of their emotions from not at all (scored as "1") to very much (scored as "7"). By responding to these three aspects of information that EmoForm asks (**P1**), student's awareness of different emotions would be triggered (**A1**).

P2: Provide DBL situational cues for awareness by documenting involved activities and collaboration

In the first section of EmoForm, students are asked to identify the DBL activities, which happen in the same time frame as their scores of associated achievement emotions. In addition to the involved activities, students need to indicate whether they work individually or collaboratively. This DBL-specific situational information can provide students cues of their associated emotions. Thus, students' awareness of situational cues, namely, functioning as one of the antecedents of students' emotions (**A2**), would be activated by recalling and filling in their involved activities (**P2**).

P3: Enable learning performance awareness by self-rating perceived concentration and learning

In the third section of EmoForm, students are required to rate the level of their perceived learning performance, which includes self-perception of learning and self-perception of concentration, respectively. These perceptions of learning are measured in the same time frame as their experienced achievement emotion. By rating the level of their perceived learning performance (**P3**), students would be aware of some of the potential effects of their emotions (**A3**).

7.3.2. Intervention and Implementation

This intervention is situated in a ten-week-long DBL course that is a part of an entire DBL educational program lasting 20 weeks. Students work on a design challenge entitled "Future Solution" that addresses a real-life problem through an iterative design process during this ten-week-long DBL course. Students' design projects can be either a group project or an individual project, which is open to students' free choice. Students who enrolled in this course are majoring in diverse subjects. Consent forms were signed before data collection. To be mentioned, the current study was implemented in a research project with dual goals. In addition to supporting students' emotion awareness in DBL presented in this paper, another goal of that research project was understanding what elements are crucial to be considered in DBL (relevant findings can be found in Chapter 6 [167]).

Figure 7.2. Example of the DBL Environment in the Present Study (Photo credit: Fontys Pulsed).

We organized a session to introduce EmoForm to students prior to the intervention. In this study, the intervention involved students using EmoForm five times during the DBL course. Students were free to choose when and on which days of this DBL course to fill EmoForm in. A total of thirteen 3rd year undergraduate students completed the intervention of using EmoForm and participated in a one-on-one semi-structured interview after this intervention. These involved students are from a diverse background who are majoring in, e.g., ICT and software engineering (N=4; including S1, S5, S7, S13), computer science (N=1; i.e., S6), civil engineering (N=1; i.e., S12), mechanical engineering (N=2; including S3, S8), mechatronics (N=3; including S4, S9, S11), international business (N=1; i.e., S10) and industrial product design (N=1; i.e., S2).

7.3.3. Data Collection and Analysis

This study uses qualitative data gathered from semi-structured in-depth interviews with students. Students were first asked to review their EmoForms for the past days and think aloud. This exercise was intended to help students recall their use of EmoForm for the subsequent parts of the interview vividly. Questions asked in the follow-up interview include (a) *students' experience of using EmoForm*, e.g., "How does it feel to use it?", "How would you use the information from it?" "What conclusion do you get from it"; (b) *the effect of using EmoForm on students,* e.g., "Did it help you in dealing with emotions?", "How did it influence you in dealing with emotions?" and (c) *strategies for* *dealing with emotions*, e.g., "How to deal with the emotions in a similar project in the future?"

All interviews were audio-recorded and transcribed verbatim. The interviews were analyzed following the thematic analysis approach [209]. Specifically, data were coded from a research-driven perspective (e.g., themes of information display, themes of behavioral adaption).

7.4. Results

7.4.1. Experience in Using EmoForm

As part of the design principle **P1**, the EmoForm uses a 7-point Likert scale to engage students in self-rating the intensity level of their emotions and learning. Regarding this closed format of rating, many students felt it is comfortable to use this scale. In contrast, just several students (e.g., S1-2, 4, 9) expressed that it is challenging to rate their emotions in a quantifiable manner. This finding is in line with our previous knowledge that rating might involve additional workload and potential distraction from the learning task [245]. However, some students (e.g., S8, 11) who found it hard to evaluate the level of their feelings at first got used to it soon. They mentioned that rating became easier by using the scores for the first 20 minutes or the first day as a baseline. Some participants (e.g., S2, 7) showed a clear preference on a 7-point Likert scale over a 5-point or 9-point Likert scale.

Furthermore, emotion-oriented awareness information (as part of P1) for students was highlighted from the interviews, including enjoyment, boredom, frustration, pride, and contentment. It is important to note a vast individual difference in temperament and experiencing personal feelings. Research has pointed out that different students can experience varied emotions, even in the same situation, as emotions involve subjective experiences that vary between individuals [143]. For example, this study found that one student (S6) said she seldom feels relaxed while another (S5) said she seems like an anxious person in general. Moreover, a few students (e.g., S6, 10) mentioned anxiety is not their primary emotion as it does not frequently take place in their cases during DBL. This finding is in line with earlier findings that anxiousness and hopelessness remain considerably low in DBL [90].

Situational appraisal-oriented awareness information is in an open and multi-choice format displayed in the first section of EmoForm. Students are asked to state the activity they are involved in and indicate whether it is teamwork or individual work (**P2**). Some students (e.g., S2, 10) favored this display format and thought it is clear to fill in and useful for them to track what they have done or even plan what they need to do next. Interestingly, student S2 stated that reviewing the combined information of activity and emotion is especially useful, while S8 liked examining the combination of learning information together with emotion information. This divergent finding is logical: some students pay more attention to the potential causal relationship between their emotions and activities, while others pay more attention to the effect of their emotions on learning. Besides, some students (e.g., S2, 11, 13) mentioned a scenario in which they can use this awareness information further to share what they feel and what they do with their coach or peers in a team. However, results also showed that the current visualization of three sets of information on EmoForm did not work well for all students. One student (S7) commented that it is hard for them to draw an overall conclusion without analyzing their reported information. Instead, generating explicit and dedicated feedback for them is preferred. This would suggest that future work is needed to explore ways of data visualization supporting explicit cross-referencing.

Students exhibited variable timing and frequencies of self-tracking with EmoForm. Most students (e.g., S3, 5-6, 10, 13) felt comfortable about recording their emotional experience on EmoForm every 20 minutes. Some of them (e.g., S6, 10) appreciated the moment of their self-recording every 20 minutes, which triggers them to reflect on their ongoing experience. For example, S10 mentioned that "*I thought about what I was going to do, and I put a point [on EmoForm] before everything so that I could see, 'This is my plan. This is what I want to do today.' Sometimes after a while, I just saw, 'I didn't get any support from a teacher. Oh, I have to do that still,' so then I could do it, it was kind of a reminder.*" However, other students (e.g., S4, 7, 8) thought it is too intrusive to record every 20 minutes choosing to record what they have done after completing a two-hour activity or after a whole day of learning. However, a few of them (e.g., S4, 8) found it difficult to recall their memories even after just two hours had elapsed. Interestingly, one student (S10) mentioned that she fills in EmoForm without following a fixed schedule, and she would typically fill it in when her learning was distracted by something or she was on a break. These findings suggest the need to set boundaries on retrospective self-reporting. This observation shows the tension that arises in obtaining reliable on-the-moment self-report and avoiding disrupting the immersed flow of learning in DBL.

7.4.2. EmoForm on Facilitating Emotion Awareness (RQ3-b)

Overall, most students (e.g., S2-3, 5-6, 8-10) stated that EmoForm was fun and useful to use. Results illustrate that all students acknowledged the impact of EmoForm on students' emotion awareness. This finding confirms that self-tracking with EmoForm facilitates emotion awareness, which is consistent with known results relating to behavior tracking [246]. More specifically, results in this study reveal the following three major effects of EmoForm, which underline the potential for emotion awareness to support DBL.

First, our results show that self-tracking with EmoForm encouraged communication and accountability of students' internal states. For example, some students (e.g., S2, 4, 6, 11) acknowledged that it is useful for confirming their impression regarding their involvement in different activities (**P2**) and their emotions (**P1**). Some of them (e.g., S6, 11) mentioned that they communicated such information with others, which resulted in an increased awareness of themselves and their peers. For example, S11 said that "*Well, I did once with someone else. You can then wake up to talk about, 'Oh, hey, you like that. I didn't like that or something like it.'*" Likewise, S6 envisioned that "*It could be nice if it [self-tracking with EmoForm] applies with many of us, [saying that], 'Okay, we're going to do this. How do you feel?'*" Similarly, S2 commented that the awareness and communication of these emotions between peers could be useful, as it can help students find out who likes and dislikes doing something so that they can locate the right person to offer help to or receive help from. Besides, one student (S10) explained that "*I think the support [of self-tracking with EmoForm] is really important that I see that I did some things.*" In this case, S10 thought self-tracking the activities she participated in using EmoForm helped her realize she had done more than what she had in impression, making her feel much better about herself.

Second, the findings demonstrate that self-tracking with EmoForm increased students' awareness and understanding of self. This holds to a different extent for different students. For example, almost all students (e.g., S2-7, 9-13) commented that self-tracking on EmoForm made them aware of their emotions (**P1**) and realize what they did right (**P3**) as well as what motivated them to do (i.e., associated activities, **P2**). This is something that they had not taken into account before. For example, S5 mentioned that "*I think it made me more aware of the concentration level because it's something I would never look at. I just think I'm concentrated, but if you actually have to discuss with yourself, e.g., was I fully focused, or was I half focused? It actually gives insight into the quality of your work.*" Besides, S3 reported that "*It was a good learning* *experience for me in a way that you become more aware of your emotions. […] Besides, for me, it was also a realization that I was experiencing more extreme emotions when working together with other people.*" Similarly, S6 said that "*I think that it's very useful because I didn't do this before. [...] I realized that I can program and make some designs. I can relax when I'm doing it.*" This finding echoes the perception that being required to self-track concerning emotional or cognitive categories might serve as a meta-cognitive prompt that helps to reflect on a task [245].

Third, this study found self-tracking with EmoForm stimulated behavior change for some students. Specifically, students (e.g., S5, 6, 10) became aware of the emotions they recorded on EmoForm, which according to them, resulted in positive behavioral changes, e.g., taking control of their emotions. For example, S5 mentioned that "*Normally I feel like I would let myself have some boredom and some frustration like a person asks you the same question three times. But I was like, 'I'm just here for them. I have to take it away from myself.' It [self-tracking with EmoForm] did make me control my emotions a little bit more, I think.*"

Many students (e.g., S3, 5- 6, 9-10, 13) felt it was useful to review what they recorded on EmoForm and believed that it helps in finding when they feel some emotions and opens the possibility to deal with these emotions in the future. For example, S9 mentioned that "*It helps in finding when you feel some emotions, and then you can deal with them. […] It gets you on the right track to eventually deal with your emotions.*" Some other students envisioned the effect of using EmoForm in this study on their future activities, just as S6 reported that "*I just focus on the programming part. Now, I know that this gets me so frustrated. [..] Maybe I can work with other projects and [asking myself], 'Okay, how I feel? Did I feel frustrated? Do I really enjoy what I'll be doing?' Because maybe I can improve my work, depending on how I feel.*" Similarly, S8 mentioned that "*Maybe if I would reflect on what I did using this [EmoForm] and using the emotions, then I might be able to do something about it. For instance, if I see that I'm frustrated and my work is bad so that I know that if I'm frustrated, I need to take a break or something to get less frustrated. I think in that way, I could be able to use it for dealing with emotions.*"

To conclude, these findings above confirm that applying the design principles (**P1-3**) displayed on EmoForm, to a different extent, facilitated students' emotion awareness in DBL.

7.4.3. Emotion Regulation Strategies

Self-awareness of emotions was seen as a strategy for emotion regulation in DBL for some students. This finding echoes the theoretical claim that encouraging students to identify their feelings may be viewed as a step towards emotion-oriented management (**A1**) [51]. For example, S10 commented, "*I also think the frustration part is good so that I can be more aware of what I don't like to do or what frustrates me. It's easy to implement it maybe later if something doesn't work out, and I get frustrated, that I maybe can change it and do it differently.*" Besides, one student (S5) mentioned a strategy of steering her process, taking into account emotions. Especially, she described, "*I would say that you have to plan your process. Taking into account what you already know about yourself. For example, I might start the next project by going around and asking people about their ideas to get this positive emotion rush. Only then, I'm going to go into documentations and sketching because if I start with that, it's like taking my motivation away at the very first step of the project.*" In particular, some of the students in this study especially mentioned that awareness tools like EmoForm could help regulate their emotions. For example, S8 stated that "*Maybe using a form like this and then actively reflecting on it. That is probably how I could deal with it, I think, which I don't really think [in the past].*"

As one step further, sharing emotions within a group is also seen by some students as a strategy for regulating emotions in DBL. For example, S9 stated, "*it's good to have a review of that day and to chat with each other, like how everyone felt of things. Maybe if someone says like, 'I didn't really feel good about that,' or 'I didn't feel any enjoyment,' then you can talk about it and change it for next time. […] Because when you're working alone, I think it's really hard to deal with emotions. It's easier if people help you with that.*" Likewise, S11 has a similar opinion to S9, saying that "*if you know the emotions of the other people in your group, you can connect to it and see, maybe they can pull you up or you can pull them up to get more motivation in the group. […] I think it is way more helpful if you know the emotions of other people as well because it's often hard to make the first step to talk about emotions.*"

Furthermore, one student (S1) argued that the teacher's intervention (e.g., having a regular meeting with the coach) might help him deal with emotions in DBL. This type of strategy points to a problem-oriented emotion regulation strategy (**A3)**. Previous studies [72,102] have already shown the teacher's influential role in students' learning and emotions. This finding suggests that future work may consider teacher intervention in developing students' emotional awareness in DBL.

Some students (e.g., S1-4, 7, 13) think having an open-minded mindset to both positive and negative emotions has also been seen as a strategy for emotion regulation (**A2**) in DBL. For example, S2 mentioned that "*I guess instead of trying to hold back of them you get positive or negative [emotions], just get it out and then work with it. If it is negative emotions, try and distract yourself from* *them; if it's positive, ride that positive wave and get as much of them as you can."* And S3 also described, "*I try to keep positive because, in that way, you're way more open for meaningful learning experiences.*" This finding aligns with the adaptive emotion regulation strategies previously proposed in the literature, such as the reappraisal or acceptance of emotions [236].

7.5. Discussion (RQ4-b)

A necessary step towards designing tools to improve emotion regulation is understanding the extent to which and how students are aware of the emotions they experienced during learning [235]. The work presented in this chapter examined whether and how self-tracking of emotions using the EmoForm can facilitate students' emotion awareness and provide more in-depth insights on how such a tool can be developed in the future.

