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Master thesis

Experiences of mathematical relevance in project-based education among selected youths between 14-and-15-year-olds in Norway

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Contents

1. Background and thesis

1.1. Introduction

The Norwegian junior high school (Ungdomsskolen) has, by the autumn semester of 2021, completed its change from the old LK06-curriculum to the new LK20-curriculum (Utdanningsdirektoratet, 2020). The new curriculum places a central role on cooperative learning and interdisciplinary topics (Utdanningsdirektoratet, 2020). Specifically, three interdisciplinary topics are part of the curriculum, and intended to address societal challenges which "[…] require engagement and effort from individuals and the community […]" (Utdanningsdirektoratet, 2020). The purpose of these interdisciplinary topics is, according to Utdanningsdirektoratet (Udir), to give pupils "insight into the challenges and dilemmas within the topics" while also allowing them to "develop knowledge and understand contexts across disciplines" (Utdanningsdirektoratet, 2020, my translation).

In addition to these interdisciplinary topics, the new mathematics curriculum clearly places emphasis on exploratory teaching, also known as *inquiry teaching*: "Mathematics shall prepare pupils for a society and working life in development by providing them with the competence to explore and solve problems." (Utdanningsforbundet, n.d.h). Indeed, the word "explore" can be found in four out of eleven competency goals in the mathematics curriculum for grade 8 (Utdanningsdirektoratet, n.d.b), and five out of ten competency goals for grade 9 (Utdanningsdirektoratet, n.d.c) as well as grade 10 (Utdanningsdirektoratet, n.d.a). Exploration is also specifically mentioned in Udir's description of the school's purpose and core values (Utdanningsdirektoratet, n.d.d):

> *Children and young people are curious and want to discover and create. The teaching and training must give the pupils rich opportunities to become engaged and develop the urge to explore. The ability to ask questions, explore and experiment are important for in-depth learning. The school must respect and nurture different ways of exploring and creating.*

There are ready parallels to be drawn between the goals of the LK20-curriculum and project-based learning (PBL), which presents students with real-world problems which often require interdisciplinary approaches and exploration to be solved (Blumenfeld, et al., 1991). Several studies have shown a positive correlation between PBL and student motivation across different subjects and ages (Chiang & Lee, 2016; Helle, Tynjälä, & Olkinuora, 2006; Blumenfeld, et al., 1991). Schools have duly introduced PBL into their education with the explicit purpose of satisfying LK20's demand for education involving the interdisciplinary topics.

This study examines several junior high school pupils' experiences of the phenomenon of mathematical relevance after such projects.

1.2. Motivation

While there are several examples of studies looking at the benefits of PBL (Chiang & Lee, 2016; Helle, Tynjälä, & Olkinuora, 2006; Blumenfeld, et al., 1991), the primary focus of these studies tend to involve older pupils at the high school level (aged 16-18) or older. In addition, the studies cited address the virtues of PBL in terms of motivation for mathematics education. However, several of the studies have participants from different vocational studies as opposed to general education. This group of students often have an adverse relationship with mathematics (Buabeng-Andoh, 2019; Dinç, Memnum, & Aydın, 2018).

While it is important to improve the mathematics education for this group of pupils, more studies are necessary on how to improve the general mathematics education which all students must partake in. At the junior high school level, all students receive the same education in mathematics, regardless if they intend to attend a vocational high school or one intended to prepare them for further university studies. This study intends to add to the body of research on PBL by focusing on pupils at the junior high school level (aged 14-15) with diverse opinions about mathematics.

Furthermore, with the increase of PBL across the country's junior high schools, the need for best (and worst!) practices for developing interdisciplinary projects is greater than ever. It is uncontroversial to claim that teachers' intentions and pupils' perceptions can often be divergent. What a teacher *believes* to be mathematically relevant and what a pupil *perceives* to be mathematically relevant is not necessarily well-aligned.

The pupils' perception is front and center in this study, because the phenomena of relevance, motivation and experienced value are deeply subjective and personal. Studies have previously shown that students at the university level who are taught using active-learning strategies – which are known to be more efficient than traditional methods – often feel as if they have learned less (Deslauriers, McCarty, Miller, Callaghan, & Kestin, 2019). Such experiences breed frustration in students, and can work to undermine their motivation in a given subject, thus potentially undoing the benefits of active learning strategies. If a student perceives an interdisciplinary project to be of little mathematical relevance, regardless of the actual merits of the project, they might similarly become frustrated by the teaching methods. This frustration might, in turn, undermine the established, positive effects of PBL – as well as Udir's intentions with interdisciplinary topics.

This study attempts to shed light on what factors generally make an interdisciplinary project feel relevant to the pupils who must engage with the said project.

1.3. Thesis and research questions

The thesis question for this study is:

"What makes an interdisciplinary project feel mathematically relevant to a pupil at the 10th grade junior high school level?"

For ease of reference, the study will use the term "research participants" or "participants" in lieu of *"pupil at the 10th grade junior high school level".*

To answer this thesis, the study will attempt to answer the following research questions:

1. *What aspects of an interdisciplinary project made participants experience mathematical relevance?*
2. *What aspects of an interdisciplinary project made the participants experience a lack, or antithesis of, mathematical relevance?*

1.4. Description of chapters

This subchapter describes the structure of this study and the chapters herein.

Chapter 1: Background and thesis lays the foundation of the study, discussing its motivation and relevance to the Norwegian school.

Chapter 2: Theoretical considerations discusses the theoretical framework which underpins the study. It is divided into one section discussing the theoretical underpinnings of project-based education (chapter 2.2 Socio-cultural theory) and one section discussing the methodological framework of the study (chapter 2.3 Phenomenology).

Chapter 3: Overview of the literature discusses some of the previous research done on relevant topics for this study. These include research which discusses some benefits of the LK20-curriculum — project-based learning (chapter 3.2) and interdisciplinarity teaching (chapter 3.3). It also discusses research on the phenomenon which this study is interested in exploring, being mathematical relevance (chapter 3.4).

Chapter 4: Method describes all aspects relating to the execution of the study. It contains a chapter dedicated to methodology (chapter 4.2), describing how data was collected, differences between the pilot study and the main study, and how pupils were selected. It also discusses the tools used to analyse the collected data (chapter 4.3), the study's authenticity and trustworthiness (chapter 4.4), limitations of the study (chapter 4.5) and the ethical considerations associated with research on minors (chapter 4.6).

Chapter 5: The school details the relevant particulars of the school involved in this study. It involves both a general description of the school (chapter 5.2) and a description of how project-based learning has been implemented at the school, including a table of projects which the participants had been involved in (chapter 5.3).

Chapter 6: Pilot study accounts for the failed pilot study, detailing answers to the interviews from the first two participants (chapters 6.2 and 6.3) as well as a justification for changing the interview format after this trial run (chapter 6.4).

Chapter 7: Main study describes the interview results of the thirteen participants whose answers were the basis for this study's analysis. The chapter includes relevant quotes from the participants. The first three subchapters discuss what mathematical relevance and irrelevance feels like (chapter 7.2), which aspects of their projects enhanced the feeling of mathematical relevance (chapter 7.3) and which aspects detracted from mathematical relevance (chapter 7.4). The next two subchapters explore the participant's answers concerning which mathematical topics feel intuitively relevant (chapter 7.5), and which other school subjects make for suitable companion-subjects to mathematics in interdisciplinary projects (chapter 7.6). Lastly, the interview data is analysed (chapter 7.7).

Chapter 8: Discussion contains some remarks about the interview data and the consequent analysis. It describes the findings' connection to the known theory and previous research (chapter **Error! Reference source not found.** and chapter **Error! Reference source not found.**) and discusses some discrepancies with these previous studies and potential causes for these differences (chapter 8.4).

Chapter 9: Conclusion serves as the closure of the study. It summarizes the findings (chapter **Error! Reference source not found.**) and discusses the potential effects on implementations of project-based education in the LK20-curriculum with a call for more research (chapter 0).

Appendix A: Audit trail describes the progression of the study and changes made to it along the way.

Appendix B: Pilot Study quotes shows the original Norwegian interview questions and replies for the pilot study.

Appendix C: Main Study quotes shows the original Norwegian interview questions and replies for the main study.

Appendix D: Consent form contains the consent form which was handed to all participants.

2. Theoretical considerations

2.1. Introduction

This chapter will explain the theoretical considerations which have informed the development and execution of this project.

It will explain the philosophical assumptions which underpin the project's methodology, in particular the socio-cultural theory of learning, which forms the basis for project-based education. It will also elaborate upon phenomenology, in particular hermeneutic phenomenology, which informs the project's method and subsequent analysis.

2.2. Socio-cultural theory

Pioneered by Vygotsky (1978), socio-cultural theory is a development of constructivist pedagogical theory. It holds that learning is not only constructed by the learner, as opposed to passively absorbed, but that it is done in a socio-cultural context – with other people as necessary elements in the learning process.

According to socio-cultural theory, learning best occurs in what is known as the *proximal zone of development* (Vygotsky, 1978). It implies the existence of three degrees of problems a learner might face.

The first being problems which the learner can solve on their own, and which offer little to no learning beyond rote and refinement (Vygotsky, 1978). Here, we might consider an average high school student faced with a problem of multiplication, such as 15 • 12. A typical high school student will be able to solve this problem without help, though they might consider it a laborious process. At best, the student might refine their proficiency with multiplication, such that they solve similar problems faster and easier in the future.

The second kind of problems are those the learner is ill-prepared to solve, even with help (Vygotsky, 1978). Consider the average pupil in 10th grade. Such a pupil will be wholly unequipped to solve a problem such as: *find the definite integral* $\int_{-4}^{12} (x^3 + \frac{23}{17})\, dx$. No amount of help will allow the pupil to learn to solve integrals like these. At best, they might be taught how to solve *that particular* integral through rote memorization of the steps, but the understanding of what each step implies will not be transferred from teacher to student.

The third kind of problem exists in the zone of proximal development; it is the kind of problem a learner can solve with assistance from a *learned other* (Vygotsky, 1978). Such problems expand the scope of what the learner can do. In other words, they result in learning and not mere refinement of techniques.

The proximal zone of development is different for each learner and will also be different for different fields. A learner might be proficient in one branch of mathematics, say geometry, but may be a novice in another branch, say functions.

The learned other, who guides the learner through the problem in the proximal zone of development, is typically the teacher, but it can also be other pupils in the classroom. This fact forms a fundament of project-based education, which often presents complex and multifaceted problems in a group context (Blumenfeld, et al., 1991).

2.3. Phenomenology

This is a phenomenological research project. On the topic of phenomenological writing, Creswell (2013) writes:

> *An individual writing a phenomenology would be remiss to not include some discussion about the philosophical presuppositions of phenomenology along with the methods in this form of inquiry. Moustakas (1994) devotes over one hundred pages to the philosophical assumptions before he turns to the methods.*

While this study is not as ambitious as Moustakas (1994) in exploring the foundational assumptions of phenomenology, it is prudent to explain what phenomenology *is* and elaborate some on its philosophical underpinnings.

In short, phenomenology concerns itself with the *lived experiences of phenomena* (Cresswell, 2013). It looks to the common elements of a phenomenon, as experienced by a wide range of subjects, to describe the *essence* of the given phenomenon.

A *phenomenon* can be anything which can be experienced, for example *love*, *stress*, or *creativity* (Cresswell, 2013). In this research project, the phenomenon at hand is *mathematical relevance,* specifically in the context of interdisciplinary PBL. The researcher finds subjects who claim to have experienced the phenomenon and interviews them about the experience (Cresswell, 2013). After the interview, the researcher attempts to find the commonalities between the experiences; the shared elements which appear to make the essence of the phenomenon. For example, people will experience *love* differently, but a researcher might find that *longing, affection,* or *attraction* are common elements between all accounts of the experience, and therefore conclude that these three sensations are core to the experience of *love*.

Key to phenomenology is the process of *bracketing*, in which the researcher is meant to rid herself of her biases and preconceived notions relating to a given phenomenon, that she may be guided by the explanations offered to her by the research subjects (Cresswell, 2013). The process of bracketing can be likened to the chemical engineer's sterilization of the tools used in the laboratory; they wish to look only at a given process, with no contamination from the outside (Cresswell, 2013). The phenomenological researcher attempts to sterilize her mind of preconceived notions, as to not contaminate the accounts of her research subjects with her own biases.

Van Manen (2016) claims that such a complete process of bracketing is impossible in its totality, and that all phenomenological research is hermeneutic by its nature; a researcher will always interpret the accounts of phenomena offered to her through the lens of her own biases. At worst, attempting to rid oneself of such biases may result in overcorrecting, where the researcher instead interprets against her biases and deliberately ignores results which speak in favour of her preconceived notions (Van Manen, 2016). This too fails to capture the true essence of the phenomenon.