Our findings are illustrative of the potential benefits of repeatedly self-reporting on students' internal states during learning. While affective computing technologies can be used elegantly and unobtrusively to create awareness implicitly [245] (without the user having to actively report them), this study emphasizes the advantages of explicit awareness through self-report, which is well known to be able to simulate reflection and behavior change [247]. On the other hand, self-reporting emotions, especially in response to a system-generated reminder (as in experience sampling), can be mistimed, obtrusive, and interrupt learning flow. There has already been a debate about using explicit feedback or an implicit feedback system to support students' emotion awareness in education [245]. Future research could explore the possibilities of a multimodal tool combining explicit self-assessment (e.g., the experience sampling form strategy) and implicit context awareness (e.g., system login data, wearable-enabled data collection) to balance the potentials and drawbacks of each technique in a fashion similar to the Reconexp tool for experience sampling [248].

Interestingly, some participants wished to share their emotion-related information with others to create social awareness in DBL. Future work could investigate the acceptance and feasibility of sharing information among students in the context of DBL. Furthermore, students seemed to use the shared emotion information to adapt their learning strategy in this study, which also raises new questions such as how to ensure comparisons between students can lead to a positive outcome. Comparisons can trigger knowledge sharing and cooperative behavior between students and trigger downward comparisons and diminishing efforts or withholding of information [245].

Besides, it would be interesting for future research to examine how to strengthen the guidance provided by emotion awareness tools in DBL with explicit advice without compromising the student's feelings of autonomy. Apart from developing new tools to support emotion awareness in DBL, future research should systematically explore the underlying mechanisms that shape the relationship between emotion awareness and learning outcomes in DBL. Questions that arise for future studies pertaining to identifying the conditions and situations where emotion awareness during DBL can lead to positive learning outcomes.

Most of our participants were positive about using EmoForm and found using it fun and useful. We do not know if this is the effect of novelty or a social desirability bias, but the reception was encouraging, showing the potential for emotion awareness to support DBL. Clearly, our findings are based on a single case study. Comparison to different cases or experimental studies may help strengthen the evidence provided here and generalize a broader range of students.

7.6. Summary

This chapter reports an intervention aiming to enhance emotion awareness in DBL. Emotion awareness was achieved by asking students to self-tracking their emotions using the EmoForm. Our empirical results confirmed the assumed influence of self-tracking with EmoForm in facilitating emotion awareness, which is in line with established approaches to self-tracking behavior in general. In particular, the effect of EmoForm in this study reflected on three aspects: (a) it encouraged communication and accountability of students' internal states; (b) it increased students' awareness and understanding of self, and (c) it stimulated behavior change. The empirical evidence provided underlines the potential for emotion awareness to support DBL. Moreover, this study identified the following design choices to be considered in developing emotion awareness tools for DBL. (a) exploring strategies for choosing appropriate timing for self-report of emotions to avoid disruption; (b) exploring ways of data visualization supporting explicit cross-referencing.

[Section IV]

Demonstration: Application of Self-awareness and Social Sharing of Emotions

Chapter

EIGHT

Social Sharing of Emotions: An Intervention Study

Chapter 8: Social Sharing of Emotions: An Intervention Study

Abstract: Research into the role of emotions in Design-Based Learning (DBL) is growing, but there has been little attention paid to regulating emotional resources for supporting DBL. Here we explore whether emotion sharing can help students regulate their emotions, which would be beneficial for learning. Chapter 8 reports two intervention studies conducted during the Covid-19 epidemic, which explored different ways of sharing task-related emotions with peers and teachers and evaluated the impact upon a total of 28 students (aged 13-16) learning experience. The first intervention study concerns implementing a group chat channel in Microsoft Teams ® for sharing emotions. The second intervention study employed FireFlies, a tangible interactive lamp, in which we assigned the four colors of FireFiles to support students to share four different task-related emotions. Data were collected through questionnaires, observations, and interviews. Based on a qualitative analysis of the data, this chapter contributes recommendations for related tools and intervention development and discusses implications for future research and education practice.

This chapter is based on the paper: Zhang, F., Markopoulos, P., An, P, & Schüll, M. (Under review) Social sharing of task-related emotions in Design-Based Learning: challenges and opportunities.

8.1. Introduction

Emotions during learning have been widely studied (e.g. [5,6,113,141]). One could argue that emotions constitute an essential part of a student’s learning experience. For instance, emotions, on the one hand, can often be triggered by academic or achievement situations [49]. On the other hand, emotions shape students' engagement and achievement in this learning experience [249]. However, less is known regarding the impact of emotions in Design-Based Learning (DBL) and how to manage students’ emotions. The literature survey (as discussed in Chapter 2 [152]) argued that a variety of DBL components (e.g., teacher, collaboration, design process, assessment, learning activities, etc.) could impact students' emotions. Several recent studies [93,152,167,250] have also noted students in DBL may undergo a dense emotional experience. Specifically, a recent empirical study demonstrated that there seems to be a subtle relationship between a student's emotional experience and different DBL activities, such that emotions experienced in DBL may change depending on tasks or strategies. [250]. Thus, this study has advocated that we should have a flexible approach towards a student's emotional experience in DBL. Despite a growing interest in research on emotions in DBL [152], less attention has been paid to the regulation of emotional resources for supporting DBL. Given that DBL is gaining increased acceptance as a promising educational approach [140], it seems requisite to tackle the challenge of emotion regulation in DBL. Recently, the COVID pandemic has created stress not only on our educational systems in learning and teaching but also in students separated from their peers and teachers, which may negatively impact their well-being [251].

Research in the context of recalled everyday routines and psychology experiments has shown that emotional experience elicits social sharing [252–254]. Such a sharing behavior can be seen as an attempt to regulate emotions through social interactions [255]. However, despite the evidence that social sharing of emotions is beneficial for emotion regulation, this aspect has not been considered in DBL research yet. Specifically, it is not yet known how to facilitate this social sharing of emotions during DBL. To address this limitation, we set out to explore and evaluate interventions, aiming to answer the following **research questions**: *How can sharing task-related emotions influence students' DBL experiences*? (RQ3-c) And *what needs to be considered when designing for the social sharing of emotions?* (RQ4-c) Below we report on two intervention studies conducted in a public high school in the Netherlands during the pandemic of 2020.

The chapter is structured as follows: we review related work pertaining to the social sharing of emotions in section 8.2. This is followed by a description of our two intervention studies and approaches used for data collection and analysis in section 8.3. Then we report findings in two major aspects: (a) students' experience on social sharing of task-related emotions in DBL (see section 8.4.1) and (b) impact of students' social sharing of task-related emotions in DBL (RQ3-c; see section 8.4.2). This chapter concludes with a discussion of the implication of this work (RQ4-c).

8.2. Relevant Background

8.2.1. Social Sharing Of Emotions: A Theoretical View

Social sharing of emotions refers to describing or expressing emotions in a socially shared language by an individual who experienced it to another [254,256]. The social sharing of emotions can occur in diverse forms. For instance, it can occur in discourse when an individual communicates with one or more persons about an emotional experience. Alternatively, it can occur in latent or indirect communications (e.g., social media, diaries, or instant messages, etc.) in which other persons are present only at a symbolic level [253]. Emotion regulation comprises attempts to change positive or negative emotional experiences [257,258], and the social sharing of emotions can be seen as a valid attempt.

More specifically, the social sharing of emotions takes place at dynamic interpersonal processes between the "*narrator*" (i.e., a person who needs to share an emotion) and the "*listener*" (i.e., a sharing target) (cf. [253]). As an illustration, this dynamic process often initiates with the narrator experiencing emotion and sharing it with the *listener*. It may be followed up by the *listener* expressing an interest in the shared content, which may stimulate the *narrator* to express the emotion more and more. In that way, a reciprocal stimulation of emotion between the *listener* and the *narrator* may enhance empathy in the *narrator*. In principle, this interpersonal dynamic may be where intrinsic or extrinsic interpersonal emotion regulation [259,260] is derived. Intrinsic interpersonal regulation refers to circumstances in which an individual initiates social contact to regulate his/her own experience. Whereas extrinsic regulation refers to one's attempt to regulate another's affect. This can be seen when the *narrator* engages in intrinsic regulation, whereas the *listener* participates in extrinsic regulation.

In particular, a two-mode model of social sharing (cf. [253]) in the domain of social psychology was proposed by Rimé, advocating the cognitive and socio-affective modes as two types of sharing ways that need to be considered. A cognitive mode occurs when the listener stimulates cognitive work in the *narrator*, e.g., re-appraising goals, re-organizing motives, or re-creating meaning. Whereas a socio-affective mode contributes to fulfilling the narrator's socio-affective needs, e.g., attention, empathy, comfort, help, or support. According to this model, the predicted effects of a cognitive response during social sharing interactions may reduce the need for sharing and mental rumination. Differently, the completion of the *narrator's* socio-affective requirements most often brings the *narrator* a sense of emotional relief. However, Rimé points out that the relieving effects are expected only to be temporary when the social sharing process solely develops along the socio-affective route without any cognitive contribution.

8.2.2. Designing and Supporting for Social Sharing of Emotions: Related Works

Earlier studies have examined the current practices of social sharing of emotions on social media. For instance, a study by Lin and Qiu [261] revealed that undergraduate students' sharing emotions on Facebook is associated with their social network size and density. Bazarova et al. [255] investigated how social media affects how people in everyday routines share emotions on Facebook and their satisfaction with this social sharing. This study suggests that people's overall satisfaction after sharing emotions in network-visible channels is strongly tied to their reply satisfaction. Burke and Develin [262] also examined the case of Facebook, with emphasis on the circumstances in which people share emotions and the characteristics of the received responses. Their results illustrate that posts with negative feelings elicit more emotional and supportive comments. In contrast, posts with positive feelings welcome more likes and comments in a more positive language tune. A comparative study of social media platforms (e.g., Facebook, Instagram, Twitter, Snapchat, Tumblr, YouTube, 9Gag, and blogs), a study by Vermeulen et al. [263] revealed that Facebook statuses, Instagram, and Snapchat are mostly used for sharing positive emotions. In contrast, Twitter and Messenger are often used for sharing negative emotions.

Other than these popular social media, sharing or expressing emotions through dedicated awareness tools has also been studied in previous works. For example, a study introduced Aurora [264], a mobile-phone-based emotion sharing and recording system, which has been evaluated as a tool to encourage the social sharing of emotions in an everyday context. Results showed that Aurora users seemed to feel comfortable sharing emotions in Aurora than in other ways, such as face-to-face or over the phone. Situated in the classroom context, Balaam et al. introduced Subtle Stone [64], a tangible lamp, which is designed to support emotional communication between students and the teacher. This study suggests that using such a tool to communicate emotions experienced in the classroom empowered students to understand and reflect on their emotional experiences.

In summary, social sharing of emotions is often seen as an emotion regulation strategy. Earlier research has examined how using social media and affective technology-enhanced devices can support this sharing of emotions. However, the social sharing of emotions during DBL has not yet being explored. Aiming to fill this gap, we set out to investigate the sharing of task-related feelings in DBL (i.e., achievement emotions [136]) as opposed to feeling that is evoked by an event that happened outside of the DBL classroom). This chapter contributes to emotion sharing literature and related tool development perspective in DBL contexts by advancing our understanding of how the sharing of task-related emotions influences students' DBL experiences.

8.3. Methods

We carried out two intervention studies sequentially during the COVID pandemic period in 2020. While these two intervention studies in this research aimed to understand the impact of social sharing of emotions in DBL, we deployed different tools to support this social sharing of emotions. The first one was conducted online during the school closure due to the pandemic in June 2020; with insights gained from the first study, the second was intended to collect more data and was conducted in September 2020 when the schools re-opened after the lockdown period. This research was approved by the Ethics Review Board of the Eindhoven University of Technology, and we received informed consent from the participants. A total of 28 students (N= 11 in study1; N = 17 in study2) voluntarily participated in this research and were recruited from a Dutch public high school. Below, we present the intervention design, number of participants, and data collection approaches for each study.

8.3.1. Study 1: Intervention Design and Study Setup

In study 1, the intervention concerns implementing a group chat-channel in Microsoft Teams ®[1], embedded in three DBL sessions (each lasting 20 minutes) spanning over a week. The week of intervention is situated towards the end of a DBL course in Microsoft Teams ®. Our implementation of a group chat channel in Teams ® ensured the convenience of engaging in the class while socially sharing their emotions.

A total of 11 students (aged 13 to 14) participated in this study. They were encouraged to share their task-related emotions with peers and the teacher in a dedicated online chat group, as seen in Figure 8.1. We asked the participating students to share emotions at least once in each 20-minute online session. In this DBL course, the design challenge was to design an escape room

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1 https://www.microsoft.com/en/microsoft-365/microsoft-teams/group-chat-software

for the local fire department to allow participants to playfully and interactively improve fire safety awareness in and around the house. In principle, three to four students work remotely and collaboratively on one team project online. The intended goal of this study was to observe how students socially share their task-related emotions in an online DBL context and how this spontaneous sharing and associated responses influenced their DBL experience.

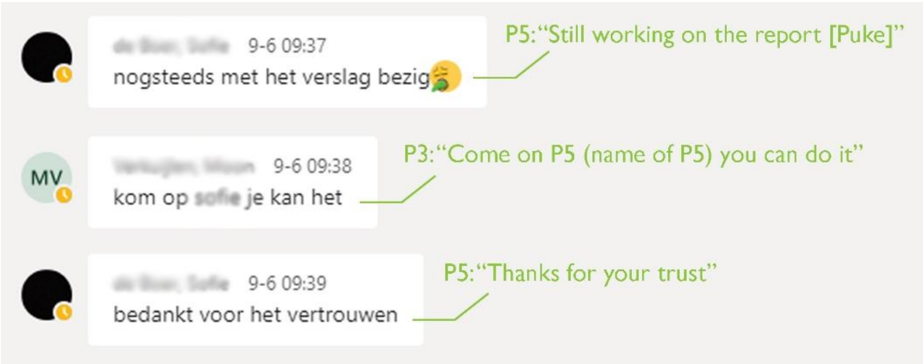

Figure 8.1. An Example of the Group Chat Conversation in Microsoft Teams during the 3rd lesson: Student P5 encouraged P3 after being aware of P5’s feelings. (Conversation is translated to English, as seen in texts in green)

We asked students to fill in a questionnaire adapted from the Intrinsic Motivation Inventory (IMI) questionnaire [265] before and after the intervention. This IMI questionnaire has been widely used in studies related to respondent’s intrinsic motivation and self-regulation. By collecting this IMI questionnaire, we aim to gain insights into the impact of sharing emotions on a student’s motivation to take the DBL course. In our adapted version, we use 27 items measured from five sub-scales, e.g., interest and enjoyment, competence, perceived choice, pressure and intense, and relatedness. We also collected students’ survey responses regarding students’ experience and view of such sharing behavior after completing the intervention.

8.3.2. Study 2: Intervention Design and Study Setup

Although we had no prior reference regarding the extent of emotion sharing one should expect to observe, the number of emotion-sharing episodes in study 1 seemed relatively low. This can be explained in a couple of ways. On the one hand, this intervention of sharing emotions was embedded in short online lessons (each lasting 20 minutes). Students had limited emotional experiences to share. On the other hand, they had little opportunity to share their feelings via the digital channel as they were quite busy with their learning tasks. Considering that this field study 1 did not provide us rich opportunities to evaluate the design intervention, we decided to conduct study 2, aiming to improve the efficiency of emotion sharing mechanisms so that such sharing would not distract students from their main tasks. For this, intervention study 2 concerns the deployment of a tangible toolkit (see Figure 8.2 and Figure 8.3), including interactive lamps called FireFlies [266,267] and a set of task cards to help students share their task-related emotions. Slightly different than open sharing in Microsoft Teams, in study 2, we facilitated sharing in a more structured way.

Pekrun [6] proposed four types of academic emotions that students experienced in learning, including achievement emotions, social emotions, topic emotions, and epistemic emotions. This study 2 focused on emotions related to achievement emotions, namely feelings related to achievement activities and outcomes [6,52]. According to the taxonomy of valance and arousal dimensions, we selected four representative emotions tied to activities that students engaged in. These include one activating positive emotion (i.e., enjoyment), one activating negative emotion (i.e., frustration), one deactivating positive emotion (i.e., relaxation), and one deactivating negative emotion (i.e., boredom). We decided to use FireFlies, a tangible and wireless interactive lamp that could support minimalist interaction (e.g., rotating to change the color), to support low-threshold emotion communication of students. We assigned the four colors of FireFiles to four different task-related emotions: Red (frustration), Yellow (boredom), Green (enjoyment), and Blue (relaxation), as seen in Figure 8.2. For instance, a student could easily turn his/her lamp to green to express the emotion of "enjoyment" without stopping an ongoing task and focally engaging with a digital interface (e.g., the GUI of Teams). These lamps distributed on students' desks (see Figure 8.4) then serve as an *ambient display* [268,269], which calmly visualize students' emotions. This way, FireFlies could afford users' *peripheral interaction* [270,271] (i.e., minimalist interaction plus ambient information display) and enable emotional sharing to become an unobtrusive secondary task be seamlessly woven into DBL activities. Moreover, using a FireFlies lamp requires very little effort for students to share emotions and makes it possible for both the teacher and the peer students to observe the shared emotions at a glance or with peripheral attention. Although this is the first time that FireFlies has been used for emotion sharing in DBL, prior studies (e.g., [266,272,273]) showed how this distributed tangible system could meaningfully support low-threshold communication and ambient awareness in the classroom without getting in the way of learning and teaching.

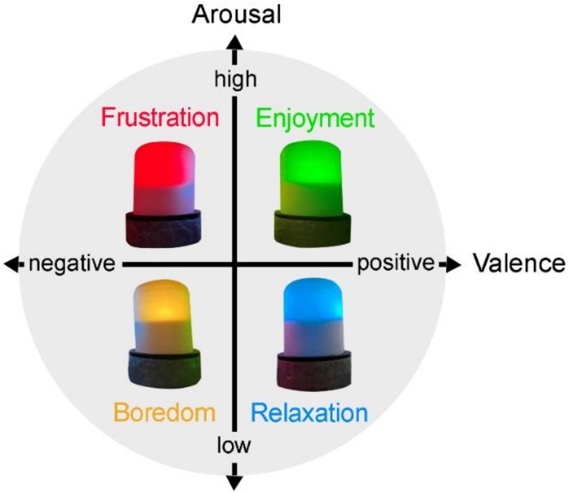

Figure 8.2. Four Task-Related Emotions are Pre-registered by FireFlies (Students can turn off the lamp if they do not feel like sharing at some moment).

Figure 8.3. The Set of Task Cards (Containing 14 Varied DBL Tasks).

Meanwhile, we also designed a set of task cards (as shown in Figure 8.3), which can be used in combination with FireFlies, providing extra contextual insights into what task is involved when a student is having an emotion. We believe introducing the use of task cards is also helpful, as it requires little effort for students to share and makes it visually possible for both the teacher and the peer students to observe the shared content. We designed the content of these tasks based on the most common DBL tasks previously measured by EmoForm (as discussed in Chapters 4 and 7 [90,167]) and addressed by the

Affect-and-Activity model of DBL (as presented in Chapter 5 [250]). As shown in Figure 8.4, students were encouraged to freely share their task-related emotions by playing around with Fireflies and task cards.

As the situation re-allows the Dutch secondary education to occur in an offline setting, this intervention study 2 was implemented in another DBL project (involving different students and teachers than in study 1) at the same high school after the summer break. In September 2020, this intervention was embedded in a face-to-face onsite DBL lesson lasting 90 minutes in the classroom (as shown in Figure 8.4), situated towards the beginning of this DBL project, and involved 17 students (aged 14 to 15). The design challenge of this DBL project was to invent a child-friendly new recipe for a food truck to encourage children to make healthy snacks at home. Students worked in a team in this project; every team consists of three to four students.

Figure 8.4. An Example of Classroom Activity during this Intervention.

Before the intervention starts in this 90-minute lesson, we asked students to fill in a pre-questionnaire (which consists of six items on a 5-point Likert scale) to measure their attitude towards social sharing of emotions in this DBL project. After the intervention, we immediately asked students to fill in an extended post-questionnaire that includes the six items in the pre-questionnaire and some more questions regarding their past sharing experiences. The purpose of an extended post-questionnaire was to reduce the time elapsed between the intervention and follow-up in-depth interview. We held in-depth interviews (see Appendix H), each lasting 10-15 minutes with 5 students the next day after the intervention and 11 students after a week of the interview. To triangulate subjective data collected by questionnaire and interview, we also conducted field observation in the classroom.

8.4. Results

The observed sharing episodes in our two interventions suggest that social sharing of task-related emotions could be triggered and facilitated in an online form (study 1) and in an offline setting (study 2). We found a total of 50 records of chat messages from 11 participating students (M = 4.55, SD = 0.93) during these three short online sessions lasting a total of 60 minutes in the intervention study 1. Table 8.1 displays examples of sharing contents in intervention **study 1**.

Table 8.1. Recorded Sharing Contents in the Intervention Study 1 (excl. repetitive records and records with less than two words). Elven participating students of the class in study 1 are denoted a number ranging from P1 to P11. (Note that students used some emoticons to express their feelings; we report them below using the [shortcut] in Microsoft Teams)

Students	Examples of recorded sharing content in Microsoft Teams
P1	I feel totally great. Oh yes, I am working on the pp. PowerPoint [Smile].
P2	I feel [Smile] and I am working on the report. Report [Smile].
P3	I feel relieved because I finally know how sketch-up works. I am still working on the room. I don't do anything [Smile]. Come on @P5 (name of P5), you can do it.
P4	[Yes] we are dividing the text. Divide text: [Smile]. Practice presentation [Speechless].
P5	I feel good because I am working on the report and it is clear what I can do. Still making the report [Sad]. Still working on the report [Puke]. Thanks for your trust (#P3).
P6	I feel good and work on the pp. The presentation [Smile]. Make the presentation [Speechless].
P7	Make a report: [Sleepy]. Nothing now: [Smile]. Adjusting small things in sketch-up: [Speechless].

P8	[Smile] I am working on the pp. Presentation and it is almost finished [Smile]. Go through PowerPoint [Smile].
P9	I feel good because I am working on the report and I know what to do. Also nothing [Smile]. Go through PowerPoint.
P10	I feel good. Because I'm eating. Presentation [Smile]. Make a presentation [Smile].
P11	I feel good and am working on the report. Oh wow, ha-ha. I am working on the R&D report [Speechless]. Make an overview of what I have to catch up per course [Speechless].

Table 8.2 illustrates the sharing episodes in intervention **study 2**. As shown in Table 8.2, we observed a total of 38 instances (M = 2.24, SD = 1.70), excluding the repetitive instances shared by an individual student. The majority of participated students were highly engaged in learning and social sharing their emotions with others, except for team F (a group of four spent most of their time sitting in front of the computer and goofing around). These results suggest that social sharing of task-related emotions in DBL could be supported by a tangible toolkit. The frequencies of sharing could vary from individual to individual. Our findings from follow-up interviews pointed out this difference may partially be due to not much variation of DBL tasks students experienced within this 90-minute lesson, which may also be associated with their ability to recognize internal feelings.

Table 8.2. Observed Sharing Contents in the Intervention Study-2. Six teams are denoted alphabetically, ranging from "A to F," and a number ranging from 1 to 3 to identify each team participant. (Note that the displaying duration for sharing content among individual students is varied.)

Team (student)		**Examples of observed sharing content** (*Emotions* were observed from the colors of the lamp; tasks were displayed by cards)
A	A1	*Boredom* during design documentation *Relaxation* during design documentation

		Enjoyment during design documentation
	A2	*Boredom* during design documentation *Boredom* during an off-task break *Relaxation* during design documentation *Frustration* during design documentation
	A3	*Enjoyment* during design documentation
B	B1	*Frustration* when chatting with peers
	B2	*Frustration* when chatting with peers
C	C1	*Enjoyment* in general (without displaying task info) *Frustration* when chatting with peers *Relaxation* when chatting with peers *Enjoyment* while making a prototype *Enjoyment* when getting feedback from others
	C2	*Frustration* when chatting with peers *Relaxation* when chatting with peers *Relaxatio*n during ideating a design solution *Boredom* during ideating a design solution
	C3	*Boredom* when chatting with peers *Relaxation* when chatting with peers *Relaxation* during ideating a design solution *Boredom* during ideating a design solution
D	D1	*Enjoyment* during ideating a design solution *Relaxation* during ideating a design solution
	D2	*Relaxation* during ideating a design solution
E	E1	*Frustration* when chatting with peers *Relaxation* during ideating a design solution in the meanwhile chatting with peers *Enjoyment* during an off-task break *Enjoyment* during ideating a design solution *Boredom* during ideating a design solution *Relaxation* during prepare the presentation
	E2	*Relaxation* while doing design documentation in the meanwhile chatting with peers *Relaxation* during design documentation
	E3	*Enjoyment* in general (without displaying task info)
F	F1	*Enjoyment* in general (without displaying task info)
	F2	*Relaxation* in general (without displaying task info)
	F3	none
	F4	*Enjoyment* during an off-task break

Our findings presented in the following sub-sections are structured as follows. In section 8.4.1, we report students' experiences in detail, first regarding what is shared, with whom, and how. In section 8.4.2, we describe the impact of this sharing episode upon students' DBL experience.

8.4.1. Social Sharing of Task-Related Emotions in DBL: What is Shared, with Whom, and How

Type of Emotions

As shown in Table 8.1 and Table 8.2, students shared both positive emotions (e.g., enjoyment, relaxation, relief, happiness) and negative emotions (e.g., frustration, boredom, sad) during our interventions. This suggests that social sharing of emotions in DBL can occur regardless of the valence of emotions. Related research outside the context has argued that the extent of sharing the intensity of emotions is positively correlated to the intensity of emotions [253]. Future research could explore whether the intensity of emotions has a similar influence on the social sharing of emotions in the context of DBL.

Our findings show that some students shared more emotions more often than others, which to some extent echoes our previous findings as presented in chapter 5 that there exist noticeable individual differences in terms of students' emotional experiences in DBL [250]. We also found that students' feelings (e.g., P5, P6 A1, A2, C1, C2, C3, and E1) towards the same task fluctuated over time, which is consistent with findings in our previous study that examined university students' emotions during DBL [167] (see chapter 6). As the patterns of emotion change can impact our psychological well-being [231], future research should examine more closely how emotions change over time in DBL. Relatedly, tracking emotions associated with task progress has been argued in chapter 6 as a potentially useful approach to take care of students' learning and well-being. Our findings suggest that social sharing of task-related emotions could be an efficient way to support emotion tracking associated with task progress.

Sharing Targets

Our findings in intervention study 2 revealed a clear pattern of students' sharing targets. Students favor sharing with team members than the teacher or the rest of the class, as shown in Table 8.3. A two-way ANOVA repeated measure with a Greenhouse-Geisser correction was conducted that examined the effect of the sharing targets (i.e., team member, teacher, the rest of the

Table 8.3. Students' Attitudes towards Different Sharing Targets (Note: score "1" as "not at all," and score "5" as "very much." Data Source: pre-and post-questionnaires)

Sharing targets	Pre-intervention				Post-intervention			
	Mean	sd	min	max	Mean	sd	min	max
Team members	3.35	1.057	1	5	3.29	.849	2	5
Teacher	1.94	.748	1	3	1.94	.748	1	3
The rest of class	2.24	1.147	1	5	2.35	1.222	1	5

Table 8.4. Frequency of Speaking about the Shared Content (Data source: post questionnaires)

Sharing targets	Reported frequency												
	A1	A2	A3	B2	C1	C2	C3	D1	D2	E1	E2	E3	F3
Team members	3	4	3	5	3	2	5	1	2	3	4	1	1
Teacher	-	-	-	1	-	-	-	-	-	1	-	-	-
The rest of the class	-	-	1	3	-	-	2	-	-	1	5	1	1

Notes: Two students (B1 and F1) were implicit about the exact times they shared. For example, B1 reported he often shared with his team members and often with others from other teams. In the case of F1, he reported he shared with his team members. Another two students (F2 and F4) said that they did not speak with all potential targets about the content they shared.

class), measurement time (i.e., pre-intervention, post-intervention condition), and their interaction effect on students' preference for sharing. Simple main effects analysis showed that the mean score for students' preference over their sharing targets was statistically significantly different, $F (1.756, 28.096) = 20.344$, $p < .001$. Post hoc tests using the Bonferroni correction revealed that students significantly preferred to share with team members than the teacher, $p < .001$.

No significant main effect was found between pre and post-intervention conditions ($p = .791$). As determined by ANOVA, there was no significant interaction between the effect of targets and measurement time ($p = .478$). This finding would suggest that students seemed to have stable preferred sharing targets. Specifically, students' autobiographic data in the post-questionnaire (as shown in Table 8.4) illustrated this clear pattern from the perspective of how often and with whom they speak about the content they shared (displayed by the lamp and task card). Most students appeared to communicate more frequently with their team members (Median = 3) than other targets during this intervention study.

Our findings derived from interviews showed several reasons that were related to students' preference for sharing targets. For example, some preferred to share with team members because they are more comfortable to share with the ones they are close to, just as D1 explained, "*[I prefer to share with the group itself] because that's what you have the most connections with. They are generally classmates and usually friends.*" Likewise, C1 stated that "*I think with my group, also because I have a nice group now, with people I trust. And when you have to do it with the whole class that is quite different, because then it is quite a large group. And yes, with the teacher, I have a less strong bond than with my group.*" Similarly, F3 thought friends or team members would be his ideal sharing targets with whom he feels comfortable sharing feelings. He mentioned, "*With my own group or with my friends […] because there I feel very comfortable to share my feelings.*" Slightly different, E2 claimed she shared more often with her close friend who is from another team, as she explained that "*I was sort of sitting next to another team and my boyfriend was on the other team, so... we were chatting when I finished my job.*"

Meanwhile, some students believed team members are the ones who may also help them to do team works, just as E1 reported, "*I just think with my teammates, because I think they understand what we are doing the most and also because they are often just my friends. They can often help you too.*" E2 also explained this potential benefit from sharing with a team member, "*I could at least show it to my group members if I was frustrated with part of an assignment so* *that they could help me. Yeah, for the rest, it was okay.*" Likewise, B1 emphasized a similar reason as E1, "*[I prefer to share] with the people in the group, so that together we can find a solution to the problem we are then dealing with.*" So does F4 as well "*because they [team members] can then help with what you can do better and what assignment you should do instead.*" Overall, these findings would suggest that students' in DBL prefer to share their feelings with their team members or close friends. This is in line with evidence in a review of social sharing of emotions [253] that intimates were the most often recipients of emotion sharing, while the professional (i.e., teacher) and non-intimates (i.e., the rest of the class) were unlikely to be selected for this role.