Instead, the bracketing process, according to Van Manen (2016) is not about ridding oneself of all preconceived notions, but rather becoming aware of them in advance. As such, the researcher can both be honest about their biases and account for them in the corresponding analysis in a more authentic and reliable manner. By not attempting to do the impossible, the researcher can more accurately present the data in front of her, and a given reader can be adequately informed of the biases which might influence the conclusions in the research.

To ensure that the researcher does not wholly misconstrue or misrepresent the lived experiences of the research subjects, the subjects are allowed to review and request edits of the research material before publication (Cresswell, 2013). This, too, is presented in the research for full transparency to the reader. This affords the research subjects due respect and allows them to claim ownership to the research in a way which might otherwise not be possible. It also alleviates some of the risks of an exploitative relationship between the researcher and the research subject.

Phenomenology's relevance for the present project is plain; the project seeks to examine the common elements of an experienced phenomenon – mathematical relevance in project-based education – such that projects can be crafted to further enhance this experience.

As has been discussed, teachers' intentions and pupils' experiences are not always aligned. It is not uncommon to hear of teachers who have spent inordinate amounts of time and energy on the production of classroom sessions with the intent of amusing and engaging their pupils, only to receive complaints from them. Indeed, entire internet communities are dedicated to jeering failed attempts of teachers and others to relate to the youth of today (r/FellowKids, 2014). It is therefore critical for this project that the pupils be allowed to express what *they* find relevant. No amount of rationalisation is likely to avail in this process. As wide array as possible of different pupils with different experiences is required to find the essence of mathematical relevance, as experienced by pupils at the given age range.

3. Overview of the literature

3.1. Introduction

This chapter concerns itself with the existing literature connected to project-based education and its positive effects, interdisciplinarity in education, as well as pre-existing literature on the phenomenon of *mathematical relevance*.

3.2. Project-based learning

3.2.1. Definition

The exact definition for PBL varies in the literature (Lattimer & Riordan, 2011), but several commonalities exist according to literature reviews on the subject (Megayanti, Busono, & Makun, 2020). PBL is an instructional model which typically sees the students divided into groups which are tasked with solving real cases or questions with high complexity (Megayanti, Busono, & Makun, 2020). The group assignment is referred to as a *project* and should last for an extended time – anywhere from a week to a full semester (Megayanti, Busono, & Makun, 2020).

3.2.2. The motivation for PBL

Schools in modern society are frequently compared to old factories, particularly the kind found during the Industrial Revolution in Great Britain (Davis, Conroy, & Clague, 2020). The source and validity of such claims is beyond this study's scope, but the metaphor enjoys a plethora of champions, from public speakers like the late Sir Ken Robinson (2006) to U.S. Secretaries of Education (Duncan, 2010). Norwegian discourse has also enjoyed the metaphor, both in lesser-known WordPress blogs (Oltedal, 2016) and in mainstream newspapers in the country, penned by board members of the country's Labour Party (Furunes, 2020).

This pejorative argument, as it is commonly presented, dictates that schools themselves resemble factories, into which society inputs children and traditional didactics as raw materials and which outputs workforce-ready adults (Davis, Conroy, & Clague, 2020). Schools are, in this view, unequipped to preserve students' individuality and creativity – especially when coupled with traditional teaching methods.

These traditional methods in education are frequently criticised for being insufficient to prepare students for the nuanced peculiarities of both their professional and personal life (Holtzman & Kraft, 2011). Studies have repeatedly shown that such methods favour standardized tests which enhance an overreliance on rote memorization (Wenglinsky, 2000). Students who perform well in settings with traditional methods frequently struggle with generalizing their rote-learned procedures to new situations (Ishartono, Nurcahyo, & Setyono, 2019).

Since the Industrial Revolution, the frontier of human knowledge and technology has been ever-waxing (Heylighen, 2007). In the modern era, these great bounds have been so accelerated that emerging technologies reshape society's proverbial landscape every decade or so, bringing with them unique benefits and challenges (Heylighen, 2007).

It is difficult to predict exactly which subjects students will benefit from in the future. It follows that methods reliant on rote memorization will be insufficient to prepare students for the challenges ahead.

Some have attempted to identify what skills are generally expected to be of use for our future workspace. The exact list differs between authors, but it is typically accepted that skills relating to problem-solving, interpersonal relationship management, and creativity are what will be needed in the 21st-century workplace (Holtzman & Kraft, 2011).

As we shall see, PBL is a good candidate to satisfy these novel requirements.

3.2.3. Problem solving

As stated, the ability to solve complex problems is one of the desired skills from 21st-century workers.

Exactly what constitutes problem solving skills — and whether these skills are a single construct or a collection of disparate disciplines — is ill-defined and not agreed upon in the literature (Smith, 1991). Indeed, several definitions exist (eg. Heppner & Krauskopf, 1987, p. 375; Anderson, Greeno, Kline, & Neves, 1981, p. 191).

Yet, in spite of a good definition of what constitutes good problem-solving skills, there are some aspects which can readily be agreed on constitutes *bad* problem-solving skills. One common aspect of poor problem-solving skills is the inability to transfer old mathematical knowledge, such as the skills and techniques mastered through routine tasks, onto new and more challenging situations (Mayer, 1998). It not uncommon for pupils to struggle with realizing how to apply what they have learned to realistic situations, i.e., to recognize which situations in the real world can be readily modelled with the mathematics they have already learned (Mayer, 1998).

This study defines problem solving in the context of mathematics in line with researchers such as Resnick and Glaser (1976, p. 236) and Liljedahl (2008, p. 33): attempts at solving problems which have not been encountered before. This choice is informed by the Norwegian Directorate of Education's definition, as expressed in the new curriculum. The new curriculum in mathematics established *Exploration and Problem solving* as one of its core elements (Utdanningsdirektoratet, 2019). The curriculum's official English translation of the value of problem solving follows:

> *[…] Problem solving in mathematics refers to developing a method for solving problems not encountered previously. Algorithmic thinking is important in the process of developing strategies and procedures to solve problems and means breaking a problem down into sub-problems that can be systematically solved. This also includes assessing whether sub-problems would be best solved with or without digital tools. Problem solving also means analysing, rethinking and finding new ways of approaching known and unknown problems, solving them and assessing whether the solutions are valid.*

In short, problem solving is — according to the LK20-curriculum — about solving mathematical problems one has not encountered before and developing strategies which allows one to transfer previously learned mathematical knowledge onto new situations. This is congruent with the previous definitions of problem solving, and also addresses the issue of *bad* problem-solving skills.

Previous research has shown that realistic problems in mathematics help to promote mathematical problem solving (Fuchs, et al., 2006). As previously stated, PBL places pupils in realistic problem-solving environments (Blumenfeld, et al., 1991). This stands in contrast to traditional learning methods, which often focus on low-level tasks. In the case of mathematics, such low-level tasks come in the familiar form of easily completed, but time-consuming routine tasks, e.g., *find the common denominator for these twelve fractions; calculate the percentage change for these ten sale prices.*

Because of the reliance on complex, authentic problems, problem solving is essential to the PBL model (Chiang & Lee, 2016). This means that though pupils may first struggle with the projects presented by PBL, their problem-solving ability is expected to be honed through the process (Chiang & Lee, 2016).

Previous studies on PBL have shown that authentic projects relating to the future profession of vocational high schoolers not only enhance the students' problem-solving skills, but that they also increase the sense of mastery and the motivation for learning (Chiang & Lee, 2016).

3.2.4. Soft skills

Soft skills are here defined as "*personality traits, goals, motivations, and preferences that are valued in the labour market, in school, and in many other domains*" (Heckman & Kautz, 2012). In particular, Heckman and Kautz (2012) identify conscientiousness, perseverance, sociability, and curiosity as valuable personality traits. These traits, they write, do not only predict future labour market success but also serve as valuable predictors of other meaningful outcomes, such as future educational attainment, crime, and health. Most importantly, soft skills may serve as a *better* predictor of these meaningful outcomes than more conventional predictors favoured in the traditional school setting — such as IQ and standardized achievement tests (Heckman & Kautz, 2012, p. 452).

The field of psychology usually refers to personality traits in terms of the Big Five (John, John, & Rao, 2020):

- *openness* — the propensity to have intellectual curiosity, active imagination, etc.
- *conscientiousness* — that is to say, the tendency to be organized, ambitious, determined, reliable and purposeful.
- *extraversion* — the tendency to be talkative, assertive, and inclined to be in large groups of people.
- *agreeableness* — the tendency to be trusting, altruistic, and cooperative; and
- *neuroticism* — the inclination towards negative emotional effects like fear, disgust, guilt, etc.

Psychology has a long history of examining the so-called Big Five personality traits in relation to academic achievement (e.g., Mammadov, 2021; John, John, & Rao, 2020; Trapmann, Hell, Hirn, & Schuler, 2007). Predictably, these studies consistently show a correlation between higher scores of *conscientiousness* and higher academic achievement. Recent studies have also shown that *openness* could be an adaptive trait in education, as changes in teaching methods, such as those brought on by the COVID-19 pandemic, are more easily tolerated by pupils with high scores of openness (Audet, Levine, Ezelbahar, Koestner, & Barcan, 2021). In addition, longitudinal studies (e.g., Soldz & Vaillant, 1999) have shown that several of the Big Five traits correspond to positive life course outcomes, for example linking *agreeableness* to social support later in life.

The traits described by Heckman & Kautz (2012) in the beginning of this subchapter are readily tied to the Big Five traits of *conscientiousness* (perseverance), *extraversion and agreeableness* (sociability), and *openness* (curiosity). Put simply, the body of evidence suggesting that these traits are associated with positive life course outcomes, including — but not limited to — labour market success, is well-established and profound.

As Heckman & Kautz (2012) puts it, personality traits are not set in stone, and can change over the course of life. Education, along with parenting and other interventions, plays a role in influencing personality traits — for better or for worse.

Concerning the potential for developing soft skills, the LK20-curriculum puts implicit emphasis on socio-cultural theory by framing *social learning* as one of its principles for education (Utdanningsforbundet, n.d.g). The core curriculum states that,

> *Learning subject matter cannot be isolated from social learning. […] The ability to understand what others think, feel and experience is the basis for empathy and friendship between pupils.[…] Everyone must learn to cooperate, function together with others and develop the ability to participate and take responsibility.*

Previous research has shown that pupils who engage in project-based learning show signs of better developed soft skills (Musa, Mufti, Latiff, & Armin, 2012). More importantly, the research shows that this improvement does not come at the cost of "traditional" academic achievement, such as test scores. Indeed, a recent meta-analysis showed a positive correlation between PBL and improved academic achievement (Chen & Yang, 2019).

In this regard, PBL shows promise as a method of learning which promotes both subject matter and the soft skills necessary to navigate an increasingly complex labour market.

3.3. Interdisciplinarity in education

3.3.1. Definition

Interdisciplinarity in education typically refers to curriculum which draws on the knowledge of, and crosses the traditional boundaries between, at least two academic disciplines (e.g. Hannon, Hocking, Legge, & Lugg, 2018; Bossio, Loch, Schier, & Mazzolini, 2014).

In this context, an academic discipline is defined as per Dillon (2008, p. 256):

> *(1) bodies of knowledge that have been structured culturally and which can be acquired, practised, and advanced through the act of creating; and (2) culturally defined symbol systems that preserve and transmit creative products to other individuals and future generations.*

It is important to note that an academic discipline is determined based on cultural and historical context. In reality, however, there is often overlap between disciplines. Consider for example the disciplines of mathematics and physics, wherein the physical formulae so integral to the study of physics have their origin in mathematics; or the complexities of biochemistry, which involves both practices from biology, chemistry, and (occasionally, in the form of quantum mechanics) physics.

Interdisciplinarity in education attempts to break education out of these culturally established disciplinary borders (Dillon, 2008).

Interdisciplinarity must not be confused with the similar terms *multidisciplinary* and *cross-disciplinary* approaches. *Multidisciplinary* refers to the "teaching of topics from more than one discipline in parallel to the other", while *cross-disciplinary* refers to an approach wherein "one discipline is crossed with the subject matter of another" (Jones, 2009).

A multidisciplinary approach to mathematics could for instance involve teaching mathematics alongside IT, with the hopes of improving both IT comprehension and mathematics comprehension (Jehlička & Rejsek, 2018). Examples of cross-disciplinary approaches to math education can come in the form of teaching the statistics of elections or the probabilities involved in radioactive decay.