Interpersonal Processes of Sharing Emotions: Expectation, Importance, and Attitude

We found there existed an interesting tension during the interpersonal process of emotion sharing. Individual students in the narrator's role who initiated a social sharing episode had varying expectations regarding the listeners' reactions (sharing targets), as shown in Table 8.5. For instance, some students (e.g., A2, B1, C3, E21, and E3) sought understanding from their listeners or simply to be listened to. As some (e.g., B2 and F3) mentioned, they did not even need any reactions other than being understood by their listeners. In contrast, other students expected their listeners to react to their sharing content on task suitability, just as F4 stated, "*That people say: 'okay, then you'd better do this and start doing something like that.'*" Alternatively, students expected extrinsic emotion regulation, which was reported by D1, "*If it is a positive emotion, they say that they will continue to do it in the same way, if it is negative that they try to adapt to make it positive.*" Interestingly, C1 expressed that she favored being understood more than getting annoying remarks "*oh, oh*" from their listeners. More than simply being understood, some students (e.g., A1, A3, C2, D2, E2, and F2) expected help from their listeners. This help-seeking occurs most in relation to the social sharing of negative emotions. These findings could guide future efforts in designing tools to facilitate social sharing interactions. These also suggest the need to investigate best practices to guide emotion sharing and minimize unhelpful emotional communications (e.g., annoying remark or joke that does not help regulate negative feelings or being understood) between the narrator and listener.

Table 8.5. Student's Expectation from Their Listeners during Sharing

Theme	Quotation Examples
Understanding and listening	*I think maybe people will understand feelings better or something like that.* (E1)
	That you understand each other better, so to speak. Understanding, yes. (E3)
	Understanding. They understand that I feel this way, and they will try to do something about it when I feel bad. (B1)
	I just think that they accept it, and if they don't like it, they will look for a solution, they can do something else or something. (C3)
	Just that they do what I ask, and yes, I don't need sympathy everywhere or anything, just that they listen. (A2)
	Well, mostly that they understand it and just like that [...]. But for me, there does not really have to be any reaction because it is often already good. (B2)
	It does not really matter to me [to receive a response or not], but for me, it would be best if they also have such feelings. (F3)
Response	*I like it when people can just react and not say, gosh, now you feel this way, and then I know they will make a lot of annoying remarks or so, but it would just be if they then know about okay... yes, that's how you are made up, that's how you feel now, you know, and that they just accept that.* (C1)
	That people say: okay, then you'd better do this and start doing something like that. (F4)
	If it is a positive emotion, they say that they will continue to do it in the same way; if it is negative, they try to adapt to make it positive. (D1)
Help	*I would most prefer that they actually help me, even if it doesn't always happen. I know that very well.* (D2)
	Well, just that people understand and that they can help you if you need it and if you don't need it just... that you are left alone so that you can work well. (C2)
	Well, that depends on what kind of feeling it is, of course. I usually think that somebody just comes, for instance, yes, to help with something and yes, well mostly that. (A1)

	Just, I think, a calm reaction and just a, yes, just that someone wants to help you. (A3)
	I would prefer that, preferably the reaction that they're just okay with it and that they're going to help me. (E2)
	Not that people are going to respond super weird or anything like that. Just, they usually find it just fine to do; usually, they help or that. (F2)

On the other hand, students who can potentially be listeners in such a sharing process valued the importance of sharing content differently, as shown in Table 8.6. Many students particularly appreciated negative emotions (e.g., frustration, stress, boredom, anger, confusion, etc.) or cases (e.g., group conflict or negotiation) that may elicit negative feelings as most important information more than positive emotions in a sharing episode. It could be because negative emotions often fuel verbal exchange and social communication [253]. It also seems to be common in the collaborative learning environment of DBL to unfold problem-oriented regulation through social interactions (e.g., offering and receiving help). For example, sharing a feeling of "frustration" seemed to be taken as a signal of seeking extrinsic regulation.

Positive emotions (e.g., relaxation, enjoyment) functioned as a signal for affective temperature checking within the team. Still, few students valued the importance of sharing positive emotions in DBL. Results from interviews suggest this may be because students only experienced minimal conversations when sharing positive emotions compared with sharing negative emotions. However, previous research suggests sharing an experience of joy was rated as more pleasant than sharing negative emotions [253]. Future research could closely examine the relationship between students' satisfaction with the DBL experience and the social sharing of positive emotions.

Interestingly, students' self-assessment on task suitability was also regarded as important information to share along with emotions. Progress tracking and self-assessment (e.g., assessing and reflecting on failure or success) per se have also been shown as emotional situations in DBL [167]. Our findings would suggest that future research could foster students' assessment and discussion of task suitability within the team in DBL to enhance their reasoning and reflection regarding positive and negative feelings in the learning process.

Table 8.6. Student's Perceived Importance in Sharing Content

Theme	Quotation Examples
Negative emotions	*I think mostly "frustrated" and "stressed." I think they are two... or "bored" as well, because if, for instance, there is something to be done and you are bored, then someone else can, for instance, see that and then explain to you what there is still to be done or so.* (A1)
	Well, it's important if you say if things aren't going very well or if you're feeling very frustrated, then you can think of a solution. But that's actually it. For the rest, it doesn't really matter to me. (D2)
	For example, if I am frustrated by the boys, we will do it differently because if you are frustrated, that is not very nice. (C1)
	If you are frustrated or something, others can help you with that, or if you just say panic and don't know what to do, you can indicate that, and then the other person knows that he can help you. (A3)
	Often frustration, because then something does not work or if I get a bit stuck and then yes, that is also why they often know how to help me further because then we are busy with a [task / certain something]. (E1)
	I would just say it if I am frustrated. If I am angry or something that I say: yes, that's just there. That they should be quieter, or, whatever it is, that they do that. (A2)
	If, for example, you don't understand something, that's not an emotion, but a confusion, if you... yes, that would be nice to show because you can ask for help and so on. (C2)
	I think, especially if you have a collision, then you understand each other better. (E3)
Positive emotions	*And if you are just relaxed, then the group of okay we are doing well now, and then they can do it again next time.* (C1)
	If they are relaxed or want to be left alone, you can just leave them alone. (E2)
Task suitability	*Whether that assignment suits you to make, because you think: I'm better at it. For example, I am better at writing a report, while then at the same time you could go and do something else.* (F4)

	I think especially if you... don't feel like it, or if you don't get on with your assignment so someone can help you. (E2)
	If you really don't feel comfortable with something you have to do or something, it is useful to share. Someone else might be able to do it instead. Still, if you just feel comfortable, I don't necessarily think you have to share or something. (C3)
	Especially how you think that things go in the group. (D1)

8.4.2. Impacts of Social Sharing of Task-Related Task-Related Emotions in DBL (RQ3-c)

Overall, we found that most students are positive about socially sharing task-related emotions in DBL. For example, we received responses from seven participating students regarding their attitudes towards social sharing emotions versus keeping them private after intervention study 1. Six out of seven students expressed that they prefer to share their task-related emotions instead of keeping them private. This result suggests a clear preference for sharing emotions over keeping them private. Besides, we conducted a paired-samples t-test to compare students' preference in this regard before and after the intervention study-2. No statistically significant difference was found in the scores before (M = 3.18, SD = 1.074) and after (M = 3.41, SD = 1.004) the intervention; t (16) = -.940, p = .361. However, both scores are higher than 3, suggesting that students in the second intervention were generally positive about the social sharing of feelings. The alleged reasons for their propensity to share emotions displayed a consistent pattern across our two interventions. Our findings suggest this mostly includes (a) using the emotion sharing tool facilitates sharing emotions, (b) positive influences of sharing an emotional episode, e.g., strengthening an understanding and a social awareness, adding additional value to the teamwork, etc.

There seemed to be no statistically significant influence of social sharing on students' motivation to take the DBL course. Students' scores for each sub-scale interest/enjoyment, competence, perceived choice, pressure/intense, and relatedness were compared before and after the intervention study 1. Overall, the Wilcoxon signed-rank test indicated that this difference was not statistically significant per sub-scale, as shown in Table 8.7. On average, we found students' relatedness towards others in this online DBL course was slightly higher after the intervention. This might be affected by the group chat channel in Microsoft Teams, while substantial evidence was still lacking to support this potential association. On the other hand, slightly decreased students' interest and increased somewhat pressure was founded after the intervention. We expect this may be a result of remote learning during the pandemic period.

Table 8.7. Students' Motivation for Taking DBL Course before and after Intervention Study 1. (Score "1" as not at all, "5" as very much; measured by adapted IMI questionnaire)

	Pre-intervention		**Post-intervention**		**Wilcoxon signed test**	
Sub-scale	Mean	sd	Mean	sd	Z	*p*
Interest/enjoyment	3.73	.61964	3.60	.68132	-1.065	.287
Competence	3.22	.50288	3.32	.56725	-.656	.512
Perceived choice	3.24	.46952	3.28	.78429	-.483	.629
Pressure/intense	2.48	.61246	2.66	.79470	-.770	.411
Relatedness	3.95	.59861	4.08	.29659	-.715	.475

Importantly, we found that the impacts of social sharing of task-related emotions in DBL reflected the aspects described below.

Gaining Social Attention and Awareness

The social sharing of task-related emotions in DBL enables students to gain awareness of others' internal states. The ambient display of the lamp helped students notice others' feelings, just as E2 stated, "*[I did notice] when I went downstairs to get something out of my classroom, and I came upstairs, and everywhere in the classroom I just saw blue lights shining. So, I thought that was funny.*" E2 further reported he felt more connected with the rest of the class due to gaining social awareness, "*you could see how everybody felt, and you could help them with that, and because of that, you feel connected, because you know how they feel.*" Specifically, C2 commented this sharing experience helped her notice others' feelings, contributing to the information exchange. She said, "*In normal life…you don't really see what someone is thinking, what someone is feeling and so on, and you see that better now […] Well, you know, if you're really busy, then your teammate doesn't have to ask, 'what are you doing?'. You can tell by the card, and you won't be distracted. Then you can just keep working.*" E3 also mentioned this useful feature of gaining awareness "*you can understand each other better, I think. […] it helped that class to understand each other better.*" Besides, this social sharing also enables students to gain self-awareness, just as A1 stated, "*It [a sharing experience] can be very useful in an assignment and a project, and it can also be very nice to see how others feel and how you, yourself, feel with a certain task or* *so.*" In the case of E1, he explained this experience of social sharing task-related emotions made him self-aware of his feelings and tasks, "*I'm normally very sensitive. I'm always like 'are you okay?' or 'how do you feel?', but that wasn't really the case yesterday, maybe because, with that lamp or something, that it was clearer then […] perhaps I, myself, get a bit of an idea of what I actually do in a lesson.*" This finding is consistent with our previous findings; as presented in Chapter 7 [274], self-tracking emotions in DBL facilitated students' emotion awareness.

Besides, we also found that students appreciated this sharing experience, which enabled students to gain social attention from their sharing targets, just as F2 stated, "*I actually like it to let the rest know a bit whatever I think.*" Specifically, B2 liked to let others easily notice what made him uncomfortable, "*it is easier, that it happens more often because it is much easier to put the lamp on than let others know that you find something annoying.*" Similarly, E1 also appreciated gaining social attention from others enabling others to take his feelings into account. He said, "*I think people can understand you better, that you can get stuck in your work or something like that and think along with it, that you can also take into account yes, I am stuck there, maybe we can give that task to somebody else who knows a bit more about it or knows something about it.*" Interestingly, F4 expressed that being able to gain social attention from others as a result of our intervention would be especially helpful for students who found it challenging to recognize others' emotions. He explained, "*That [being able to share and see other's feelings] is nice, but it's normal too. I think that some people find it more difficult to distinguish feelings from others and that you have to learn to indicate them better, but it's nice that you can see each other's feelings so easily.*". Likewise, C3 pointed out another scenario that being able to gain social attention from others would be helpful for students who are shy about sharing emotions, "*It could help, but for me, it doesn't really matter that much. Maybe if they are not so open or so open, they find it more difficult to tell [their emotions]. And if everyone is with a lamp that makes it easier for them to see or so.*"

Arousing Emotional Relief

The interview with E1 suggests that this sharing behavior seemed to arouse a subtle emotional relief. For example, he mentioned that his frustration was solved by talking to the team members about it, "*yesterday [we] had a bit of frustration towards each other, because we came up with some sort of recipe and when certain ingredients that didn't match what everyone had in mind. We saw that too, on the poster we had made, we thought: 'it is not correct at all,' but it was correct according to the person who had made it, and that was all a bit of* *frustration, but that was just solved - so to speak. The frustrations were turned into a relaxed vibe, so to speak.*" Our observation revealed sharing emotions through our toolkit per se may be a channel to vent feelings. This has been observed in the case of C2. At that time, she looked around the room without doing anything and leaned her head on her hand, then she started tapping the lamp (on-off-on-off-on-off) and switching its colors around. After all this, she turned the lamp to the color of boredom.

Developing Conversations

We found sharing task-related emotions via our toolkit sparked conversations between students and their sharing targets. For example, there developed discussions relating to the planning of their tasks, just as C1 reported, "*she [team member C2] said for a moment she thought of: 'oh, we have to do something else now… Actually, what I did after that [sharing with C1] just keeping working on what I was doing and sometimes make a comment to another like 'yes it's nice that you see that way or so.'*" Another example of conversations that developed between students and their targets is related to explaining why students had such feelings; as A3 mentioned, "*It was just... just a pretty normal reaction. They asked "why?" and they just helped me and explained what to do.*" Likewise, B1 also stated this similar conversation, "*the lamp was on, and everyone could see it. And if I were then angry or unsatisfied, then people sometimes asked why that was the case.*" In addition, C3 expressed she liked the response she received during her conversation: "*we thought it was funny to have a little look and try it out or something and then talk about it like: 'Oh, now I'm bored,' and then someone said 'yes, I don't think it's very interesting.'*"

We also found this phenomenon of developing conversations from our classroom observations. For instance, one related episode was observed in team C. C3 set her lamp to the color of frustration, and C2 set it to the color of relaxation. Quick after about two minutes, C3 and C2 put the lamp on the color of frustration and started to talk about what they were annoyed about (the annoyance concerned the project groups). Another observed conversation episode in team C was with the teacher. C1 was standing and looked a bit 'overwhelmed' (which was suggested by the silence and her facial expression). The teacher noticed the color of frustration on her lamps and came to ask her what is going on. C1 switched to relaxation after talking to the teacher about her frustrations and possible solutions for this frustration. In this observed episode, C2 also joined the conversation with C1 and the teacher. However, there seemed not to be the same emotional relief of transforming from frustration to relaxation in C1. During this interaction, C2 seemed bored since she started turning the lamp around, passing all the colors, and finally retained the color of frustration (displaying the red light).