Interdisciplinarity attempts to go beyond these two modes of instructions, which are certainly useful in their own right. A proper interdisciplinary approach to education involves examining problems in which several academic disciplines are fully integrated at all levels.

Concerning mathematics, it is insufficient for mathematics to be merely a tool with which one can examine questions central to other disciplines. The questions – and their answers – must draw on the knowledge of both mathematics and the other relevant disciplines and must be phrased in such a way that the use of each involved discipline can occur naturally and intuitively. The problem must be examined from multiple perspectives and these perspectives must then be synthesized into a coherent framework (Dillon, 2008)..

3.3.2. Interdisciplinarity in the LK20-curriculum

In the context of the new Norwegian curriculum, interdisciplinarity in education takes its form through three topics which span all subjects of the curriculum (Utdanningsdirektoratet, 2020). These topics are *health and life skills, democracy and citizenship,* and *sustainable development* (Utdanningsdirektoratet, n.d.f).

Though it is not explicitly declared in the curriculum, these topics lend themselves well to PBL, in that they present complex, interdisciplinary topics in which a multitude of opinions and perspectives will be available in the classroom. For instance, the topic of *health and life skills* concerns both physical and mental health. Udir describes relevant areas as “lifestyle habits, sexuality and gender, drug abuse, media use and consumption and personal economy” (Utdanningsdirektoratet, n.d.f). In a given classroom, there may be as many perspectives of what is considered appropriate media consumption as there are pupils. It is natural, therefore, to allow pupils to examine these topics in groups and give them extended time to learn from each other. This fits neatly within the definition of PBL as given in chapter 3.2.1.

3.3.3. The motivation for interdisciplinary education.

Existing literature chiefly motivates interdisciplinary education with the premise that the challenges of the modern day are too complex to be constrained to individual disciplines. If an interdisciplinary approach is necessary to face the challenges of the modern day, an interdisciplinary approach to education will better prepare students for these complexities (e.g., Duerr, 2008).

The benefits of interdisciplinary education are many when compared to traditional modes of education. Beyond mere academic achievement, there is evidence to suggest that interdisciplinary instruction allows pupils to develop skills and attitudes which are worthwhile both in future education, everyday life and the workplace (Duerr, 2008). The skills can chiefly be summarized as the ability to tolerate ambiguity, greater creativity, better critical thinking, heightened sensitivity to bias, and balancing objective and subjective thinking (Field, Lee, & Field, 1994).

These qualities are plainly related to the soft skills mentioned in chapter 3.2.4 as well as providing their own benefits.

That is not to say that an interdisciplinary approach to education is without disadvantages. The primary difficulties with interdisciplinary education come in the form of time; it is difficult to produce a meaningful curriculum which breaches previously established boundaries of academic disciplines. When prepared poorly, such as a result of lack of time, it can lead to integration confusion, leaving some disciplines merely “tacked on” (Duerr, 2008).

3.4. Mathematical relevance

3.4.1. Definition

The concept of mathematical relevance is multifaceted and no one definition exists. Instead, different authors focus on different aspects of what it means for a mathematical problem to be *relevant* to the pupil.

A ubiquitous example of an attempt to make mathematics feel more relevant to students is *word problems*. A word problem here refers to a text that describes a situation familiar to the reader and which poses a quantitative question which can be answered by means of mathematical operations performed on the data provided in the text (Greer, Verschaffel, & De Corte, 2002). Greer et al. suggest two purposes of word problems: they allow students to practice problems which relate to reality, and they serve as vehicles for reasoning about mathematical structures through stories.

Indeed, stories are a common form of relevance-building exercises and are frequently employed by teachers to make abstract concepts more concrete (Darby, 2008). The goal of these stories is typically to increase pupil comprehension and motivation by linking the subject matter to their lives (Darby, 2008). Beyond supplying pupils with ready stories through instruction, some teachers also charge the pupils with crafting stories to fit a given topic (Darby, 2008).

Beyond word problems, stories in mathematics can also come in the shape of concrete physical examples to aid with comprehension of mathematical symbols. Darby (2008) mentions one teacher using the real-life objects of apples and bananas in place of the abstract notations for variables *a* and *b*, as an example of stories in mathematics.

The goal of stories, whether in word problems or for illustration of abstract mathematical operations or symbols, remains the same: to make the abstract concrete and to provide a link between the abstract field of mathematics and the lives of pupils (Darby, 2008).

Two aspects of mathematical relevance can thus be discerned from word problems alone: relevant in terms of practical utility and relevant in terms of academic utility. Similarly, an effect of mathematical relevance is plainly that of heightened motivation for the subject.

Considering the first point of practical utility: mathematics is relevant for vocational studies and professional settings, as it is integral to many fields. Several studies have examined mathematics' relevance for vocational studies and students' perceptions of the role mathematics plays for their future. For example, Flegg, Mallet & Lupton (2012) investigated students' perceptions on the relevance of mathematics in the field of engineering. They highlight the precarious relationship between mathematics and vocational studies: math, they write, is integral to the field of engineering, yet students may associate the subject of mathematics with explicit and repeated use of predetermined formulae. Thus, while the ability to think mathematically is integral to engineering, the value of the subject may be obscured by the students' (negative) experiences with it (Flegg, Mallet, & Lupton, 2012).

In addition to the relevance of mathematics to the fields of science and engineering, or relevance for future academic studies, some authors — such as Hernandez-Martinez & Vos (2018) — have also identified an immediate use for coming exams as a short-term form of mathematical relevance. Some students attribute value to their education based on the perception of how likely it is to yield them the skills necessary to attain a high grade. This is separate from future academic utility, in that it concerns itself with the immediate goal of high attainment; a transient, extrinsic motivated goal, as opposed to a lasting, intrinsic motivated goal in the case of future mastery of more advanced subjects.

3.4.2. Cultural relevance

Mathematics is a product of human creation, requiring human creativity in its proofs and discoveries (Raattkainen, 2005). As a human endeavour, it is shaped by the cultures of the humans that participate in it. Through history, attempts have been made to standardize mathematics into a cross-cultural form — and these attempts have been criticized for being Eurocentric in execution (Ravn & Skovsmose, 2019). Nevertheless, mathematics is ingrained in the culture of those who practice mathematics, for example in art and literature (Barton, Poisard, & Domite, 2006).

Mathematics forms an integral component of Western culture, from its connection to the physical sciences to the dependence of economy on mathematics. From the cultural perspective of mathematics education, it is desirable that mathematics be connected to the culture and everyday lives of the pupils (Glanfield & Sterenberg, 2020).

The topic of mathematics and cultural relevance is vast and complex. Relevant for this study is that mathematics can be perceived as more relevant by pupils when the socio-cultural context presented by their education corresponds well with their out-of-school experiences (Gebremichael, Goodchild, & Nygaard, 2019).

3.4.3. Benefits on motivation

As has previously been described, one of the main reasons for enhancing mathematical relevance is the improvement it offers for motivation (Darby, 2008). This effect can be seen even in pupils who do not anticipate having personal use for the topics covered (Hernandez-Martinez & Vos, 2018). It appears that merely having context for how some people use the mathematical topics covered increases the sensation of mathematical relevance and thereby improves motivation and morale (Hernandez-Martinez & Vos, 2018).

Beyond the potential for increasing extrinsic motivation related to immediate academic attainment (Hernandez-Martinez & Vos, 2018), studies show that tying subject matter to pupil's own everyday experiences improves the sensation of mathematic relevance — and as a result, the motivation to learn the subject matter (Miettinen, 1999). Put simply, by seeing how the subject matter can come to benefit them personally and concretely, pupils are motivated to learn (Miettinen, 1999).

However, the motivational effect of mathematical relevance is dependent on pupil identities and goals (Michelsen & Sriraman, 2009). To maximize the effects on motivation, it is important to take the pupil's future goals in consideration when presenting them with content and stories meant to improve mathematical relevance (Sealey & Noyes, 2010).

4. Method

4.1. Introduction

In this chapter, the research method of the study is presented along with its anchoring in existing literature. The merits and limitations of the study are discussed, as well as ethical concerns. It is thusly divided into subchapters:

In *Design and methodology*, the data collection, designs of both the pilot and main study, and the pupil selection is described.

In *Methods of analysis,* Moustaka's (1994) specific method is explained and justified for the project.

In *Authenticity and trustworthiness*, the concept of *reliability* in qualitative – and especially phenomenological – works are discussed. The concepts of *authenticity* and *trustworthiness* are defined and presented as alternatives to *reliability*.

In *Limitations of the study*, both challenges to the study as well as the scope with which the study intends to answer the thesis question and research questions are elaborated upon.

Ethical considerations contains the author's musings on the ethical responsibilities of the study, as well as the ethical difficulties involved in researching on minors.

4.2. Design and methodology

4.2.1. Data collection

This study uses Moustakas' (1994) approach to phenomenological research, as presented by Cresswell (2013) because it, in the words of Cresswell (2013, s. 80), "has systematic steps in the data analysis procedure and guidelines for assembling the textual and structural descriptions".

Cresswell presents the method in five steps:

1) The researcher determines if the research problem is best examined using a phenomenological approach. According to Cresswell, the problems which best lend themselves to such an approach are those which seek to examine the shared experiences of individuals. This study seeks to examine just that: the shared experiences of several pupils.

2) The phenomenon of interest is identified. In this case, the phenomenon is the experience of mathematical relevance.
3) The researcher recognises and specifies the broad philosophical assumptions of phenomenology. See the theory chapter on Phenomenology.
4) Data is collected from the individuals who have experienced the phenomenon. Cresswell points out that other phenomenological scholars such as Polkinghorne (1989) recommends 5-25 individuals who have all experienced the phenomenon. This study uses a heterogenous sample of research participants to explore not only the phenomenon of mathematical relevance, but also what influences its unfortunate counterpart, the absence of mathematical relevance – or mathematical irrelevance.
5) The participants are asked two broad, general questions, relating to their experiences of the phenomenon. They are asked both what they have experienced in terms of the phenomenon and also what situations have influenced the experience. Cresswell (2013) mentions that other open-ended questions may also be asked. Van Manen (2016) cautions the use of open-ended interviews without careful deliberation. The researcher should, according to Van Manen (2016), always remain cognizant of the experiential phenomenon which is intended to be researched. Van Manen (2016, s. 316) mentions that exploring what might constitute as examples or counterexamples of the intended phenomenon are ways to ensure the quality of the interview. For this study, such examples were elaborated on and kept present during the interview.

Once data has been collected, it is analysed according to phenomenological principles (see Methods for analysis).

4.2.2. Pupil selection

The study was presented to students of each 10th grade class during the start-up lessons in the mornings during week 6 of the spring semester 2021. Pupils were allowed to volunteer to be interviewed for the study. Particular care was taken to explain that their grades were in no way affected by their participation. Furthermore, the purpose of the study was elaborated on, using the project relating to personal economics as an example of a project some pupils felt showed how mathematics can be relevant to their everyday lives, while some pupils disagreed. The pupils were informed that the interview would be recorded, but that their participation was anonymous, and that the interview would be deleted following the completion of the study. Finally, they were informed that they could withdraw their consent at any moment.

Pupils were allowed to volunteer to the study over a period of three weeks following their introduction to the study. Each volunteer was given a consent form to bring home to their parents or legal guardians as per recommendations from the Norwegian Center for Research Data (Norsk Senter for Forskningsdata: NSD) (Norsk Senter for Forskningsdata, n.d.).

Following this period, 18 pupils volunteered to participate in the study. However, three of these pupils withdrew their consent after learning that the researcher could not guarantee that they would be allowed to participate in the study instead of attending their usual lessons; meaning they might be asked to participate in their spare time.

4.2.3. Pilot study design

A pilot study was conducted with two participants. The findings in the pilot study necessitated a change in methodology.

These two initial participants were invited one-on-one to the interview during their usual lessons. The interviews took place in a group room adjoining their respective main classroom.

The interview began with a brief repetition of the purpose of the study. The participants were allowed to confirm that they understood that their participation was voluntary and had neither a negative nor positive effect on their grades in any subject.

Once the participant had reaffirmed their consent and confirmed their understanding of the study's separation from their curriculum, they were given an introductory question, here presented translated from Norwegian (for the original, see Appendix B):

> *Pilot Question 1:*
>
> *You have had some eight projects now since eighth grade. In some of them, like the last one you had, you could use math to answer the questions. Can you tell me if you found math to be useful and relevant in any of these projects?*

The intention with this opening question was simply to allow the participants to freely recollect any of their old projects, as opposed to forcing them to consider only one, such as the most recent one.

In line with Moustakas' method (Cresswell, 2013; Moustakas, 1994) (see Data collection), the interview kept a casual, conversation-like air. The pupils were allowed to lead the conversation, talking about what they desired, and were only questioned or prompted to add more for the sake of clarity.

In addition, a second question was posed to discern which contexts provided antithesis of the experiences of mathematical relevance. It was decided against asking which projects felt mathematically irrelevant, as irrelevance is defined as the *absence of relevance*. A project can be designed to facilitate the use of different subjects, having no intention of being relevant for mathematics. While it might be of some value to discover which components the participants could discern made such projects mathematically irrelevant, this study concerns itself with the *antithesis of mathematical relevance*. This implies not only an absence of relevance, which is by itself neutral, but something prompting negative affect towards a given project.

Once they confirmed they had exhausted the subject, they were asked the following question (once more translated from Norwegian – see Appendix B for the original):

> *Pilot Question 2:*
>
> *Is there any project in which you felt math should have been useful and relevant but wasn't? If so, can you think of what was lacking?*

Like with the first question, the participants were allowed to naturally exhaust the subject.

The data in this section is not presented chronologically, but rather grouped after the participants' answers to Pilot Question 1 and Pilot Question 2.

In addition to the specific method of an unstructured, open-ended interview as described above, Van Manen (2016) presents other general considerations for *the phenomenological interview*. In particular, he recommends the interviewee to be personable in order to win the trust of the research participants, thereby allowing them to more easily open up about their experiences. To facilitate trust, he recommends *developing a relationship of personal sharing, closeness or friendliness* before seriously opening up the topic of research (Van Manen, 2016, s. 315). Because the school's group rooms were separated from the main classroom by the means of a glass wall, the interview was held away from the participant's regular classroom, in order to mitigate the disruptive sensation of being observed by classmates during the interview. Van Manen writes (Van Manen, 2016, s. 315): *Perhaps it is better to think of the interview as a conversation than as "interview." Conversations require the right kind of atmosphere and tone.* With this in mind, snacks in the form of cinnamon rolls were served to foster a relaxed atmosphere, while maintaining COVID-19 restrictions. The interviewer also dressed casually and specifically adopted a relaxed body language to reduce the formality of the interview, for example by sitting slouched, keeping one foot on a nearby chair for support.

4.2.4. Main study design

As stated, the interview questions were changed between the Pilot study and the Main study. This was done in response to the findings of the Pilot study, which yielded no analysable results (see Analysis of the Pilot Study). In addition, the interviews in the Main study had to be conducted online, using the Microsoft Teams app. This necessitated different choices for fostering the desired relaxed atmosphere for the study. Two methods were used to promote ease and informality: *mirroring* and talking about the participant's hobbies and interests when they were known to the researcher. Mirroring typically refers to the unconscious process by which participants in a conversation assume the same body language, tone of voice and facial mimicry as the other participant. Research on mirroring has found that when one party mirrors the other, positive affect and bonding is promoted (Drolet & Morris, 2000). In the study, the techniques used to mirror the participants were limited, owed to the aforementioned use of Microsoft Teams – but some methods could still be utilized: slouching or sitting up depending on the participant's posture or using formal or informal modes of speech – like cursing or slang – depending on the participant's use thereof. The participants were also allowed to choose whether to turn on their camera for the Teams meeting, without prompting one way or the other, while the researcher kept the camera on for each interview.

Similar to the Pilot Study, each interview began with an explanation of the research project's purpose, as well as a reiteration of the pupil's rights concerning validating the interview transcript, withdrawing consent, etc. The pupils were asked to express their impression of the project lessons before any of the main questions were posed. This was done to garner better context for the interview answers and to assure a heterogenous interview group, as discussed in the Analysis-subchapter.

The participants were allowed to answer as extensively as they desired on each subject, with only occasional questions being raised for the sake of clarification or to prompt them to continue speaking when they appeared hesitant.

Each interview began with a variation of Pilot Question 1.

> *Introductory Question:*
>
> *You have had some eight projects now since eighth grade. Some have been better than others – can you tell me which one you liked the most?*

While not a neutral question, the intention with this leading introductory question was to place the participants in a more positive frame of mind for the rest of the interview. Follow-up questions were posed about what made the given project the pupil's favourite when relevant. The researcher also reminded the participants of past projects when prompted.

If the participant had not begun to speak of mathematical relevance on their own, the following question was offered:

> *Main Question 1:*
>
> *Math has been more relevant for some projects than others. Think about the most mathematically relevant project you remember. What made it feel mathematically relevant?*

No clarification of the term *relevant* was kept prepared; in case of questions about the word's definition, the researcher intended to instead query the pupil for their own definition of the word, this to promote ownership to their own narration. However, the question was never posed by any of the participants. As such, if they had not already elaborated on the experience naturally, they were asked in various ways to express their experience of mathematical relevance as part of this question.

Pilot Question 2 was retained in the main study, as it was deemed likely to return answers which might better illustrate what aspects of a project should be avoided.

> *Main Question 2:*
>
> *Was there a project you felt should have been mathematically relevant, but which wasn't? If yes, what made it so?*

In addition to the two main questions, the following optional question was prepared in the event that the interview stalled:

Optional Question:

How and why would you design a project if you wanted to make it feel mathematically relevant?

The qualitative data in this study arises from individual interviews. The main study's data comprises 13 such interviews from a heterogenous group of pupils. Table 2 shows a summary of the participants in the order they were interviewed, as well as additional information about each pupil, such as sex, class, attainment characteristic in mathematics, and their self-reported feelings about the project (poor, neutral, positive) as described by the participant in the introductory talks leading up to the interviews. To ensure anonymization of the participants, the class names have been rebranded α, β, γ, δ, ε and ζ.

The attainment characteristic corresponds to the pupil's grade in mathematics and is divided into three categories: Low (corresponding to grade 2), Medium (corresponding to grade 3-4), and High (corresponding to grade 5-6). This was their half-year grade during the autumn semester of 2020.

The interview audio files were transcribed. The details of this transcription as will be elaborated upon in the Methods for analysis-chapter. All participants expressed satisfaction that they interview transcripts were valid, meaning they seemed to represent what the participant had actually meant during the interview, and accurate, meaning the transcripts were congruent with what the participants remembered.

The participants were also allowed to retroactively add additional comments to the interview transcript in the event that they had thought of new aspects of the questions since the interview. This option was used by four of the participants. Their additions are remarked on in Appendix A.

The relevant quotes were translated to English for the sake of consistency in this report. The original statements quoted in Norwegian can be found in Appendix C. For some quotes, the same Norwegian word has been translated to different English ones. This has been done to preserve the connotations of the used words, as the Norwegian language frequently uses the same word in different contexts.

Of note is the overrepresentation of negativity towards the projects. Only three of the participants reported positive affect ("I like the projects", "I learn a lot from the projects") and impressions, while six reported explicitly negative sentiments ("I dislike the projects", "I think the projects are a waste of time").

Table 4-1. Participants of the main study.

Participant description	Pseudonym	Attainment characteristic	Affect towards project lessons	Duration of interview [min]
Male, Class α	"Armin"	High	Poor	42
Female, Class β	"Betty"	High	Neutral	37
Male, Class α	"Cedric"	Low	Poor	36
Male, Class γ	"Dave"	Medium	Positive	82
Female, Class γ	"Eva"	Medium	Poor	40
Male, Class β	"Fred"	Low	Poor	38
Male, Class δ	"George"	High	Poor	36
Male, Class α	"Henry"	Medium	Neutral	42
Female, Class α	"Ida"	High	Positive	28
Female, Class ε	"Johanna"	Low	Positive	43
Male, Class ζ	"Kevin"	High	Poor	35
Male, Class ζ	"Leo"	High	Neutral	37
Male, Class β	"Mark"	Medium	Neutral	52

4.3. Methods for analysis

The analysis was done in accordance with Moustakas' (1994) and Polkinghorne's (1989) previous work, and was conducted in the following steps:

1) *transcription* of the spoken interview to text-form,
2) *horizontalization* of significant statements,
3) production of *textural and structural descriptions*
4) construction of *essential, invariant structure*
5) *comparison to existing literature*

4.3.1. Transcription

The interviews were transcribed to text. This is listed as part of the analysis because some interpretation was necessary to streamline the participants' responses. For example, filler words ("uh", "um", "hmm", etc.) were pruned and stuttering was clarified. Each participant was allowed to offer alterations or additions to the interview transcript.

One participant was uncomfortable with having their voice recorded at all. For this participant, no interview was recorded. Instead, the interview progressed slowly, with each statement written down verbatim by the researcher in the course of the interview. This text was then transcribed and approved by the participant like the other interviews.

4.3.2. Horizontalization

Horizontalization refers to the process of highlighting "significant statements" in the interview transcripts (Moustakas, 1994). For this study, significant statements were those remarks, comments, or answers given by the participants which related to their experiences of mathematical relevance in their project lessons.

Such statements might take different forms: positive statements, relating to occasions when they felt a project was indeed mathematically relevant; negative statements, relating to instances when they felt the project was far removed from mathematical relevance; neutral musings, such as contemplating what might make a project mathematically relevant or irrelevant, and so on.

This process was repeated several times in order to better catch different patterns of the lived experiences of the participants.

4.3.3. Textural and structural description

The significant statements were sorted, or *clustered*, into themes. In this process, repetitive statements are removed. Overlapping statements – statements which refer to the same theme, but which are worded differently – are also pruned from the data.

The *clusters of meaning* were used to write a description of the participants' experience. This is known as a *textural description* (Cresswell, 2013). In addition, a description of the contexts which influenced the experience was produced, known as a *structural description* (Cresswell, 2013). Per the principle of *member checking* (see Chapter 4.4.2 Trustworthiness), the description was presented to the participants, who were allowed to come with suggestions for changes to the description. Per Moustakas (1994), the author of the study also wrote about personal experiences which influenced the analysis (see the concept of reflexivity in the chapter on Trustworthiness)

4.3.4. Essential, invariant structure

From the textural and structural description, two composite *essential, invariant structures,* corresponding to each research question, was written. These summarize the experiences across all participants. Also called the “essence”, an essential, invariant structure contains the properties of the phenomenon which were shared between all participants. This summary often takes form of a descriptive paragraph (Polkinghorne, 1989) and it is no different in this study.

4.4. Authenticity and trustworthiness

According to Van Manen (2016, p. 26), all phenomenology is interpretative in nature. This is explicitly true for this study, as its stated goal is to interpret what the participants say mathematical relevance means to them in light of existing literature on the subject. As such, the study is not *reliable* in the sense that another researcher cannot conduct the study under similar circumstances and be certain that they will achieve the same results; such is the nature of interpretation. Instead, the study must be evaluated based on the principles of *authenticity* and *trustworthiness* (Lincoln & Guba, 1985).

Trustworthiness most accurately models the positivist demands for objectivity and reliability, being methodological in nature (Lincoln & Guba, 1985). As the name suggests, it concerns the methods taken to ensure that the results and conclusions of the study are trustworthy.

Authenticity concerns the participant’s ability to participate in the research in a moral way. This study purports to report on the experiences of minors. Per authenticity, care must be taken in the design of the study, that the participants are appropriately empowered and represented; and that the researchers are accountable for the interpretations they present.

Considering the steps taken by this study to ascertain authenticity and trustworthiness, the suggestions provided by Lincoln & Guba (1985) have primarily been used. One additional method for promoting trustworthiness, reflexivity (see 4.4.2 Trustworthiness), has also been used. Proposed by Amin et al. in a paper aimed for pharmacy research (Establishing trustworthiness and authenticity in qualitative pharmacy research, 2020), it is generally applicable to all qualitative research.

4.4.1. Authenticity

Four aspects of authenticity are relevant to this study: *fairness*, *ontological authenticity*, *educative authenticity*, and *tactical authenticity* (Lincoln & Guba, 1985).

Fairness refers to the extent with which a given work acknowledges value-pluralism. In simple terms, qualitative inquiry is a product of a researcher’s value structures and views of reality. It is possible to construct inquiry in such a way that it excludes alternative constructions of reality to that of the researcher, thereby locking participants to adhere to the researcher's point of view. An extreme example of a lack of fairness may be found in the *loaded question fallacy*, the traditional example of which takes the form "have you stopped beating your wife yet?". This question is locked in the sense that it excludes the possibility that no wife-beating has ever occurred. Similarly, research questions can be constructed such that the participants cannot provide an answer which aligns with their worldview or values.