Similarly, our observation suggests the social sharing of task-related emotions triggered conversations for E1. He sat alone working on the design documentation, and his lamp was set to the color of relaxation. Sometime later, he walked to his teammates and complained about being bored. After saying some things to his teammates, he walked back and switched his task card to 'review others' work.' This task seemed to make him frustrated since he soon changed his lamp to the color of frustration. He again walked to his teammates to initiate a chat, as demonstrated by his task card 'chat with peers.' His body language suggests that he discussed what was frustrating him with his teammates. After this chat, he walked back and switched his lamp back to the color of relaxation.

Stimulating Various Level of Help

More than having a conversation, some students explicitly reported that such sharing behavior invited various levels of help. For instance, A1 said he received a reaction from her team member after sharing her task-related feeling, "*I was working on an assignment with one team member at the time, and then at some point, I did not understand something, so it kept going wrong. But then he just explained what I had to do. Then it was like 'okay, yes,' it was quite an easy assignment in itself.*" Specifically, A1 explained her overall feelings regarding sharing and how this sharing may stimulate help, "*if I'm really involved with something. I share it; it feels good because you know that others then at least know. Well, I, for instance, have a very important task or something and I really don't know what to do with it, or I really get stuck with it. So, I am stuck with it, then it is very nice if you can tell it and if you know that your teammates and at least your teammates know because then they might, for instance, be able to continue with their own task or something, then they might be able to explain or work together or something like that.*"

Similarly, A3 also reported that her teammates helped her and explained what to do after emotion sharing. A3 further commented that such sharing is helpful, "*I think it helps, and you should do it.*" Especially, E1 mentioned he received tips on how to proceed with his task, "*I often get further help just or 'oh yes, go and do something else, then we'll do this' or 'we should have done it this and that way.' Or I'm going to help you or something.*" Likewise, E2 reported receiving help and support as a reaction "*one person who helped me and the other who 'supported' […] E3 went to help me look for the information I needed because I couldn't find it. In the end, we had found it together. And E3 said: 'Oh, you can do* *that.' Yeah, well. And then we succeeded."* Besides, an observed episode illustrated how emotion sharing could trigger the teacher to help, as in the case of D2. At that time, D2 had his lamp set to the color of boredom and looked upwards and singing while not participating in the teams' discussion. The teacher noticed that; he walked over and offered help. After receiving support from the teacher, D2 switched his lamp to the color of enjoyment.

Some students valued this sharing experience enabling them to receive help from others. For instance, C1 said, *"I thought it was very interesting, something different, let's say than normal, because you share a bit more, sort of, with the group. And I don't know exactly what others think about that. But I thought that if they can then see how you feel, maybe they can do things differently, or things might be nice."* E2 also expressed a positive comment on his past sharing experience, *"I could at least show it to my group members if I was frustrated with part of an assignment so that they could help me."* D2 mentioned the lamp and task card created awareness and timely signal for help-seeking, *"That people who have problems with the assignment, can be helped more quickly [...] people who are good at a certain subject can be the ones who help with that."* Other students liked this sharing experience enabling them to offer help to others. For example, B1 stated, *"I think it was useful that the others could also express their feelings well because then you could help to come up with a solution if it was bad."* C1 reported an episode in which she helped her teammate, *"sometimes I help her to see what she's doing and then I see that lamp, say, with 'boredom,' and then I try to help."* F4 valued this sharing behavior and argued that it could encourage students to help each other and understand others' behavior better, *"it's nice that you can see each other's feelings so easily. Because then you can help someone and otherwise someone runs away or something. And then you don't know why he is running away or that he is doing something or that he is bored."*

Strengthening Team Cooperation

Interestingly, some students especially commented on how this sharing may strengthen teamwork, which is in line with finding a recent study [275] that sharing emotions contributes to collaborative problem-solving regulation. For instance, E2 stated that social sharing of task-related feelings helped him progress in his project, *"[The result is] that the project went faster. Because if I hadn't, I wouldn't have had any help, and it might have taken longer."* A member of team E also mentioned that emotion sharing helped them resolve disagreements aligning their views on a subject. F4 envisioned the reactions he received, which may help the division of teamwork, *"[For instance, the reactions I got were] 'Then you'd better start doing something like that, and I'll do* *the assignment.' [As a result of this sharing experience], you can then continue to work together by knowing whether or not the assignment suits him or her."* In particular, F4 explained why he had better team cooperation from this sharing experience, *"if you share feelings with each other then you understand better what they are doing and then you can make better use of each other's qualities. If someone says I can't write a report, then you can say: okay, I can write a report, then look with you, can I help you or do you sketch, because I'm better at writing reports and I have to sketch, that's my job now... I think it's easier to talk about it if you share emotions with each other."*

8.5. Discussion (RQ4-c)

The two reported intervention cases were encouraging regarding the social sharing of task-related emotions. We found a clear pattern of students' sharing targets that they favor sharing with team members than the teacher or the rest of the class. Besides, results showed an interesting tension during the interpersonal process of emotion sharing. The type of emotions an individual experiences and the intimacy with others influence this interpersonal regulation process and play a vital role in bringing about this tension. Furthermore, our findings illustrated multiple functions of sharing task-related emotions in DBL, including (a) it gains social attention and awareness, (b) it arouses emotional relief, (c) it develops conversations, (d) it stimulates various levels of help, and (e) it strengthens team cooperation. Overall, this paper contributes to our understanding of how such sharing behavior has the potential to support collaborative learning and subtle emotion relief in DBL and points to implications for the design of tools and interventions.

Despite the fact that many ways can be used for sharing emotions, spontaneous narrative sharing (e.g., in everyday routines or on social media) may be insufficient to fuel the cognitive route which promotes the narrators to re-work on their frustrating goals and thus achieves emotional regulation. As an illustration, in an empirical review of social sharing of emotions [253], it has been shown that its relieving effects from responses (e.g., offering empathy, comfort) towards a sharing content involving negative feelings may be temporary if it lacks cognitive contribution. Especially for learning scenarios, there are many opportunities for sharing situations provided by professional intervention to contribute to emotional regulation. For example, future research could develop professional interventions in which, e.g., students are instructed by strategies for sharing emotions in learning and responding to others' sharing content. Future intervention research could also focus on enabling teachers to, e.g., create a caring classroom culture or moderate students' social sharing of emotions within student teams. An earlier prototyping intervention [95] (which lasting seven hours) describes how middle school students (grade 5-6) in the US were taught the process and fail-forward mindset of iterative prototyping. The results of this study demonstrated how this "fail-forward" mindset can promote healthier reactions to failure in DBL. Self-evaluation on failures or successes can often elicit emotions in students [167]. Future research may also consider developing an intervention that fosters healthier reactions to failure in DBL to facilitate students' emotion regulation.

The social sharing of emotions in learning has received inadequate attention so far. This social sharing behavior may be beneficial for emotional regulation and bonding between peers or teachers, lacking during the pandemic situation, especially in online education. Our results suggest that expressing and sharing in both online and offline contexts of DBL seems essential for students and actionable in education practice. Although one study [276] showed that Flemish adolescents mostly prefer to share emotions face to face, a body of literature (e.g., examples in section 8.2.2) has illustrated the affordances of technologies for sharing and expressing emotions. Technology-employed intervention fits the requirement of a remote learning situation well during the pandemic situation when everyone has to keep social distancing. Technologies such as ambient displays [268] may help. Our study 2 adds to the research line on Fireflies, where the devices are seen as a distributed ambient display in the classroom space, which the teacher can use to guide their interactions with the class [267]. So far, various things have been tried with FireFlies (e.g., providing feedback on how much proximity students have received from the teacher or students' learning progress in learning software). However, sharing emotions had not been tried before, while it can be meaningful and actionable information to promote peer awareness of learners and personalized interventions of teachers. It is still crucial for researchers and practitioners to consider technology-employed design intervention even in the post-pandemic period. Technology is evolving incredibly fast nowadays, and many believe technology is helping future students embrace the new learning methodologies.

Specifically, we argue that there are many opportunities to develop a **related tool** for sharing DBL emotions. First, we would suggest related tool development consider the *flexibility* of what is shared (i.e., type of emotions, specify contextual information: e.g., involved tasks) in learning situations. For instance, our findings suggest many students valued the importance of sharing negative feelings. It is not saying that the social sharing of positive emotions is meaningless. Rimé [253] has argued that social sharing of positive emotions is a good way to achieve capitalization and is beneficial to those who have a similar experience. Some participating students in our research mentioned that self-assessment on task suitability is also vital information to share. Future efforts should pay attention to balance the degree of sharing and consider the trade-off of greater openness to sharing content. Second, we would suggest related tool development consider how *public* social sharing of emotions should be. As discussed in a design framework [269] (which focuses on supporting social communication and interaction in the design of awareness system), one key design consideration is pertaining to the information relevant to a group of connected individuals forming one's social community. Not surprisingly, adolescent students in our research prefer to choose their teammates or close friends as sharing targets. Future work could start with developing tools for using in a small team and exploring the possibilities for being used across teams if students favor remaining their existing links to friends in other groups. A previous work [277] argued that social visibility is an important dimension to be considered in designing real-time teaching argumentation tools for classrooms within a secondary education context, given that a shared awareness may introduce a risk of undesirable social effects. Future research could also explore the impacts of displaying emotion-related information anonymously or in a low-resolution manner across teams. Third, we would suggest related tool development consider the *modality* of how sharing content is displayed (e.g., implicit or explicit format of displaying). Implicit displaying has an advantage concerning gaining information unobtrusively during collaborative learning [245], while explicit displaying might serve as a meta-cognitive prompt that helps them reflect on their internal feelings and the task in detail. Future work may consider the *modality* of sharing when considering the sharing targets (*publicity*) and sharing content (*flexibility*). For example, shared content may be displayed explicitly to prompt a timely reaction. In contrast, content with a lower priority could be displayed in more subtle and private ways. Another approach would be to support different degrees of sharing emotions for different users, e.g., more explicit information for the more intimate social contacts (e.g., teammates or close friends). In contrast, one could display information in a more concealed and private way for users in a broader social circle. Future research could also explore the impacts of showing anonymized or low-resolution information about emotions across teams, or showing their own historical emotion data regarding a same task.

The reported intervention studies are the first exploration in this area, and three limitations to the current studies are important to note. First, this research may suffer from self-selection bias, as students who agreed to participate in this study may be particularly willing to disclose their emotions and socially share an emotional experience. Second, our study might also be affected by reactivity with individuals sharing emotions because they might feel they are expected to. This may even be seen as social desirability bias [278], with students sharing positive emotions to appear more appealing to researchers and the teacher. Third, the two intervention studies were implemented within a short period, in which students did not yet experience a full range of DBL tasks. To address these limitations, future research could replicate this study for a more extended period to investigate factors facilitating emotion relief and emotional regulation in DBL could be studied. Students experience task-related emotions and social emotions (i.e., emotions related to teacher-to-student and student-to-student interaction and group learning). It would be interesting for future research to explore the sharing of social feelings in DBL.

8.6. Summary

Despite the fact that the social sharing of emotions is beneficial for emotion regulation, this aspect has not been considered in DBL research yet. To investigate how to facilitate this social sharing of emotions during DBL, we set out to explore and evaluate two intervention studies conducted in a public high school during the pandemic of 2020. We analyzed data collected through questionnaires, observations, and interviews. Results revealed that students are positive about social sharing their task-related emotions; the tool used for sharing emotions and responses students received during such a sharing process may be associated with this propensity. We found a clear pattern of students' sharing targets that they favor sharing with team members than the teacher or the rest of the class. Besides, results showed an interesting tension during the interpersonal process of emotion sharing. The type of emotions and how intimate with the person during this interpersonal regulation process may play a vital role in bringing about this tension. Furthermore, data from interviews and classroom observations illustrated multiple functions of sharing task-related emotions in DBL. As the first exploration in this area, this chapter contributes to our understanding of how the sharing of task-related emotions influences students' DBL experiences.

Chapter

NINE

Conclusion

Chapter 9: Conclusion

Abstract: The research reported in this thesis has explored the emotional facets of DBL, aiming to understand how to support DBL by considering the emotions that students experience. This thesis has addressed the following research questions: (1) What is a suitable tool for capturing students' emotions in DBL? (2) What are the affective DBL components that influence emotions? (3) What are the impacts of emotions and emotional awareness on DBL? (4) How can we support DBL by considering students' emotions? The conclusions regarding these questions are as follows: (1) a tailored tool for capturing emotions in a DBL context needs to refer to a clear concept of emotion and a consistent DBL framework. To illustrate how to address the challenges of capturing emotions and their context during DBL, we developed three possible tools. (2) We found lists of components that elicited students' emotions and introduced the Activity-and-Affect Model of DBL for describing how these components independently impact students' emotions. (3) Emotions in DBL have both positive and negative impacts on students. Self-tracking emotions in DBL facilitate students' emotional awareness. Social sharing of task-related emotions has the potential to support collaborative learning and subtle emotion relief in DBL. (4) We propose guidelines for orchestrating DBL activities in practice and several design considerations for designing related emotion awareness and emotion sharing tools. Overall, this thesis contributes to the intersection of Child-Computer Interaction and Learning Sciences fields, and in particular, to the sub-field focusing on design and making in learning. The main limitation of this research concerns the limited generalizability of the findings and of the age of participants. Future work could detect emotional aspects of learning from multimodal data collected using emerging technologies and design and evaluate how affective technologies could become incorporated into a positive psychology intervention.

9.1. Introduction

Motivated by the notion that emotions greatly influence the learning process, this thesis has investigated how students experience DBL through the lens of emotions using a design-based research approach [66–68]. First, we conducted a systematic literature review to capture the state-of-the-art in this field (Chapter 2). Meanwhile, we carried out an exploratory field observation involving students from a Dutch public high school to understand what role emotions play during DBL in current practice (Chapter 3). Both collected theoretical and empirical evidence thus suggests the need for tools for collecting emotion data in the context of DBL. Therefore, we developed a self-reporting tool (EmoForm) following an experience sampling approach tailored to the DBL environment (Chapter 4). This tool was used in a three-month mixed-method field study involving students from a Dutch public high school to gain an in-depth understanding of how students experienced emotions during a DBL course (Chapter 5). As a follow-up, we conducted a qualitative case study involving third-year undergraduate students at a Dutch university to examine learning and emotions during DBL in a post-secondary education context (Chapter 6). We implemented an intervention study in the same research setting, using EmoForm as an emotion awareness tool. This intervention explored how emotion awareness facilitated by a tool such as EmoForm influences DBL (Chapter 7). Finally, we conducted an intervention (which was evaluated in two case studies) in a Dutch public high school, using Microsoft Teams ® and a tangible toolkit to encourage students' social sharing of task-related emotions. These two studies examine how important the social sharing of task-related emotions can play in DBL and what design considerations of related emotion-sharing tools in the DBL classroom (Chapter 8). See Figure 1.1 to gain an overview of how these chapters address the four main research questions in this thesis.