This study has attempted to ensure fairness by relying on open, unstructured interviews, in which the participants were allowed to lead the discussion. In addition to equalizing the power dynamics of the researcher-respondent relationship, the intention with this approach was to allow for all possible constructions related to the project. In this study, these constructions chiefly concern different impressions of the value of PBL in general and the school's implementation of it in particular. The participants were also offered the chance to approve of the interview transcripts and offer any corrections, addendums, or retractions as they saw fit — a process called member checking. The only aspect of the study which is fixed is the premise that the pupils have participated project lessons. That said, as described in chapter 4.2.4, the initial responses in the pilot study necessitated a change in interview structure, primarily through the inclusion of the introductory interview question. This question inherently assumes that the participant has found some projects to be better than other. However, given the diverse nature of the projects thus far (as described in Table 5-1: Projects at the school.), it stands to reason that some variation in experience can be expected.

While there is inherent positive bias in asking which project the participants liked the most, just as there is inherent bias in declaring that some projects have been more mathematically relevant than others, the other questions in the interview are designed to provide a counterbalance by highlighting negative aspects of the projects. The end result should be a nuanced perspective of the positive and negative experiences relating to the school's projects, without hampering the participant's ability to express any potential opinion on the quality of these projects.

Ontological authenticity refers to the extent an individual respondent's early constructions are improved and elaborated upon, "so that all parties possess more information" (Lincoln & Guba, 1985). Lincoln and Guba (1985) propose establishing the *a priori* positions of the researcher and respondents, as well as comparing to later constructions after the research is conducted. The ability for the participants to add, change, or detract statements from their interview transcripts should cover this criterion, as it allowed a number of participants to change their answers and introspect on the change after the fact. The details of all such changes with relevant introspection can be found in the audit trail. No further attempts were made to examine the post-study constructions of the participants.

Educative authenticity is defined as “the extent to which individual respondents (and the inquirer) possess enhanced understanding of, appreciation for, and tolerance of the constructions of others outside their own stakeholding group” (Amin, et al., 2020). Among the proposals for ascertaining educative authenticity is the maintenance of an audit trail, which has already been described. In addition, each participant was presented with the study’s conclusions and analysis and were allowed to make comments on it, discuss disagreements with the premise or conclusions, or make additions. This was done after the first offer of appending or adjusting the initial interview. For the sake of transparency, no disagreements were voiced by the participants and all participants stated that they agreed with the interpretations of the study.

Tactical authenticity refers to the degree all participants are empowered take the actions that the inquiry implies or proposes (Amin, et al., 2020). Specifically, it refers not to whether the participants of this study are able to construct their own projects but whether they are empowered to participate in the study itself. Proposed methods to improve tactical authenticity which are also used in this study are confidentiality, elaborate and clear consent forms (see Appendix D), member checking (as described earlier), and early agreement of power (Amin, et al., 2020). The early agreement of power in this study refers to both the explicit mention that the study in no way affects the participant’s academic attainment, as well as the specification that the participant both has the right to withdraw from the study at any time and that they have the opportunity to change their answers or influence the conclusions drawn as they see fit. Specifically, each participant was told that the study would not be completed before they had all given their approval of the content within it.

4.4.2. Trustworthiness

According to Lincoln & Guba (1985), *trustworthiness* is comprised of four aspects: credibility, transferability, dependability, and confirmability. Some authors (e.g., Korstjens & Moser, 2018) add reflexivity as its own point to this list. In other words, it concerns to what extent the study’s conclusions can be trusted to be feasible and applicable to other circumstances than the exact particulars of the study.

Credibility is the quality which describes whether the research and its interpretations of the participants' data accurately describes the participants' original views (Korstjens & Moser, 2017, s. 121). Several techniques have been used to ensure the study's credibility. In this study, it is chiefly member checking (Birt, Scott, Cavers, Campbell, & Walter, 2016) which is used to ascertain that the participants feel that they have been accurately represented. In particular, the interview transcripts were returned to the pupils for verification. During these processes, the pupils were able to raise objections and offer corrections. Such corrections are detailed where relevant in Appendix A.

In addition to member checking, *prolonged engagement* (Korstjens & Moser, 2017) has been used to better comprehend the culture of project-based education at the given school. The author of this study worked a year with the participants before the study was conducted and could thus monitor the participants' opinions relating to mathematics and their project lessons through the year.

Transferability is *"the degree to which the results of the qualitative research can be transferred to other contexts or settings with other respondents"* (Korstjens & Moser, 2017). The most common technique used to ascertain transferability is called *thick description*, in which not only the results are presented, also the context in which the results were found (Lincoln & Guba, 1985). This aspect synergizes well with prolonged engagement (see *credibility* above), as the researcher's acclimatization to the participants' culture and idiosyncrasies should allow for better contextualization. In this study, particular care is given to descriptions of the school in which the study took place. When relevant, additional context for the participant data is provided, such as influences at home, corrections to interview transcripts offered by the participant, and other such factors.

Dependability describes the stability of findings over time and is ascertained through an audit trail (Lincoln & Guba, 1985), described in Appendix A. Whenever any alteration was made to findings, on account of further analysis of interview data or otherwise, it was added to the audit trail. Whenever participants added to, withdrew from, or confirmed their satisfaction with their interviews, this was also logged in the audit trail.

Confirmability describes whether the conclusions from the data are indeed derived from the data and not the researcher's imagination (Lincoln & Guba, 1985). In short, it describes whether other researchers are likely to reach the same conclusions as the study, given similar material. Two methods are proposed by Lincoln and Guba (1985) to enhance confirmability: audits — which have already been described, and *triangulation*.

Triangulation refers to the process of using several means of data collection in order to establish concordance of the findings. By using more than one perspective, the researcher can discover congruent findings between the perspectives, which enhances the confirmability. Data triangulation refers to using different sampling strategies for the data collection. This study only looks at interview data. As such, while efforts have been made to ensure a heterogenous participant selection, this study does not make use of triangulation to shore up the quality of its findings.

In addition to audits and triangulation, some authors propose reflexivity as a method to further promote confirmability. Reflexivity is the process by which the researcher acknowledges their own biases, preferences, preconceived notions, and other affect or cognition which might influence their judgement (Korstjens & Moser, 2017). This is in line with Giorgi's ideas of phenomenological bracketing. According to Giorgi (2009) and unlike other forms of phenomenology, the process of bracketing is not about the researcher emptying themselves of their lived experiences, but rather ensuring that past knowledge does not (or at least, to as minimally an extent as possible) influence the interpretations of another's experiences.

To this end, a description of the author of the study, along with any potential biases which might influence the analysis of the data, can be found in chapter 7.7.2 Authorial context.

4.5. Limitations of the study

The thesis question in this study is ambitious, while the sample size of students – indeed of schools (one singular) participating – is miniscule. This study does not claim to fully answer the thesis question but hopes to shed some light on which aspects of PBL and interdisciplinary topics might be worth considering for further research when it pertains increasing the feeling of mathematical relevance.

One primary weakness of the study is its complete reliance on interview data from volunteers. Confirmability could be better achieved through methodological triangulation, but due to limitations of time and resources, this was not achieved in this study.

4.6. Ethical considerations

Any studies involving minors must be subjected to stringent scrutiny. In Norway, minors above the age of 16 can consent to their participation in research. For younger participants, consent must typically be acquired from their legal guardians if sensitive data is collected (Norsk Senter for Forskningsdata, n.d.). Even though the study does not concern itself with the collection of sensitive data, these legal concerns are anchored in several ethical considerations which are central to this study.

Research is inherently affected by power imbalance. The power dynamics in research are inherently skewed in favour of the researcher and against the respondents. It is the researcher who possesses the final say on how the respondents' accounts are interpreted, what is included in the article, and what conclusions are drawn.

This is doubly problematic when the respondents are minors. Adults hold an intrinsic authority over minors, which risks putting a coercive spin on even the most innocuous of discussions. Indeed, NSD places a particular emphasis on ascertaining the voluntary participation of minors in research (Norsk Senter for Forskningsdata, n.d.).

All respondents had to sign a consent form to participate in this study. Parental consent was also required in the consent form. The form can be seen in Appendix D.

5. The school

5.1. Introduction

This section contains information about the pilot study and the main study of this paper. Both were conducted at the same school, and both used the same method of pupil selection. As such, this chapter begins with a brief description of the school, that important context for the study may be presented.

5.2. Description of the school

The study was conducted at a dedicated junior high school – taking in classes at the 8th through 10th grade level – in the Greater Oslo Region of Norway. According to the administration of the school, the school had begun implementing PBL in 2017 to prepare for the coming changes in the LK20 curriculum, specifically the interdisciplinary topics.

5.3. PBL-implementation at the school

The school has prepared for the coming changes in the national curriculum by introducing project-based education into the school's lesson plans. Each school year is divided into three periods (one for each interdisciplinary topic), with each one being designated an interdisciplinary project. Several subjects "give time" from their schedules to the project, which is labelled as a separate subject in the pupils' timetable. The intention is that the interdisciplinarity of the project "lessons" will make up for the time taken from other subjects. All classes at a given grade partake in the same project at the same time.

According to some of the teachers at the school, opinions about the project-based education given at the school vary significantly among the pupils. Some claim they "learn nothing" during the project lessons, which are designed to be free form, allowing students to work on what they deem most important for the given project. Others have expressed that the project lessons are liberating compared to the "stressful and boring" regular lessons.

The general impression among the teacher core is that the pupils with negative opinions about the projects outnumber the positive ones. They also claim that it is culturally acceptable for the pupils to be vocally critical of the projects, while it is seen as socially stigmatizing to be vocally in favour of them. The author's experiences at the school support this notion anecdotally, though no attempt was made to quantify this.

The chapter PBL-implementation at the school shows an overview of both the previously conducted projects and the planned projects for the participants of the study. At the time of the study, the 10th grade pupils had just finished the first of their three periods and completed a project based on personal economy. During the economy project, pupils were tasked with freely choosing a problem relating to personal economy, which they then attempted to resolve or answer through their work. The pupils chose which subjects to be graded in as well as the method of presentation for the final product. Some chose mathematics, as they had covered economics in preparation of the project in their math lessons during the period, but some chose entirely different subjects.

Table 5-1: Projects at the school.

Grade	Project number	*Project name* (Original title in Norwegian)	Notes
8	1	*My voice* (Min stemme)	Politics, in connection with the ongoing election in Norway.
	2	*We save the world. A little* (Vi redder verden. Litt)	Sustainable development. Pupils produced a film relating to sustainability.
	3	*The world's best country* (Verdens beste land)	Geopolitics. Pupils compared Norway to other countries worldwide.
9	1	*The Dream Party* (Drømmepartiet)	Politics. Pupils make up their own political party and participate in the developmental planning of their local community.
	2	*Andromeda* (Andromeda)	Storyline-based. Considered themes of the Earth's destruction and humanity's continued survival.
	3	*Never again 9th April* (Aldri mer 9. April)	WW2 themed. Heavily affected by the COVID-19 lockdowns.
10	1	*The Luxury Trap* (Luksusfellen)	Personal economy. Pupils were allowed to create their own problem and choose which subjects to incorporate.
	2	*Life, plain and simply* (Livet, rett og slett)	Relating to criminality, sexuality, drug use and psychological health. Pupils were allowed to create their own problem and choose which subjects to incorporate.
	-	*Exam preparation*	Pupils prepare for the coming exams. No projects.

6. Pilot study

6.1. Introduction

At first, no pilot study was planned for the project. However, after the first two interviews, it became clear that the study could benefit from some minor alterations in order to produce fruitful data.

The two first participants were from different classes, of disparaging grade levels in mathematics, and with no discernible relation. Despite this, both participants offered surprisingly similar, wholly negative accounts of their experiences with the school's projects during their respective interviews.

The data in this section is not presented chronologically, but rather grouped after the participants' answers to Pilot Question 1 and Pilot Question 2, which were described and justified in chapter 4.2.3 Pilot study design:

1. *You have had some eight projects now since eighth grade. In some of them, like the last one you had, you could use math to answer the questions. Can you tell me if you found math to be useful and relevant in any of these projects?*
2. *Is there any project in which you felt math should have been useful and relevant but wasn't? If so, can you think of what was lacking?*

6.2. Answers to Pilot Question 1

Both participants expressly denied having ever felt that their projects were useful. The first participant (P1) was particularly vitriolic in their description of the school's implementation of PBL. Their translated rebuke follows:

P1: *Project is so worthless. I'm sorry, but it's such a waste of time. We don't learn anything. We aren't even graded.*

Interviewer: *What about the project you just completed, that one about economics? What do you think about the math relevance there?*

P1: *It was awful. So boring. We didn't learn anything math.*

The second participant was likewise negatively inclined towards projects in general and the economics-project in particular:

P2:	*Project is the worst subject we have. You always get grouped with people who don't do anything. You don't learn anything. Nobody does anything because we don't get graded anyway. The teachers don't even care.*
Interviewer:	*I understand that you are displeased with projects. But, has there been any project at all which you have felt has been better than the rest? More relevant?*
P2:	*No, it's all trash.*

Both participants were asked what might be improved in order to make the project lessons feel more worthwhile, and both participants answered some variation of "everything". Neither offered any elaboration on how they would design a project to make it more conducive for learning, requesting instead that projects were removed entirely from the school's schedule and replaced with traditional methods, such as whiteboard instructions, written tests, and no group activities.

6.3. Answers to Pilot Question 2

Neither of the participants offered a detailed view on which projects they expected to be mathematically relevant, but which failed to live up to these expectations. Less time was spent on this question than the first as both participants appeared to be satisfied with their initial rebuffs of the school's project.

They both claimed they could think of no project which fit the description in Pilot Question 2.

6.4. Analysis

The results, though extreme, appears congruent with the general climate towards the school's project lessons. As previously stated, many pupils expressed a significant displeasure with school's implementation of PBL.

Both participants were so thoroughly negative in their discussion about projects that no further analysis of the data could be performed. It is the opinion and interpretation of the researcher that they used the interview as a vector for ventilating their frustrations with the school's particular implementation of PBL, and that they would not entertain the stated purpose of the research project. Put another way, the two participants appeared on a mission to convince the researcher that the concept of project-based education, at least in the shape of the school's implementation, was a waste of time and should be generally discouraged.

While all possible conclusions to the research questions must be entertained, it was decided to make slight alterations to the interview questions to facilitate a wider nuance of responses from the future participants.

7. Main study

7.1. Introduction

This section contains the results of the main study. A total of thirteen pupils participated in the main study, which differed from the pilot study in that the choice of opening statements. As remarked upon in the pilot study chapter, the initial two participants in the study expressed themselves so ardently against PBL in general and the school's implementation of it in particular, that no nuance could be extracted from their statements for the purpose of answering the study's research questions.

An additional challenge in the Main Study was the occurrence of another lockdown order due to heavy infection rates of COVID-19 in the school's municipality. The interviews were thus conducted through Microsoft Teams, which all pupils were familiar with. The change to an online interview format prompted other methods for ensuring the participants' sense of comfort. These changes are described in further detail in the *Design and methodology* chapter.

This chapter begins with descriptions of common elements for the experience of both mathematical relevance and irrelevance by the participants.

After conducting the interviews, three general patterns of answers could be determined from the interview transcripts. *Positive project aspects* details what aspects of the previous projects made them feel the project was mathematically relevant. Similarly, *Negative project aspects* describes what aspects of past projects made the participants experience a lack of, or antithesis of, mathematical relevance. *Relevant mathematical topics* details which of the topics the participants had received instruction in through their junior high school career was associated with mathematical relevance. Finally, *Fitting school subjects for interdisciplinarity* describes the other school subjects which the participants felt naturally connected with mathematics and would make for clear and intuitive partners for mathematics, either for a future project or as an example of matchups in previous projects they felt worked well.

7.2. The experience of the participants

The aim of this subchapter is to detail the participant's reports of the experience of mathematical relevance and irrelevance.

7.2.1. Mathematical relevance

A ubiquitous theme in the descriptions of all participants was the heightening of motivation to exert effort to solve the given problem. To quote participant "Henry's" almost poetic description:

"Henry": *When it's relevant, you bother. When it's not relevant, you don't bother.*

This sentiment was repeated by all other participants in one form or another. For instance, "Fred" — whose opinions about mathematics were self-reported as bleak on the best of days — stated it as:

"Fred": *There's not much math I think is relevant, but when there is some, you want to do it. Like, you don't give up as easy even if normally you wouldn't bother.*

Others were more colourful in their descriptions. "Betty" was particularly enthusiastic about the benefits of relevant mathematics, describing a more overpowering sensation of motivational increase:

"Betty": *It feels like you just have to see it through. I can get completely obsessive about it's relevant. I sit for hours and just work and work.*

In her descriptions of the experience, "Betty" also touched upon another aspect of the feeling of relevance which was shared by many participants:

"Betty": *It's fun. You enjoy doing it. And you want to see what comes next.*

Not every participant agreed that relevance produced mathematics which was fun to participate in. Some described it as a chore, albeit a less tedious chore than normal.

The notion that relevance produces a curiosity of *what comes next* was a common description shared by a majority of the participants, with exceptions only in pupils like "Fred" whose opinions about the subject were profoundly negative:

"Fred": *No, I never find math interesting. When it's relevant, I can survive it though.*

7.2.2. Mathematical irrelevance

This subchapter will describe the experiences of the participants when discussing the antithesis or lack of mathematical relevance.

Just as an increase in motivation was ubiquitous for relevant mathematics, so was a loss of motivation for irrelevant mathematics. Several participants describe a nearly sedative effect of irrelevant mathematics.

"Armin" described this sedating influence in no uncertain terms:

"Armin": *When it isn't relevant, it's so boring you feel like going to sleep.*

All other participants mentioned boredom and an increased propensity for tiredness when exposed to irrelevant topics of mathematics.

Not all instances of irrelevance produce somnolent pupils, however. Depending on the circumstances, far negative affect can be begotten. All participants reported increased confusion and frustration when exposed to topics which were not only personally irrelevant, but for which they could not perceive the potential relevance at all. "Cedric" highlighted this frustration well and touched on another important aspect of it:

"Cedric": *I'm stupid. I often don't see the point of math. What is the teacher talking about, you know? I get angry with them for not explaining it better. What are we doing and why are we doing it? I get angry with myself for being so stupid too.*

Not only does "Cedric" punctuate the teacher's responsibility for providing context but he also touches on the risks of failing to do so by expressing how he feels stupid for not understanding the relevance of some mathematical topics.

Indeed, anger and despair over one's own capabilities was a common theme from "Cedric", "Fred" and "Johanna", who all shared a low attainment characteristic in mathematics. Others described similar frustrations, albeit in less despairing ways.

At the high end of the attainment characteristics spectrum, the despair over one's lacking abilities seems to have been replaced by disappointment instead: "Betty", "George", "Ida" and “Kevin” all described similar experiences when talking about being instructed in a mathematical topic they did not perceive as relevant. To quote “George”:

“George:” *It’s a little ridiculous when you’re shown something on the whiteboard that seems completely pointless [laughs]. I know that it’s rarely the case, but sometimes you just don’t know why they’re showing you something. It’s disappointing. You can’t judge how much effort you should put into it. Is it important? Will it be on a test? Is it important for learning something else in the future? Or is the teacher just being weird about this one specific thing? I think a lot of frustrations could be avoided if teachers talked more about what things were for.*

There is no indication that “George” or his peers considered themselves or their cognitive abilities lesser when exposed to irrelevant topics. The prevailing experience appears instead to be related to having their time wasted: “You can’t judge how much effort you should put into it. […] Will it be on a test? […] Or is the teacher just being weird about this one specific thing?”.

7.3. Positive project aspects

This subchapter will detail the significant statements relating to what the participants related to triggering a sensation of mathematical relevance during their project lessons.

Ubiquitous to the experience of relevance was the feeling of heightened motivation when exposed to a project which highlighted relevant mathematics. Other common descriptions of relevance concerned understanding and comprehension; the participants all reported improved relational understanding, that they felt mathematics was relevant to them when they understood both *what* they were doing and *why* they were doing it (Skemp, 1976, p. 21).

Though the experience of mathematical relevance is undoubtedly important in its own right, this study concerns itself with the aspects of interdisciplinary projects promote the sensation. Therefore, while the experience of mathematical relevance will be briefly presented as it was described by the participants, this section will focus on the reported triggers of mathematical relevance. Stated differently, this section concerns itself less with *how* mathematical relevance is experienced and more with *what* the participants could recognize brought about the experience.

Though participants expressed widely differing impressions of the triggers to the phenomenon of mathematical relevance, showing different and often contradictory priorities to one another, there were some commonalities.

The interviews revealed at least four common categories of responses: “*future utility*, referring to recognizing that the math in the project will be useful to the participant later in life; *novelty*, meaning the subjects covered were new; *practicality*, meaning the mathematical subjects allowed the pupil to use their body in some manner to solve the problem; and *complexity*, meaning it challenged the pupil in a manner they found granted the problem an air of realism. Table 7-1 shows the most common answers relating to *Main Question 1.* The participants often gave answers which fit in more than one category and are registered thus.

Table 7-1. Common statements regarding the triggers of positive sensation of mathematical relevance.

Positive triggers of mathematical relevance		
Statement Category	Frequency	Relative frequency
Future utility: Everyday life	10	77%
Future utility: Vocational	9	69%
Future utility: Educational	6	46%
Novelty	5	38%
Practicality	4	31%
Complexity	4	31%

7.3.1. Future utility

Though the participants described the sensation of mathematical relevance in connection with the projects with widely differing impressions, there were some prevailing commonalities. A common theme was a heightened sense of motivation to learn and perform, spurred by a sense of *future utility*: all thirteen participants described feeling that mathematics was relevant to the project when they could picture themselves performing the same mathematical operations at some point in their future. “Henry” put the matter succinctly:

“Henry”: It’s a waste of time if we have no use for it.

This ubiquitous description took different forms from different participants. The most common form was that of utility in everyday life, meaning mathematics which the participants felt could conceivably be used in a domestic setting, such as at home or at the grocery store. Many of the participants recognized that this narrowed the branches of relevant mathematics down to the essentials of arithmetic and possibly some geometry. The participants with low attainment characteristics in mathematics all explicitly stated that other forms of mathematics, particularly mathematics reliant on algebraic notation, was irrelevant to their everyday lives. "Fred" appeared particularly frustrated by the discrepancy in time allotted to the more abstract topics of mathematics, such as algebra or functions:

> *"Fred":* *There's no point at all in learning about graphs or equations. We don't need it. I'm not going to sit at home and make a graph about my groceries or an equation about my job. I'm not going to go, 'right okay, we need to pay x this month', it's stupid, I'll just add it up. That's all you need! Plus and minus and times. Maybe divided. Maybe percentages like once a month on sale but even then, they tell you what it costs at the store.*

Though most others did not express Fred's particular degree of frustration, many participants expressed a lack of comprehension pertaining to the usefulness of many of the mathematical topics covered at the junior high school level. "Mark" expressed the confusion in a nuanced manner which seemed to echo the complaints of his peers:

> *"Mark":* *We don't know why we must learn these things. Like, we know it's useful. But it's only useful for some other people. Scientists maybe, and mathematicians. I don't think my mum sits and thinks about functions.*

Other participants put their emphasis on vocational utility instead – meaning that they felt mathematics were relevant if they could picture themselves performing the mathematical techniques learned in pursuit of some professional goal. "Mark" also mentioned this:

> *"Mark":* *I want to be an electrician. Do electricians have to solve equations every day? I don't know. Maybe they do, but I just don't know. So, I don't know if equations are relevant to me.*

Some participants – “Cedric”, “Johanna” and “Henry” – brought up future utility with a sole focus on vocational utility. Johanna’s statements can be used to summarize the attitudes of these three participants:

> *“Johanna”:* *Most of what we learn is useless to us. You just learn it for the problem and then you forget it. I wish we could just learn what we must, to do our jobs.*

Johanna had, in particular, described her disdain for school mathematics which served only to build a foundation of more school mathematics, using algebraic notation with letters for variable names as an example. When she mentioned that math felt relevant if it was useful for the future, the possibility of further studies in mathematics was raised as a potential use. She rejected this:

> *“Johanna”:* *No, it’s not relevant. Like, I know I won’t sit and do algebra at home […] I won’t be a mathematician or a teacher or whatever, so I don’t need it. I need to know how to pay bills and taxes and not become poor. Maybe I need to learn how to use Excel and stuff if I have to work with it.*

Other pupils did not mention the vocational aspect at all. “Dave”, “George”, “Ida”, “Kevin” and “Leo” all mentioned the future utility of mathematics from an educational standpoint instead: math is relevant if it helps them learn other forms of math, or other subjects such as physics, later on. “George”, a pupil who partook in theoretical math at a secondary education level, phrased it thus:

> *“George”:* *Some math, you learn once and never revisit it again. Other things, like Pythagoras’ thesis, you get to use again and again. It helps you learn trigonometry […] and you can use it in graphs and for vectors […] Functions are also […] useful. You need them for calculus. Can’t do calculus without functions.*

Though the other participants who also mentioned this category lacked “George’s” explicit comprehension of future math subjects, they nevertheless expressed that mathematics chiefly became relevant for them if it helped them understand how the mathematical themes would help them progress in later education. “Ida” further elaborated on the complexities with correlating current math with future math. The pupils often do not know which concepts will be useful for them in the future, which serves as a double-edged sword. While some subjects are unfairly considered irrelevant because the pupil cannot see the use in the future, “Ida” expressed a particular delight in suddenly seeing the connection to future subjects:

> *“Ida”:* *Some of the topics are confusing. The binominal formulas were like that. Then, I understood that you can use them on second degree functions […] to rewrite them so they’re easier to work with. That made them awesome. Before, they were dull. But then they suddenly turned nice. […] It was sick when it finally clicked.*

7.3.2. Novelty

Some pupils who view relevance in terms of future educational utility might lack the patience to wait for these connections to reveal themselves. Several participants expressed that they only experience relevance when working on novel concepts. They expressed that excitement is the unifying sensation of all instances of experienced relevance. “Dave” tied this sensation to future utility in that he could clearly see the relevance of a given subject of mathematics if it introduced a wholly novel branch of the subject. Abhorring repetition, he appeared to reject the ideas of Ida. He expressed that it was insufficient for a given theme to elaborate on or provide nuance to already examined subjects. He also dismissed the notion of using an already mastered method or technique in math on a novel problem. Instead, he advocated for the introduction of such problems in the project lessons as would force a student to take “the next step” in their mathematical development:

> *“Dave”:* *I think it gets boring too quickly. We always do the same and the same and the same. You can’t really call it relevant anymore because you’ve already done it. It’s just tediously doing it again. It’s only relevant to me when you have to learn something new to solve [the project].*

As an example, Dave referred to the Andromeda-project, which he felt could easily have provided opportunity to learn the math used in different physics formulae relating to the force of gravity or rocket science. Though Dave was alone in the specificity of this request, there was a sizeable minority of the participants who related relevance to novelty, meaning that they expressed that the sensation of relevance dropped the more familiar they were with the topics discussed.