In this present chapter, we summarize the main findings to research questions (section 9.2), outline contributions of all the presented works in this thesis (section 9.3), discuss the limitation of this research and implications for future works (section 9.4 and 9.5).

9.2. Answers to Research Questions

The research reported in this thesis has explored secondary school students' (aged between 12 and 15) emotional experiences and extended to a post-secondary education context (with 3rd-year undergraduate students). All the field studies presented in this thesis were conducted between 2016 and 2020 in the Netherlands. This research aimed to answer four research questions, which we recap below along with our findings.

9.2.1. What is a suitable tool for capturing students' emotions in DBL? (RQ1)

In Chapter 2, we reviewed state-of-the-art regarding how students' emotions were measured in DBL. We found that questionnaires, interviews, observations, and video coding are frequently used to capture students' emotions in DBL literature. However, we also found that current DBL studies appear loosely connected and highly fragmented. They refer to different conceptions of emotion, and many just treat emotions as a part of an overall post-hoc evaluation of a DBL activity. Furthermore, we realized how across these studies, observational and interview data have been analyzed without referring to a clear and consistent theoretical framework of DBL. From this literature review, we concluded that it is of considerable interest to develop a tailored tool for capturing emotions in a DBL context. In Chapter 3, an exploratory field study helped identify several challenges pertaining to measuring students' emotions in the DBL classroom. For instance, data collected from self-reports may suffer from a social desirability bias, or that repeated self-reporting measurement may interrupt students' learning flow.

Motivated by the insights from Chapters 2 and 3, we argued that there is a need to triangulate DBL emotion research findings by combining self-reporting with other sources, e.g., observational or psychophysiological measurement. Chapter 4 presented the EmoForm that is a questionnaire designed for repeated application at the end of each lesson throughout an entire DBL project. The EmoForm was intended to capture information regarding students' achievement emotions, engagement, and the DBL activities these emotions pertain to. The EmoForm, combines self-reporting, retrospection, and experience sampling strategy to address the challenges of capturing emotions and their context during DBL. Based on an evaluation study, we believe that the EmoForm is reliable and can help map how DBL activities contribute to students' emotional experience. Next to the EmoForm, we proposed the EmoLens and the EmoWatch, which are another two ways for capturing emotions in the context of DBL, based on the same emotion theory and DBL component framework as the EmoForm. These concepts illustrate different possibilities for capturing emotions in the DBL context but were not further developed or used in this thesis.

9.2.2. What are the affective DBL components that influence emotions? (RQ2)

Chapter 2 showed how to describe a DBL project based on a general curriculum development framework [58]. We identified eight components that influence students' emotions in the reviewed studies, e.g., *content*, *learning activity*, *teacher's role*, *grouping*, *materials and resources*, *assessment*, *aims and objectives*, and *time*. Furthermore, the results of an exploratory study in Chapter 3 reported a few components (e.g., *content, learning activity, teacher's role, grouping, materials and resources,* and *time*) which are consistent with the findings in Chapter 2. Overall, we found the evidence of specific incidents involving students' associated negative emotions is limited in current studies. As argued in Chapter 2, one possible cause may be that published studies consider emotions at a macro-level, perhaps overlooking individual DBL episodes during the process.

Following up, we conducted a field study as presented in Chapter 5 to develop a fine-grained understanding of the DBL process (e.g., how DBL activities unfold in the classroom) and the students' associated emotional experience. To reconstruct the dynamic processes of DBL activities, we zoomed in on some of the DBL components to examine the student's dynamic engagement and interaction with the tasks and other individuals during DBL. We thus refined the DBL description with situational information pertaining to four interdependent aspects: *the learning activity*, *the grouping strategy*, *the social interaction*, and *the temporal aspects of the learning task*. Based on this study's findings, Chapter 5 introduces the Activity-and-Affect Model of DBL, which describes a student's emotional experiences of DBL activities along three dimensions: *the task*, *the task strategy* (i.e., multitasking vs. single-tasking), and *the collaboration strategy.* Elements in all these three dimensions interdependently impact the student's emotional experience.

Extending this research to a different student demographic, the study presented in Chapter 6 examined what aspects of DBL that university students perceive as the most effective for learning and the emotions these DBL aspects evoke. We conducted a thematic analysis of in-depth interview data obtained by university students participating in a DBL course. The results demonstrate nine essential elements that influence students' emotions, including, e.g., *novelty versus uncertainty*, *relevance*, *feedback*, *progress assessment*, *social interaction*, *collaboration strategy*, *task strategy*, *design process*, and *time management*. These findings recognized specific elements presented in the proposed Activity-and-Affect Model of DBL and add two more aspects (i.e., *novelty versus uncertainty* and *relevance*) that are influential in students' DBL experiences.

9.2.3. What are the impacts of emotions and emotional awareness on DBL? (RQ3)

The literature survey of Chapter 2 found relatively little evidence regarding the impact of emotions in DBL. For example, enjoyment was found in one study to have no significant effect on a student's intention to join similar activities in the future, whereas happiness had a positive impact and anxiety negatively affected. Students' situational interest in another reviewed study was found to be correlated with excitement, curiosity, and frustration. The exploration study of chapter 3 found that two students claim that enjoyment facilitated their learning during minds-on activities but did not find similar evidence for hands-on activities. Generally, pride and elation were found to have a positive influence on students during DBL.

Chapter 6 extended our investigation into the impacts of emotions in DBL. It also showed the positive effects of emotions experienced in DBL, e.g., increasing motivation or confidence in doing something and easing tasks or enhancing memory. Several negative impacts of emotions were found, e.g., disengaging or demotivating in doing something, lowering the quality of work or triggering errors, and not learning. In particular, Chapter 6 suggested that frustration can have a complex impact. For instance, students' frustration about tasks in DBL fueled their motivation, while frustration about a group conflict was found to demotivate learning.

Slightly differently, Chapter 7 examines the impacts of self-tracking emotions during DBL in which we use EmoForm as a tracking tool. Overall, we found self-tracking with EmoForm facilitates students' emotional awareness. This was manifested in three ways: (a) it encouraged communication and accountability of students' internal states; (b) it increased students' awareness and understanding of self, and (c) it stimulated behavior change.

The study presented in Chapter 8 explored the impact of sharing task-related emotions upon students' learning experience. Chapter 8 documents two design interventions in which different ways of sharing task-related emotions using the chat channel of Microsoft Teams® and the FireFlies as a probe tool correspondingly are evaluated. The social sharing of task-related emotions in DBL impacted learning in the following ways: (a) it helped gain social attention and awareness; (b) it aroused emotional relief; (c) it developed conversations; (d) it stimulated various level of help; and (e) it strengthened team cooperation.

9.2.4. How can we support DBL by taking into account students' emotions? (RQ4)

A list of instructional practice guidelines (as seen in Table 2.9) was derived from the literature survey of chapter 2. These guidelines suggest ways of designing DBL activities to foster a positive emotional response in students. Chapter 5 introduced the Activity-and-Affect Model of DBL and envision this model will help educators and students understand and communicate their involved activities and associated emotions.

Chapter 7 discusses three design principles for developing emotion awareness in DBL. These design principles are as follows: (a) support emotion-oriented awareness by differentiating and quantifying emotions; (b) provide DBL situational cues for awareness by documenting involved activities and collaboration; (c) enable learning performance awareness by self-rating perceived concentration and learning.

Chapter 8 discussed three design considerations to guide future tool development that facilitates social sharing and communicating emotions in DBL. First, tools should ensure flexibility regarding what is shared (e.g., type of emotions, specify contextual information, e.g., involved tasks). Second, we suggest related tool development could consider how public social sharing of emotions should be. Third, we would suggest related tool development consider the modality of how sharing content is displayed (e.g., implicit or explicit format of displaying). We especially point out specific directions in which future work may consider the modality of sharing when considering the sharing targets (publicity) and sharing content (flexibility).

9.3. Summary of Contributions

The works presented in this thesis contribute to the intersection of Child-Computer Interaction (CCI) and Learning Sciences (LS) fields, particularly to the sub-field focusing on design and making in learning. Besides, this thesis extends a large body of research on emotions in learning into the field of DBL. In past research, the descriptions of emotions experienced in DBL is too coarse-grained (as described in Chapter 2 [152]). For example, DBL studies have often dealt with assessing affective aspects of DBL and often treating students' emotions as an outcome measure regarding their engagement.

There has been a little explicit emphasis on the role of emotions in DBL, understanding what they are, and dealing with them. While there exists an early attempt [93] that closely investigates how students' achievement emotions during DBL, this work is still insufficient for guiding researchers and educators in how to support students' emotions in DBL because this does not propose a clear strategy for intervention. An important exception is the Control-Value Theory of achievement emotions by Pekrun (cf. [51,52]) that outlines an integrative approach to research emotions in education, which has been previously applied in various learning contexts (e.g., game-based learning [279], learning mathematics [147] and sciences [280]). Specifically, this theory provides a social-cognitive perspective accounting for how emotions are elicited (e.g., the antecedents and effects of emotions experienced in academic settings) and possible regulation strategies (e.g., regulation and development of achievement emotions). However, this valuable work has not been extensively applied in the DBL context yet, which leaves questions largely unanswered as to how students' emotions relate to

DBL contextual factors (e.g., design process, learning from trials and errors) that are underrepresented in a traditional learning environment. This also requires a further investigation considering how emotion regulation strategies are malleable to the DBL environment.

In short, current literature does not suffice for guiding researchers and educators in how to understand and support students' emotions in DBL. This mainly because their description of emotion is too coarse grain, does not relate to the DBL components, and does not propose a clear intervention strategy. This thesis has addressed these shortcomings by examining measurement techniques, proposing the Activity-and-Affect model of DBL, and designing and evaluating emotional awareness interventions in DBL. To summarize, this thesis makes four main contributions:

- This thesis details a fruitful investigation of students' DBL activities and associated emotions, which advances our understanding of emotions experienced in DBL. Findings such as the role of emotions in DBL and emotions varied in different design phases could inspire future research on potential educational problems during the learning and designing processes that need to be tackled. Emotions so far have received inadequate attention within LS and CCI. This thesis explicitly argues how important the emotional aspects of learning can play, which encourages future researchers to contribute.
- This thesis contributes to the conceptualization of DBL activity. While some DBL frameworks, e.g., [25,281], have been previously used, no prior work has formalized a model for describing students' emotional experiences of DBL activities. The novelty of the Activity-and-Affect Model of DBL lies in conceptualizing a design-based activity from a multi-dimensional view that paves a fundamental basis for future related research.
- There is a contribution to a set of DBL guidelines considering its potential relationship between DBL activities and students' emotions. This could inspire future research and practice on how to orchestrate DBL activities that will foster positive emotional responses in students.
- Another contribution is methodologically showing (a) how to design tools for capturing emotions in DBL and (b) how to implement an intervention involving emotion awareness tools in DBL. Specifically, this thesis advocates three different approaches to measuring emotions in DBL. This thesis also proposes three design principles for developing an emotion awareness tool and three design considerations for creating a sharing emotions tool.

9.4. Discussion of Main Findings

In Chapter 1, we had initially identified three main research challenges (i.e., C1-3; see section 1.1.5) when reviewing related literature within the DBL context. In the following paragraphs, we briefly revisit them to reflect on to what extent how our works resolved the research challenges. Meanwhile, we reflect on how these works relate to previous work and what might be meaningful to investigate as a next step.

The first research challenge is the methodological challenge of measuring emotions in DBL (C1). Unlike emotion research in laboratory settings, studying or measuring emotions within the DBL context occurs in a natural environment, making the data collection more complex and challenging than laboratory studies. In Chapter 2 [152], our review suggests that many previous techniques (see section 2.4.1) of measuring and reporting emotions in DBL, e.g., questionnaire, interview, were limited in their purpose and, in some cases, driven by studying emotions as part of the evaluation of DBL intervention outcome. To address the lack of a suitable specialized instrument in DBL, we explored and experimented with possible solutions in Chapters 3 and 4. Overall, these works expand the methodological considerations for related educational researchers and practitioners in measuring emotions in the classroom as a living laboratory. For instance, in Chapter 3, to measure students' emotions during different design phases, we devised emotion cards [26] based on the conception of the Five Degrees of Happiness [137], which was based on the widely known Smileyometer [132] in CCI community. This was the first attempt at using the Five Degrees of Happiness [137] to repeatedly measure the intensity of students' emotional responses during the design process. As a step further, the works in Chapter 4 (see section 4.3 and 4.4) showcase three different ways of capturing emotions in DBL that acknowledge the power of self-reporting (e.g., EmoForm [90]), classroom observation (e.g., EmoLens), and the convenience of a wearable device (e.g., EmoWatch). Whereas earlier studies of emotions have measured emotions and experience almost exclusively based on either self-report (e.g., Achievement Emotions Questionnaire-Elementary School [147]), retrospection (e.g., MemoLine [138,139]), or experience sampling [156] (e.g., ESM diary [157]). Through EmoForm, we provide an exemplar for future researchers in the CCI and LS community of developing an emotion measurement combined the advantage of self-reporting, retrospection, and experience sample strategy. Besides, all the explorations in developing EmoWatch and EmoLens spark insightful directions and expand our understanding of measuring emotions in different ways with or without technology aid. It would also be valuable in future work to explore and validate whether technology-embedded emotion capturing tools, e.g. [64,142] which are used in other contexts, would be useful in the DBL context.

Another research challenge we identified concerns the understanding of constructive component of the DBL context is lacking (C2). Earlier DBL frameworks (e.g. [1,25,62]) address the critical elements of instructional settings, such as the teacher's role, assessment, design elements, project characteristics, reflection, and collaborative learning. These elements are interweaved when zooming into the specific contextual factors of DBL. In response to this, we proposed the Activity-and-Affect Model of DBL (see Figure 5.4), which expands upon earlier descriptions of the DBL process, such as the DBL framework [62], the Reflective DBL framework [25], and the Learning-by-Design framework [1]. Specifically, the Activity-and-Affect Model of DBL is proposed to address the following two intentions underrepresented in the existing literature within the LS community: (1) *Describing the DBL activities from a multi-dimensional perspective*. For example, all these vital DBL elements are mapped along the task dimension, the task strategy dimension, and the collaboration strategy dimension. (2) *Having a nuanced view of how a specific activity could be associated with an emotional experience*. This model establishes the nuanced channels between DBL activities and students' emotional experiences. As noted in the literature [1], it is challenging for teachers to orchestrate activities in the classroom to assess individuals' progress. We envisioned several useful scenarios using this model by educators and students themselves (see section 5.5.3). Our exploration opens opportunities and invites future works to evaluate and validate how these tools can make useful contributions to educational practices. Additionally, this thesis studied emotions primarily from a students' perspective, despite that the teacher's role (e.g., how they interact with or coach the students) influenced students' emotions and was acknowledged as one of the affective components of the DBL context. Future work could explicitly aim to complement this research through a comprehensive investigation of emotions from a teacher's perspective. As mentioned in Chapter 1, we refer to the pedagogical pillar of the curriculum development framework [59], which provides a general structure of the learning activity framework in school education. There are still more components (e.g., location, time) that lack systematic investigation in this thesis. For instance, future work may investigate the effect on students' feelings toward DBL from different locations and learning settings (i.e., formal, non-formal, and informal learning). It would also be valuable to pay attention to students' different emotions in both offline and online DBL learning in the future. 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 school subjects.