The participants who did not mention future educational utility as a trigger for mathematical relevance, but who nevertheless identified novelty as a contributing factor, were not concerned with learning novel mathematical techniques or themes. Instead, they reported experiencing mathematical relevance when known mathematical techniques were applied in novel contexts. Eva expressed her desire for novelty in a manner which tied neatly to her previously stated aspects of future utility in everyday life and vocational circumstances:

> *"Eva":* *It's neat when you get to see [the mathematical techniques] used. Usually, it's just in a book. And like, I guess that's fine, but it's better when I can really see how it's used, for real. […] The best was when I did the economy project and we used functions for saving money. I already knew [exponential functions] from class, but we had used it on flowers and the likes. It was neat, seeing it suddenly useful for saving money.*

"Armin", "Leo", and "Ida" also mentioned novelty in their interviews. Like Eva, they brought up that their feelings of mathematical relevance were heightened when they could see old techniques from their math lessons applied in new situations in the project lessons. Though "Eva", "Armin", "Leo" and "Ida" all mentioned different mathematical subjects (e.g., exponential functions for savings in the case of "Eva") in their examples of old techniques used in novel situations, they all expressed delight in seeing Microsoft Excel being useful for practical everyday matters relating to economy, such as budgeting, or vocational matters such as accounting.

7.3.3. Practicality

A recurring, albeit less common (at 4 out of 13 answers), suggestion was that the feeling of mathematical relevance was heightened during practical contexts. Here, a *practical context* refers to any situation where the pupils are obliged to move, physically exert themselves, or otherwise use their bodies in ways outside of the ordinary classroom setting.

The participants could provide several examples, both of past instances and of desired hypothetical situations, which could help promote the feeling of mathematical relevance. In particular, they referred to the previous project *The Dream Party*. In it, they were asked to imagine themselves forming a political party and participating in the local politics of their municipality. As part of the project, they were tasked with planning out an activity house for the youth of the municipality. This, they reported, allowed them to find novel situations which required hitherto unknown mathematics to solve.

When discussing the experience, participant Armin expressed the benefit of using real-life, practical situations to improve pupil participation in a given mathematical project:

> *"Armin":* *When you have project [lessons] you're meant to consider what you would've done in a given situation. And many will then think, what would I have done? In that case, they'd think more and would use math in a more relevant way.*

This aspect of practicality seemed to be tantalizing for the participants because it allowed them to learn new mathematics, tying the practicality of the exercise to *novelty* and *future utility* both.

Another aspect of practicality which repeatedly came up was in relation to statistics. In this instance, the participants mentioned the use of practical situations as a beneficial alternative to textbook exercises. When learning about statistics, they reasoned, they would understand the contexts of properties like the median, average, mode, and range, if they were made to go outside and conduct their own statistical examination. A similar approach, they claimed, would help them understand the contexts for other mathematical concepts, by first introducing them in the classroom and then allowing them to explore the real-life contexts which give rise to their necessity.

While similar to the first aspect of practicality, the order of context and method instruction are flipped in this case. In the former, the pupils first discovered the context where they required new mathematical methods and were then given instructions relating to the methods required to solve the problem at hand. In the latter, the pupils are taught the method in the classroom, but are then allowed to construct their own examination or situation where they are required to use the method.

7.3.4. Complexity

Another sizeable minority specifically mentioned complexity as a trigger for the sensation of mathematical relevance. When participants in this group discussed relevance, they did so without mentioning utility for themselves — be it vocational, educational, or in everyday life — but instead specifically and explicitly mentioned that the complexity of a problem caused it to *feel* relevant.

Complexity in this instance must be carefully defined. The participants were careful to remark that *complex* does not mean *difficult*, in the sense that the problem was beyond their ability to solve without help. Rather, they specified that a complex problem has a solution which requires more steps than a simple one. For example, "Leo" phrased it thus:

> *"Leo":* *It's not that it should require, like, a new function we've never seen before. But a relevant problem isn't just solved in 1-2-3. It could be that you first have to calculate the volume of something, and then the mass, and once you have the mass, you get the acceleration, and then you can answer whether or not it would cost too much to do it.*

As seen from "Leo's" example, the notion of a *complex problem* here involves several steps each of which makes use of familiar concepts. Solving it becomes a matter of seeing connections between different formulae and concepts, rather than simply finding the one solution which will elegantly undo the problem.

Though initially without reference to real life contexts, the participants conceded that the complexity of certain problems gave them a heightened sense of verisimilitude compared to simpler problems. The following quote from "Eva" highlights the connection between complexity and problems which feel authentic:

> *"Eva":* *In real life, you don't get it served on a silver platter. Like, it's never that you have to find just the hypothenuse. It's that you want to build a table, or something. And the hypothenuse is just the distance between the legs, which you have to know to figure out where to put the screw holes, or something like that.*

The other participants also mentioned that a good complex problem should have a deceptively simple phrasing, in line with Eva's "build a table"-suggestion. Instead of having a problem which is explicitly subdivided into sub-problems, which spell out the solution for them, they requested apparent simplicity in the initial constraints and the problem's formulation, such as: "A solid gold ball has the circumference 10 cm. Could you afford the gold ball at $1800/kg if you have $500 to spend?".

In the problem above, which the participants confirmed was a decent (but not great) example of what they meant, the problem's goal is explicitly stated ("can you afford the object in question") and the initial constraints are given (the circumference of the ball, the gold price per kg, your budget). Yet, the solution requires you to:

1) First calculate the radius of the ball through the circumference formula, which must be manipulated to provide the desired parameter.
2) Then, the volume of the ball must be calculated.
3) Then, using the density of gold, the weight can be calculated and potentially be converted from grams to kilograms.
4) Once the weight of the ball is established, the price of the gold ball can be calculated with the given price.
5) At last, this price is compared to the budget given in the problem, and an answer can be given[1].

7.4. Negative project aspects

This subchapter lists the aspects of projects which were mentioned in association with mathematical irrelevance by the participants.

7.4.1. Disorganization

All participants mentioned disorganization as a cause for feeling an entire project — including the mathematical aspects thereof — was irrelevant. The majority of them mentioned the project *Never again 9th April* as an example of a poorly organized project. This project, intending to explore Norway's role during World War II, as well as the Nazi occupation of the country during that era, was heavily impacted by COVID-19 lockdowns during the spring of 2020. As a result of these lockdowns, which included extensive periods of digital schooling for the pupils, many of the intended activities for the project — such as visits to museums, memorials, or the production of miniature panoramas of scenes from the war — were abandoned for more traditional essay-like submissions, often with what the participants described as a haphazard and makeshift quality.

While not relevant to mathematics specifically, the participants expressed that disorganization in general made them "tune out" from any given project and made them less inclined to work. In the words of "Kevin":

> *"Kevin":* *If not even the teachers can be bothered to do it properly, it can't be very relevant, can it?*

[1] For completion's sake, the answer is *no, you cannot afford it.*

7.4.2. Project teachers with inadequate interdisciplinary expertise

More critically than the general condition of good organization, participants mentioned feeling less relevance when they encountered project teachers who were unable to answer their inquiries related to subject matter. The problem appeared exacerbated when more abstract subjects were involved, such as a social studies teacher failing to answer a question about mathematics.

As an example, "Dave" mentioned a telling example in discussing the project "*We save the world a little"*. In this project, the pupils were tasked with researching a topic related to sustainability and the environment, for example global warming. They were expected to examine the root cause of their chosen problem as well as potential solutions to it, including conflicts of interests which may stand in the way of realizing these solutions.

When he asked to social sciences teacher attending the project lesson about a particular aspect of the theory of global warming, he could not receive a satisfactory answer:

"Dave": *It kind of defeats the point of interdisciplinarity. It's meant to be these two subjects coming together. But if the teacher doesn't know more than their own subject, it's not very believable.*

Others had similar experiences to share, relating more directly to mathematics.

"Betty": *One time, I asked [a substitute teacher] how to make a graph over the economy and he said he didn't know and that it probably wasn't that important.*

Interviewer: *In a project in which you had picked math as one of the subjects to be graded in?*

"Betty": *Yes! And, like, I know he was wrong in a way. But at the time, it made the whole thing feel irrelevant.*

Interviewer: *Why do you think that is?*

"Betty": *Like… If he couldn't do it, had no use for it, and he made it out fine, it doesn't seem like it's necessary. So, it's just like propaganda, you know?*

Interviewer: *Propaganda? That functions and the likes are useful?*

"Betty": *Yeah.*

7.4.3. Problem ambiguity

The participants who requested complexity from their projects also specified a difference between the unknown steps from beginning to end in a complex problem and *ambiguity*. While they professed a fondness for problems which required several steps but were not explicitly subdivided to show the necessary steps, they also professed a strong dislike for ambiguous problems. Those who could refer to examples all referred to certain open-ended questions, which required the pupil to make assumptions about the constraints of the problem. "Eva" provided a specific example from the math lessons:

"Eva": *We got a problem about paying for something in the store. I think it was sodas and pastries, like two or three sodas and four pastries, and together they cost 50kr or something.*

Interviewer: *This was a bad and ambiguous problem?*

"Eva": *Yeah.*

Interviewer: *What was the problem exactly? What did it ask?*

"Eva": *Like, we were meant to find out what the price for one soda and one pastry could be.*

Interviewer: *Right, I understand. Why was it bad, do you think?*

"Eva": *It could be anything! Like, you could make the sodas cost ten each and the pastries cost, uh, wait ["Eva" fiddles with her phone, presumably a calculator] ... seven and a half. Or you could make the sodas cost fifteen each and the pastries five. But it could be anything. There's no way of getting a right answer. There's no way of knowing!*

The problem's constraints were ambiguous in this instance; is the pupil expected to find an integer solution, or use only known constellations of monetary fractions from the store? While intended to allow for several, creative answers, the participants reported both frustration and an absence of the feeling of mathematical relevance from such open-ended problems.

7.5. Relevant mathematical topics

In addition to the positive triggers of mathematical relevance discussed in the previous chapter, the pupils made statements regarding which mathematical topics they felt were most relevant to them.

All mentions of mathematical topics which were tied to relevance are shown in Table 7-2.

Of note is that all participants mentioned basic arithmetic as relevant to them. However, as arithmetic forms the backbone of all other topics, its relevance is addressed through the other topics.

As with *triggers for mathematical relevance*, a wide variety of subjects were mentioned, though there was complete agreement in associating the topic of *economy* with relevance. Several participants mentioned the economy-project — *the Luxury Trap* (see Table 5-1: Projects at the school.) explicitly when discussing which projects felt the most relevant to them.

Table 7-2. Mathematical subjects covered by the junior high school curriculum, coupled with statements linking them to mathematical relevance by the participants.