The third research challenge presented in Chapter 1 is that tools supporting emotion awareness in the DBL classroom are lacking (C3). With the intention of using emotions as an educational tool in DBL, we explored two ways to help students become aware of and regulate their emotions: (1) creating self-awareness of emotions via self-tracking (see Chapter 7) and (2) social sharing of emotions with others in the class using Microsoft Teams and FireFlies (see Chapter 8). These works illustrated how currently used tools can be potentially adapted to support emotional awareness and communication in the online and offline DBL classroom. More specifically, the work presented in Chapter 7 adds to our understanding of the advantages of explicit awareness through self-report in DBL, which is well known to stimulate reflection and behavior change in a broader context [247]. Further, our intervention study 1 in Chapter 8 expands our understanding of how commonly used educational software such as Microsoft Teams could contribute to emotion regulation and learning in DBL. Our intervention study 2 in Chapter 8 contributes to the research on peripheral interaction in the classroom, using the FireFlies devices as a distributed ambient display in the classroom space [267]. Our study illustrates how the ambient display can be adapted to communicate emotions experienced in DBL. Overall, our works in this thesis sketched a vision of what the CCI and LS community might do next regarding capturing and understanding emotions experienced by students. For example, our work (e.g., Chapters 7 and 8) explored the appraisal-oriented regulation (e.g., self-aware and reflect on the feelings of perceived importance and control over achievement activities) and the combined appraisal-oriented and emotion-oriented regulation in DBL (e.g., social sharing of emotions experienced in DBL with others). As proposed in the control-value theory (CVT) of achievement emotions [51], there are two other ways of regulation and treatment of achievement emotions, such as problem-oriented regulation (e.g., training of learning skills) and classroom instruction (design of learning and social environment). Future work could develop and implement interventions to facilitate these types of regulation of achievement emotions in students.

9.5. Limitations and Future Works

One limitation of this research concerns the limited generalizability of the findings. This research involved small samples of participants taken from two public high schools and one university at an applied science level in the Netherlands. Qualitative data collection and analysis helped to gain a deeper understanding of DBL and students' associated emotional experiences. This, however, limits our ability to generalize our conclusions to different contexts and a larger student population. Another concern is that the sampling criteria in some studies were not very strict, as we selected a convenience sample of students from one school that agreed to cooperate in this research and did not exclude any students from participating classes unless they chose not to participate. This may influence the generalizability of our results, given that one would expect individual differences in students' abilities to recognize and express emotions. Future research on implementing and evaluating a related intervention could revise the sampling strategy.

Another limitation concerning the generalizability of our results concerns the age of participants. The studies in this thesis primarily involved secondary school students and were extended to a post-secondary education context in the study of Chapter 6. Overall, the findings were quite consistent across the two age groups, which lends more confidence to the conclusions. However, further research should explore thoroughly whether the results hold for different ages of the students. Furthermore, most participants in the studies reported in this thesis already had experience with DBL before participating in the studies reported in this thesis. This may have biased the results. One could argue that students experiencing DBL for the first time could experience different emotions, e.g., the novelty of the experience may result in more positive evaluation and a different execution of the design process. On the other hand, there was no evidence found that such a novelty effect confounds the results. Future research could examine how activities affect participants' emotions for groups with varying levels of experience in DBL.

By choosing the control-value theory (CVT) of achievement emotions [51] as the theoretical pillar of emotions in this thesis, we looked at some components of emotions, primarily providing an account of understanding students' subjective feelings and appraisal of DBL experiences. This guided the means of interpreting our insights gained in this thesis. As an illustration, as we discussed in the study presented in Chapter 6, we found a dynamic feedback loop of emotions, their antecedents, and their effects over time within individuals, which is assumed by CVT, appears to be explainable, especially in the case of failure recognition during DBL. In this study, students believed failures and mistakes are learning opportunities and experienced emotions from their failures. Given that emotions are complex, many factors may influence students' emotions, which means that only studying students' subjective feelings and appraisal of DBL experiences may not capture the complete picture behind how students think and feel how they feel. Scherer [165] argued that the nature of emotions has multiple components that include the component of subjective feeling (emotional experience), cognitive (appraisal), neurophysiological (bodily symptoms), motivational (action tendencies), and motor expression (facial and vocal expression). Future research could study and measure emotions experienced in DBL from a different perspective. Additionally, we focused more on the achievement emotions students experienced during DBL in our intervention studies, while other academic emotions [6] (e.g., social emotions, topic emotions, or epistemic emotions) are also of considerable interest to investigate closely in the future.

Finally, the results were reported pertaining to a DBL context. Still, it could be interesting to replicate and adapt the approaches for emotion tracking and emotion sharing in other (non-DBL) contexts following an active learning approach.

9.6. Future Vision

In a world of rapid change and uncertainty nowadays, we face the urgent challenge of preparing young generations with the needed skills. Despite that research in DBL is relatively young, existing research has already demonstrated its promise in preparing students with twenty-one-century skills such as problem-solving and collaboration [1]. Many previous successful DBL programs at school levels have emerged independently in different countries. An era mediated by technology and data will speed up the blooming of many forms of learning, e.g., onsite classroom, online module, informal workshop or camp, digital game-based learning, etc. This may open up opportunities for implementing DBL at a global scale and the opportunities for collaboration between learners, learning communities, and their stakeholders. As a result, it may also provide a means of reducing current gaps and inequalities between countries and regions worldwide. It would be interesting to see how geographically distributed learners can work collaboratively on global issues taking on design challenges pertaining to sustainability, climate-changing, mobility, or inclusive society.

The Covid-19 pandemic has also increased awareness regarding an urgent need to further understand students' and educators' mental health, especially when facing isolation, uncertainty, and dislocation. A recent study [251] showed Covid-19 pandemic represents a psychological crisis as it can be associated with declines in an individual's subjective well-being. So far, inadequate attention has been paid to better understanding and supporting the emotional, motivational, and social aspects of learning in DBL. Supporting these aspects can provide insights related to potential problems during the learning process (e.g., dropout due to lack of emotional engagement or intrinsic motivation) that are crucial for the quality of a learner's well-being. Self-tracking, which was the subject of investigation in research labs when DBL started, has now been commoditized, facilitating self-awareness and self-discovery based on tracking data. Self-optimizing individuals could voluntarily use tracking tools on their smartphones and smartwatches to monitor all sorts of things regarding their activity, app use, health, and everyday behaviors. One direction for future research could be to capture and access detailed data of these aspects of learning from data obtained using emerging technologies such as advanced sensing and artificial intelligence (AI). For instance, detecting emotional response signals during learning can be powered by using embodied sensors (e.g., heart rate, skin conductance sensors) and personal devices (e.g., smartphone, smartwatch, smart ring). This would deliver quantifiable insights into students' internal states and triangulate different data collected from multiple modalities spread across spaces of a learning context. It is a small leap of imagination to tie in the sensing of psychophysiological measures relating to emotions in DBL and to use AI to personalize and draw inferences regarding students' activities and learning processes. This could enable a more comprehensive understanding of the learning processes and a timely account of students' internal states over time. Another possible direction for future research concerns the design, development, and evaluation of emotion regulation interventions in diverse learning contexts. For example, well-being could be taught in schools as an aid to students' learning and creative thinking and as a catalyst for increasing their life satisfaction [282]. Finally, it would be interesting to see how affective technologies (e.g., a robot-based chat agent, an affective tutoring system, a computer-mediated communication tool) could become incorporated as tools for psychological intervention, and whether these tools would have a noticeable effect, be it in a positive or negative direction.

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Appendix A: Full-text Literature Selection Process

Title of the paper	Decision		
	Coder-1	Coder-2	Final
Impact of a prototyping intervention on middle school students' iterative practices and reactions to failure	IN	IN	Included
Integrating Design Thinking into peer-learning community: Impacts on professional development and learning	IN	IN	Included
Emoform: Capturing children's emotions during design based learning	IN	IN	Included
Exploring modalities of reflection using social online portfolios for maker-oriented project-based learning	IN	OUT	Included
Project-based learning (Pjbl) in three southeastern public schools: Academic, behavioral, and social-emotional outcomes	OUT	OUT	-
"It's the magic circle"! using cogenerative dialogues to create a safe environment to address emotional conflicts in a project-based learning science internship	OUT	OUT	-
Motivational factors in makerspaces: a mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions	IN	IN	Included
Can the problem-based learning model affect students' mathematical literacy ability and emotional intelligence?	OUT	OUT	-
Practical independent research projects in science: a synthesis and evaluation of the evidence of impact on high school students	OUT	OUT	-
Increasing Early Opportunities in Engineering for Advanced Learners in Elementary Classrooms: A Review of Recent Literature	OUT	OUT	-

The role of children's emotions during design-based learning activity: A case study at a Dutch high school	IN	IN	Included
The development and application of a STEAM program for middle school students using an internet of things teaching aid	IN	IN	Included
The Invention bootcamp, a four-week Summer course for high school underrepresented students in a university setting	IN	IN	Included
Reforming abstract geometrical ideas through 3D printing: A proposal for experiential e-Making technology in creative education	OUT	OUT	-
Indirect teaching for all and autism spectrum disorder (ASD) in design class (ITAD) encouraging their emotional empathy	OUT	OUT	-
Urban High School Student Engagement Through CincySTEM iTEST Projects	OUT	OUT	-
Students' motivational attitudes in introductory STEM courses: The relationship between assessment and externalization	OUT	OUT	-
Effects of a peer competition-based mobile learning approach on students' affective domain exhibition in social studies courses	OUT	OUT	-
How teaching science using project-based learning strategies affects the classroom learning environment	IN	IN	Included
Greek Students Research the Effects of Fire on the Soil System through Project-based Learning	OUT	OUT	-
Engineering first: How engineering design thinking affects science learning	OUT	OUT	-
Fake Mars, real STEM	IN	IN	Included
How Science, Technology, Engineering, And Mathematics (Stem) Project-Based Learning (Pbl) Affects High, Middle, And Low Achievers Differently: The Impact Of Student Factors On Achievement	OUT	OUT	-

The role of problem-based learning in developing creative expertise	OUT	OUT	-
Using the similarities between biological and computer virus behavior to connect and teach introductory concepts in cybersecurity in a biology classroom	OUT	IN	Included
The effect of the project-based learning approach on the academic achievements of the students in science classes in Turkey: A meta-analysis study	OUT	OUT	-
Media space	OUT	OUT	-
Biodiesel and integrated STEM: Vertical alignment of high school biology/biochemistry and chemistry	OUT	OUT	-
Cognitive and socio-affective outcomes of project-based learning: Perceptions of Greek Second Chance School students	OUT	OUT	-
Teacher, i had a dream: A glimpse of the spiritual domain of children using project-based learning	OUT	OUT	-
Are children capable of learning image processing concepts? cognitive and affective aspects	OUT	OUT	-
Empowerment through design: Engaging alternative high school students through the design, development and crafting of digitally-enhanced pets	OUT	OUT	-
The impact of a Problem-based Learning Launcher Unit on eighth grade students' motivation and interest in science	IN	IN	Included
K-12 engineering for service: Do project-based service-learning design experiences impact attitudes in high school engineering students?	OUT	OUT	-
Robotics teaching in primary school education by project based learning for supporting science and technology courses	IN	OUT	Included
Motivational styles in problem-based learning	OUT	OUT	-

Evaluating students' perceptions and attitudes toward computer-mediated project-based learning environment: A case study	OUT	OUT	-
Destination, imagination & the fires within: Design thinking in a middle school classroom	IN	IN	Included
Design based learning: Comparative effects on high school student's interest in engineering	IN	IN	Included
The effects of Problem Based Learning on mathematics performance and affective attributes in learning statistics at form four secondary level	OUT	OUT	-
Implementation of problem based learning in cooperative learning groups: An example of movement of vertical shooting	OUT	OUT	-
Bringing engineering education into a girls' senior high school in Taiwan: Integrating hands-on and problem-based learning activities into a robotics course	IN	OUT	-
Identifying students' perceptions of the important classroom features affecting learning aspects of a design-based learning environment	IN	IN	Included
The effects of problem-based active learning in science education on students' academic achievement, attitude and concept learning	OUT	OUT	-
'Here's one I made earlier!' A qualitative report on creativity in a residential primary school for children with social, emotional and behavioural difficulties	OUT	OUT	-
Implementation and assessment of project-based learning in a flexible environment	IN	IN	Included
Comparing problem-based learning and traditional instruction in high school economics	OUT	OUT	-
Students' responses to curricular activities as indicator of coherence in project-based science	IN	IN	Included

Happy girls engaging with technology: Assessing emotions and engagement related to programming activities	IN	IN	Included
The influence of gender grouping on female students' academic engagement and achievement in engineering and biology: A case of small group work in design-based learning (work in progress)	IN	IN	Included
Sensors, programming and devices in Art Education sessions. One case in the context of primary education	IN	IN	Included
The Influence of Gender Grouping in Design-Based Science on High School Girls' Biology Engagement	IN	IN	Included
Pupils Identify Key Aspects and Outcomes of a Technological Learning Environment	IN	IN	Included
Increasing Student Awareness of and Interest in Engineering as a Career Option through Design-Based Learning*	IN	IN	Included
What motivates children to become creators of digital enriched artifacts?	IN	IN	Included
The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education	IN	IN	Included
Integrating the Cognitive Research Trust (CoRT) Programme for Creative Thinking into a Project-based Technology Curriculum	IN	IN	Included
Autonomy support: Teacher beliefs and practices during steam instruction and its influence on elementary students	OUT	OUT	-
The effects of project-based learning and motivation on students with disabilities	IN	IN	Included
A Case Study of a High School Fab Lab	IN	IN	Included
Project Based Learning: Evaluation Report and Executive Summary	IN	IN	Included
Engage Me and I Learn	OUT	OUT	-

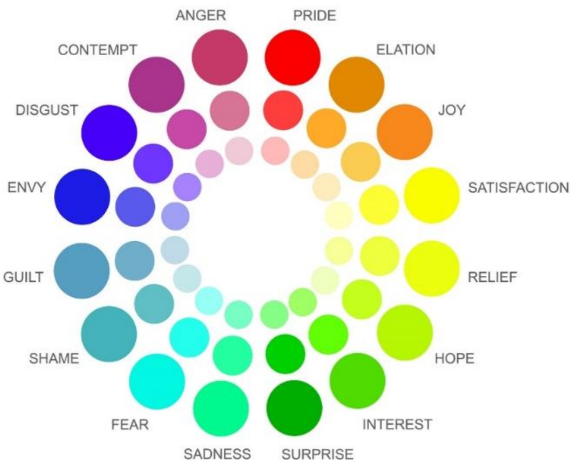
Evaluation of Learning by Making i3 Project: STEM Success for Rural Schools	IN	OUT	Included
The Impact of a Brief Design Thinking Intervention on Students' Design Knowledge, Iterative Dispositions, and Attitudes Towards Failure	IN	IN	Included
Fun in Making: Understanding the experience of fun and learning through curriculum-based Making in the elementary school classroom	IN	IN	Included
Bringing Engineering Design into High School Science Classrooms: The Heating/Cooling Unit	IN	IN	Included

Appendix B: GEW Questionnaire

How did you feel about your design-based learning experience in the past sessions?

1. Please rate the intensity of no more than 3 emotions in the below emotion wheel which best describes what you felt.

2. Then briefly describe or draw what you have experienced in term of these emotions on the blank.



Appendix C: Group Interview Protocol

Participants: 4-5 children in one group

The main body of the interview:

What do they like about this design-based learning (workshop)?
Which parts do they most like to participate in?
How might they help to improve this DBL experience?

Ask questions related to their questionnaires.
Review the questionnaire, and share the stories of their emotional experience.

Ask questions related to their emotion cards in different sessions.

a. Review it on the emotion card, and share their emotion mark in the empathize /define /ideate session.
b. What did they experience in the empathize/define/ideate session?
c. Why did they circle a certain emotion in the empathize /define /ideate session?

The closing phase:
Thank them all.

Appendix D: DBL Project Information

Design challenge: Fire can cause a lot of damage and suffering. You can prevent fire or limit the damage with a few simple measures. Unfortunately, many people do not know what actions they should take if there is a fire.

For tips on fire safety in and around the house, see this link https://www.brandweer.nl/brandveiligheid.

Escape rooms have become enormously popular. The Eindhoven fire service wants to introduce people to fire safety in and around the house in a modern and interactive way via an escape room. Together with other people, you will be stocked in a place and try to escape from the room through instructions and solving puzzles.

Design client: You have been hired as a game designer to design an escape room for the fire brigade of Eindhoven. The client is Mr. Peter van der Horst from the Eindhoven fire department.

Assignment: Design a mobile escape room that allows participants to get acquainted with fire safety in and around the house. This mobile escape room must fit into a sea container so that it can be deployed at different locations.

There are several conditions:

1. A group of participants must be able to escape in half an hour.
2. At least two puzzle assignments must be mechanical and/or electronic.

Assignment guide: To achieve a good result, you may need to go through several steps:

- Step 1: Brainstorming. What do you already know about the subject? Which ideas come to you immediately? The client asks for a mind map of the ideas that the assignment evokes.
- Step 2: Professional training. You will work as a game developer during this assignment. The client wants you to briefly describe what exercise you can do to become a game developer and what the training entails. Also, he wants you to explain what this profession involves and what the activities are.
- Step 3: Understanding technical knowledge. The client wants to be informed about the professional language of the game developer. He expects to know the technical terms in this field and explain how you apply them in the assignment.
- Step 4: Researching escape rooms. The client wonders which game elements provide an ultimate escape room experience. To answer this question, the client expects you to analyze several existing (educational)

escape rooms. The client wants to see an analysis of the storyline, the plot, the operation of the 'puzzles,' and the atmosphere worked out.

- Step 5: Researching fire safety. What knowledge about fire safety do you want to impart to the visitors of the escape room? The client is curious about what themes around fire safety you find suitable as a red thread for the escape room (setting up a safe house or what you can do when there is danger).
- Step 6: Identifying design requirements and parameters. The client wants a set of requirements and design parameters of the escape room based on your preliminary investigation. He expects to see an overview in which you indicate what parameters and conditions are set for the form, the content, and the use of the escape room.
- Step 7: Ideating a storyline. A strong story with a good plot is a basis for an escape room. This story connects the puzzles and ensures that the game runs logically. The client challenges you to develop an engaging storyline that informs visitors about your theme within half an hour. What surprising twists are there? What links are there in the story that visitors have to discover? It is expected that step by step is explained what happens in the story.
- Step 8: Sketching design puzzles. "There are many ways that lead to Rome." Your story can still be worked out in various ways. For every step in the story, several puzzles can be considered. The client wants to see a brainstorm of puzzles per step in the story of every team member. You can refer to the ideas and puzzle forms from Escape rooms that you have found as an example in the preliminary investigation. Sketches and captions will make clear how the puzzle works and which materials are used.
- Step 9: Designing. There are now several (three to four) ideas per step in the game! It is up to you to respond to each other's ideas in a constructive manner and choose the best puzzle per step in the story or make a combination of good ideas. The client expects that the red thread (storyline) comes to the fore through the choice of the puzzles, a good balance of the type of games, and a lot of variety (physical, thinking, mechanical, electronic, etc.). To assess everything accurately, the client wants to see an overall picture of the game and the puzzles that will be discussed. He expects you to explain in the file as visually as possible how the game progresses. He also likes to see an explanation of why your game meets the design requirements.

- Step 10: Prototyping. The client wants to work out at least two puzzles in the form of a working prototype (preferably scale 1: 1). At least one prototype is mechanical and/or electronic. The client expects technical drawings (dimensions in millimeters) and a working drawing so that he has a good view of the requirements for doing the puzzle.
- Step 11: Completion of the assignment. The project is completed with a video presentation of the escape room in action. With this, the client has to get a good picture of your escape room. Show how each puzzle works and how it fits into the storyline. How does your escape room ensure that people gain relevant knowledge and found it fun to do?”

Appendix E: Example of Prototypes

Students' puzzle design prototypes addressing the escape room design challenge in this DBL project are varied. For example, one group used the Littlebits to make a system that unlocked a door by a sensor. Some created traditional puzzles (e.g., testing such a prototype in the photo below), while some invented informative puzzles. Some groups used accessible electronics (e.g., lights) to design their interactive puzzles. Some used physical principles (e.g., magnetism) to get a key out of a tube by a magnet.

Example of testing a puzzle prototype

Appendix F: Table 5.9. Coefficients of multiple linear regressions

5.9-a Coefficient (dependent variable: enjoyment)			
Model	Predictors	Std. β	*p*
	(Constant)		.000
	DDP	-.122	.000
	CT	.112	.000
	ST	-.138	.000
	MP	.129	.000
	PP	-.049	.042

5.9-b Coefficient (dependent variable: relaxation)			
Model	Predictors	Std. β	p
	(Constant)		.000
	EDU	-.062	.019
	GFO	.101	.000
	DD	-.064	.010
	GST	.075	.002
	%DTP-TSI	.090	.000
	MP	.086	.001

5.9-c Coefficient (dependent variable: contentment)			
Model	Predictors	Std. β	*p*
	(Constant)		.000
	EDU	-.197	.000
	TP	-.132	.006
	IDS	-.130	.009

5.9-d Coefficient (dependent variable: pride)

Model	Predictors	Std. β	*p*
	(Constant)		.000
	ST	-.339	.000
	MP	.133	.008
	%DTP	-.127	.032

5.9-e Coefficient (dependent variable: concentration)

Model	Predictors	Std. β	*p*
	(Constant)		.000
	IDS	-.106	.000
	MP	.201	.000
	ST	-.163	.000
	IT	-.074	.002

5.9-f Coefficient (dependent variable: learn better)

Model	Predictors	Std. β	*p*
	(Constant)		.000
	ST	-.158	.000
	IDS	-.067	.007
	PL	-.058	.016
	%DTP-PM	.050	.039

5.9-g Coefficient (dependent variable: hopelessness)

Model	Predictors	Std. β	*p*
	(Constant)		.000
	MP	-.130	.008
	DDP	.109	.026

5.9-h Coefficient (dependent variable: anxiety)

Model	Predictors	Std. β	*p*

	(Constant)		.000
	%PM-TSI	.170	.001
	PP	.148	.002

5.9-i Coefficient (dependent variable: boredom)			
Model	Predictors	Std. β	*p*
	(Constant)		.000
	MP	-.198	.000
	EDU	.148	.000
	DDP	.075	.002
	%DTP	-.071	.004
	PL	-.061	.009
	GST	.059	.012
	%DTP-PM	-.054	.021

5.9-j Coefficient (dependent variable: frustration)			
Model	Predictors	Std. β	*p*
	(Constant)		.000
	%DTP-TSI	.231	.000
	EDU	.157	.000
	PP	.082	.001
	TP	.070	.004
	intT	-.047	.052
	GST	.049	.040
	DD	.049	.043

Abbreviations: EDU empathize with design user; DDP define design problem; IDS ideate design solution; MP make prototype; TP test prototype; PP prepare/present presentation; GST get support from the teacher; GFO get feedback from others; DD design documentation; PL planning; intT intertwined individual and collaborative tasking; %DTP design thinking process; %DTP-TSI combined design thinking process and task-related social interaction; %DTP-PM combined design thinking process and project management; %PM-TSI combined project management and task-related social interaction.

Appendix G: Interview Questions

Introduction: (2′)

Thank you xxx for participating in this interview. We will have around 30 minutes to talk regarding your experience and feelings in this design based project. Let me briefly introduce the schedule. Overall, this interview has three parts. We would:

First, start with some general questions,

Then follow some specific questions on emotions,

Last we would have some questions on your experience of recording emotions with form.

The audio of our conversation will be recorded. It will be completely anonymous and cannot be traced back to you.

Do you have any questions before starting? Let's start right now!

Part 1: (6′)

Can you tell me what is your major (Q1a)?

What is your learning goal in this project (Q1b)?

And what is your expectation in this project?

What is learning to you in such a design-based project (Q1c)?

From your point of view, do you see any learning opportunities in this project (Q1d)? Where are they?

Which part of this FS project is your favorite (Q1e)? Can you explain why?

Part 2: (10-12′)

Now, let talk about your feelings experienced in this FS project.

My first question is: compared with your major project, where do positive emotions pop up in this design based project (Q2a)? And where do negative emotions pop up in this project?

Still, compared with the major project, where emotions do not pop up during this project (Q2b)?

For you, which one (your major project or this FS project) brings stronger positive emotion or negative emotion to you (Q2c)?

Can you describe one specific case that how positive emotion influences your learning (Q2d) in this project? Can you describe one more specific case that how negative emotions influence your learning?

During this project, you may achieve all kinds of successes. Can you describe one case of your success and explain what do you feel about this success (Q2e)?

Could you also share one case of failure and explain what you feel about this failure (Q2f)?

Part 3: (8-10′)

In the last section, we will talk about the experience of recording emotions with this form.

There are the forms you filled in in the past weeks. Could you pick one of the forms to share with me the story you recorded in the form (Q3a)?

I was curious how does it feel to use this form (Q3b)?

How did you experience recording emotion with this form (Q3c)?

And can you tell me how you would use the information from the form? What conclusion do you get from it (Q3d)?

Did this form help you in dealing with emotions? How does it help you (Q3e)?

Do you have any suggestions on helping deal with emotions in a similar project (Q3f)?

Close: (2′)

Now, that is all the questions for this interview.

Before closing, I was wondering if there is anything you would like to add?

Thank you xxx very much for having your time and your appreciated opinions.

Appendix H: Interview Protocol

Introduction

Thank you for participating in this study. During this interview, we will discuss your experience and view of sharing feelings. There are no right or wrong answers: this is an explorative interview. Before we begin, I would like to ask you to confirm that you agree that the talks are recorded and that the data is handled confidentially. (Make sure a unique number is assigned to the interviewee when start recording the conversation; this will be used to related to their questionnaire data.)

Part A: Questions about questionnaire answers (0-5 mins)

During this interview, we will talk about your experience of sharing emotions with others.

A-1: Can you tell a little bit more about what you said in this questionnaire?

Ask pre-selected questions related to their answers in a questionnaire.

Part B: Questions about how sharing emotions influence their DBL activities (10 mins)

B-1: Can you tell me what was happening when sharing your feelings of doing something with others?

- What emotion did you share? (Enjoyment, relaxation, boredom, or frustration)
- With whom? Is the one you shared your team member/ classmate from another team/ the teacher?
- What reactions or feedback did you receive when sharing this information?
- What did you do after sharing this with others? How different was this from before?
- What do you see as the results of sharing this information with others? How did this happen?
- How does it feel to share your feelings with others? Can you say why?

B-2: Did you notice some of your classmate's feelings about doing tasks?

- If yes, what made you notice this information?
- What were you doing at this moment, and what were your classmate doing?

- How did you feel when seeing other's feelings of doing tasks? Can you say why?

Part C: Questions about the experience of using the lamp and cards to share feelings (5 mins)

C-1: Can you tell me how did you use the lamp to share information with others?

- What parts of this lamp do you like most? What do you like least? Can you say why?
- What do you see as the values of using this lamp?
- What is missing when using this lamp to share your feelings with others?

C-2: Can you tell me how does it feel to use the task cards?

- What do you like most about these cards? What do you like least?
- What do you see as the values of using these cards?
- What is missing in these cards?

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Curriculum Vitae

Biography

Feiran Zhang (1991) was born in Hunan, China. Feiran received her bachelor's degree in Art Design (with a top 5% GPA grade) from the Beijing Jiaotong University, China, in 2013. She received a master's degree in Industrial Design Engineering (with a top 5% GPA) from Beijing Jiaotong University in 2016. During 2014 and 2015, she was awarded the Sino-Dutch Bilateral Exchange Scholarship (funded by the ministries of education of the People's Republic of China and the Netherlands) to visit the University of Twente, the Netherlands. From 2016 to 2020, she was funded by the China Scholarship Council to conduct her doctoral research at Eindhoven University of Technology. This thesis is the results of her doctoral research under the guidance of Prof. Dr. Panos Markopoulos and Prof. Dr. Tilde Bekker on the topic of "Emotions in Design-Based Learning."

Publications

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- **Zhang, F.**, Markopoulos, P. & Bekker, T. Children's Emotions in Design-Based Learning: a Systematic Review. J Sci Educ Technol 29, 459–481 (2020). https://doi.org/10.1007/s10956-020-09830-y
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- **Zhang, F.**, Markopoulos, P. An, P, & Schüll, M. (under review) Social sharing of task-related emotions in Design-Based Learning: challenges and opportunities.

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- **Zhang, F.**, Markopoulos, P., Bekker, T., Schüll, M., & Paule-Ruíz, M. (2019, March). EmoForm: Capturing Children's Emotions during Design Based Learning. In Proceedings of FabLearn 2019 (pp. 18-25). ACM.
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Peer-reviewed doctoral consortium paper:

- **Zhang, F.** (Accepted/in press) (2019). Supporting Design-based Learning from the Lens of Emotions. 14th European Conference on Technology Enhanced Learning Doctoral Consortium. CEUR Workshop Proceedings.

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