Math subject	Frequency	Relative frequency
Arithmetic	13	100%
Economy	13	100%
Statistics	8	62%
Geometry	3	23%
Equations	2	15%
Functions	2	15%
Algebra	0	0%
Probability	0	0%

7.5.1. Economy

All participants mentioned economy as a relevant topic. As “Kevin” put it:

> *“Kevin”:* *Economy is the most relevant topic because we all have to make money to not get poor. There’s a lot of tricks out there. Like, tricks we can use to save money through investments and the likes. You can’t just get Bitcoin and GameStop*[2] *and hope for the best. And like, there’s tricks they use to take our money too. It’s important to know about.*

These sentiments were echoed by other pupils. By far the most common statement across all participants was the notion that their feelings of mathematical relevance were heightened in the project The Luxury Trap (see Table 5-1: Projects at the school.) — a project concerning economy and how to be fiscally responsible. “Betty” summarily expressed the matter in a manner which seemed to represent the verdicts of all participants well:

> *“Betty”:* *That economy-project was relevant. You can at least say that it’s something we’ll need — with interest rates and such. It becomes more relevant. People are encouraged to do it since they’ll need it.*

7.5.2. Statistics

Another popular subject was statistics, with 8 of the 13 participants mentioning it explicitly. The vast majority of these pupils mentioned its relevance in terms of the potential practicality of the education; through statistics, they argued, they could be given tasks which involve conducting statistical examinations outside of the school building. Only three of them, all with high attainment characteristics in mathematics, mentioned future utility in association with statistics — the usefulness of understanding statistics in order to better comprehend the news or for inoculating themselves against misinformation, promoted through bad statistics.

[2] This refers to the sudden inflation of the GameStop Corp. stock price of 2021 (Chohan, 2021), which became infamous (WallStreetBets GameStop Short Squeeze, 2021) in some circles of the internet frequented by several of the participants.

7.5.3. Other topics

Other suggestions were rarer. As the third most common suggestion, geometry had only three advocates. All of these participants mentioned the first project of 1st grade, "The dream party", wherein they designed a youth activity house using familiar geometric shapes.

Equations and functions were also mentioned, but only by two participants — Armin and George — as subjects which promoted relevance. In their musings on how these subjects feel relevant, both participants mentioned that they could be considered essential skills to master for budding entrepreneurs. Equations and functions can for example be constructed to represent earnings per product sold.

7.5.4. "Missing" topics

The Norwegian curriculum at the time of the study also contains the subjects algebra and probability (Utdanningsdirektoratet, 2013). These are listed in Table 7.3 for the sake of completion, even though no participant mentioned them as relevant subjects.

With this in mind, a potentially important piece of context relating to the subjects *economy* and *statistics* is that the participants had recently completed instructions in these subjects shortly before they were introduced to a project in which they could be considered natural to apply.

The economy subject was exhausted during a period of four weeks with the project The luxury trap (relating to personal economics) beginning during week three of this instruction. Similarly, the participants had already received several weeks of instruction relating to statistics when they began the project The dream party. This party, being political in nature, was reported by many participants as feeling natural for the subject of statistics, as it pertained to voting and voter's opinions.

The lack of inclusion of probability, and the high frequency of replies lauding economy and statistics as relevant subjects, is indicative of a recency bias joining the subject of mathematics and the projects, which will be further explored in chapter 10 Discussion.

7.6. Fitting school subjects for interdisciplinarity

Several participants mentioned other school subjects which they felt could be paired well with mathematics in order to facilitate more relevant projects. Their answers are shown in Table 7-3.

Table 7-3. School subjects reported as good fits for interdisciplinary projects paired with mathematics.

Subject corresponding to math relevance	Frequency	Relative frequency
Science	7	54%
Social studies	5	39%
Programming[3]	6	46%
Art	2	15%

7.6.1. Science

The most popular choice was evidently the subject of science. In particular, the participants who proposed science pointed at the topic of physics, which is covered in the science subject. Because physical formulae are mathematical in nature, they reported it as a natural pairing with math.

Another common answer among those who recommended science was a disappointment with the project *Andromeda*. In this project, the pupils were presented an imaginary setting in which the world was about to end and in which they had to flee to the neighbouring galaxy Andromeda to ensure the survival of mankind. This, they reported, they expected to involve mathematics far more than they did. They reported expecting physics-based problems, coupled with resource management tasks. The problems they were faced with were instead focused on social studies, with moral and political questions such as how they should choose who could and could not get a spot on the rocket and how to make first contact with potential alien species. The project also involved the art subject, with pupils designing planets and rockets based on aesthetics alone. While many pupils enjoyed the consequently *relaxed* atmosphere of the project, others were decidedly displeased. Among them was participant “Dave”, self-described as “an avid science fiction nerd”:

“Dave”: *I expected something like out of Star Trek where we had to pretend to solve problems with the ship and the likes. Maybe there were asteroids in the way, but the engines had malfunctioned, that sort of thing. I don’t know, it just seemed like such an opportunity to use the physics we learned this year. Like forces and energy and more about space.*

[3] An electable at the time of the study.

Other participants with more traditional high attainment characteristics echoed the sentiment, describing that they had anticipated a project with more traditional “hard” subjects (so described by participant “Armin”). The realization that the project would primarily involve “soft” subjects reportedly “ruined” the project for many of these participants to such an extent that they were no longer interested in participating. To quote “Ida”, whose opinions of the project were normally positive:

“Ida”: *We already had a lot of projects about politics and really only one about science before, way back when. I feel like it was a wasted opportunity, to be completely honest. I didn’t want to do it. [laughs] I mean, I did, I always do, but it’s just… I don’t know, it just felt like such a waste.*

Not only physics was suggested as a worthy scientific topic to pair with mathematics. Climate change was also proposed in relation to statistics and functions; statistics because the evidence of climate change is often presented with graphs and functions because climate change makes predictions of the future.

7.6.2. Social studies

The second most common suggestion was social studies, particularly when tied to statistics and economy. Much like with climate change, statistics was highlighted as a useful mathematical topic to combine with social studies. In social studies, the participants reported that they had often seen demographical figures which employed statistical graphs and other such concepts during their lessons.

The project *the dream party* was a common example of a project which would fit well with math integration, as several of the participants had chosen to conduct a statistical questionnaire of the public.

7.6.3. Programming and Art

Some of the participants had chosen the electable subject programming and proposed it as a suitable subject to combine with mathematics. Of interest is that the four participants in the study who had programming as an electable chose to recommend it for interdisciplinarity with mathematics. One of the pupils, “Leo”, expressed the suitability for math and programming:

"Leo": *There's a lot of stuff common between programming and math. Like, all computers work with numbers anyway. I think math lets you understand more.*

When asked what kind of problem he could envision that would be suitable for an interdisciplinary problem with math and programming, he suggested after some deliberation:

"Leo": *Computers are good at doing calculations over and over. So, I'm thinking, maybe a project where you have to do a calculation, say, a hundred thousand times. That sort of thing.*

While this is not a specific problem, it highlights the expectation for what interdisciplinary cooperation between mathematics and programming would look like for these participants: math supplies the problem and programming supplies the solution.

Two participants mentioned art as suitable to pair with mathematics. These two also mentioned programming in connection with this integration, even though neither of them had programming as their electable. The basis for their suggestion was an assignment they had conducted earlier in the year in art wherein they were tasked with creating the image of a snowflake using the block-programming software Scratch (The Scratch Foundation, n.d.). Mathematics, they said, was necessary to program the correct angles of the various shapes of the snowflake, while programming was used to repeat the drawing of one of the snowflake's arms six times to construct the full image.

7.6.4. Unsuitable subjects and topics

The participants did not only mention subjects they felt were suitable for interdisciplinarity. They also mentioned subjects which they felt were ill-suited for combining with mathematics. Chief among these were the language subjects — Norwegian, English, and third language (most commonly Spanish, German or French) — with many pupils unable to even picture how such an integration might look.

Some social studies topics were also declared unsuitable for interdisciplinarity with mathematics. Particularly history was disparaged as an unfavourable match-up. Participant "Cedric" said:

"Cedric": *The only numbers we see in history is in the years. So, like, at best, we could figure out how long time something took, but that isn't much.*

Religion and ethics were also mentioned as unsuitable topics from the subject of social studies, for the same reasons as history: the only mathematics the participants could conceive as useful in association with these topics was basic arithmetic.

Gym class was another such subject limited to basic arithmetic and which was declared unsuitable.

7.7. Analysis

7.7.1. Introduction

This chapter endeavours to analyse the findings of the main study through the lens of phenomenology. It attempts, to the degree possible, to answer the research questions. Phenomenological analysis begins with a textural and structural description of the phenomenon being examined.

First, authorial context is established, to pinpoint areas of potential analytical bias.

Then, phenomenological analysis is used on the interview data, producing a textural and structural description. The textural description concerns what the participants *felt*. The structural description concerns the *contexts which facilitated those experiences*. These descriptions also come coupled with a subchapter on authorial context, where the author of the study is presented that potential biases in the analysis can be uncovered and discussed.

From these descriptions, an essential, invariant structure is synthesized, containing the common experiences of all participants.

7.7.2. Authorial context

The author is, at the time of writing, a 30-year-old male with a penchant for natural sciences and mathematics, having a Bachelor's degree in Astronomy from the University of Stockholm. Due to his background, he favours and is most experienced with empirical, quantitative methods, which are not present in this study. This may promote a preponderance of caution in discussing limitations of the study, its results, and implications.

Concerning project-based education, he is positively inclined based on the research he has read, such as Blumenfeld, et al. (1991), Chen & Yang (2019) and Chiang & Lee (2016). When it pertains the school's implementation of PBL, the author finds some projects — in particular the economy project *the Luxury Trap* — to have a clear potential for promoting mathematical relevance. This may promote a bias in reporting positive aspects relating to relevance and this project.

The author's experiences with the participants are based off a one-year long career at their school. Overhearing how the pupils discuss PBL at the school makes him predisposed to think that they are negatively inclined towards project-based education in general and he is biased against the participants' positions on the matter because he finds their common complaints against the implementation of PBL poorly reasoned and ill-developed. In particular, he has heard many complaints against the promotion of soft skills as irrelevant to the pupils, both from pupils and their parents.

Lastly, concerning the author's specific views on mathematics-integration with other subjects for the sake of PBL, the author reports no impressions of restrictions. The author is a proponent that all school subjects can be meaningfully tied to mathematics. This may lead to a positive bias in discussing the potential of PBL and interdisciplinary instruction as well as an underrepresentation of answers relating to "unfit" subjects for interdisciplinarity with mathematics in chapter 7.4.

To combat any and all biases relating to authorial context, both member-checking and an audit trail have been used. For more information, see chapter 4.4.

7.7.3. Analysis of Research Question 1

For Research Question 1, the phenomenon examined is the experience of "mathematical relevance in an interdisciplinary project". Put simply, for the textural description, the study concerns itself with how mathematical relevance felt to the participants when experienced in their projects.

From the interviews to judge, mathematical relevance gave all participants a surge of motivation, characterized by an increase in working interest, curiosity, and perseverance. When experiencing mathematical relevance in their projects, the pupils were able to see how they could use the topics covered by the project in the future — meaning they could see the purpose of the mathematical topics covered, their future application, and their own potential benefit in using them. The nature of this future utility took many forms. Some pupils were concerned with their everyday life and focused on more mundane and practical mathematics as a result. Topics favoured by these pupils was basic arithmetic and economy. Others looked instead to vocational application, such as for engineering, science, and economy. A third group were primarily concerned with academic achievement and considered future utility to concern their ability to understand and learn more advanced mathematics later in life.

The structural description concerns the contexts which facilitated the experience of the phenomenon. Here, this relates directly to the first research question: “What aspects of an interdisciplinary project made participants experience mathematical relevance?”

To summarize the findings, the results show that the participants experienced mathematical relevance when the project allowed them to perform work they could picture themselves replicating to solve real-life problems — that is, problems outside of the current classroom setting — be they every day, vocational, or academical. As expected, the precise shape of the future life application appears dependent on the pupil’s own goals and expectations for the future.

Recency appears to play a profound role in determining whether a project will feel mathematically relevant or not: when useful mathematical topics were covered just before or during a given projects, more participants experienced mathematical relevance.

When certain topics in mathematics are covered, the experience of relevance is further heightened. In particular, the topics of economy and statistics appear more closely linked to the experience of relevance than others, so a project utilizing these topics is more likely to promote the feeling of relevance.

Interdisciplinarity with select other subjects can also enhance the feeling of relevance, with clear favourites being science studies and social studies.

7.7.4. Analysis of Research Question 2

Research Question 2 concerns: “What aspects of an interdisciplinary project made the participants experience a lack, or antithesis of, mathematical relevance?”

Here, the textural structure relates to what the participants felt when they experienced a lack or antithesis of mathematical relevance.

The experiences of the participants were — as expected — diverse, but based on the interviews, they primarily consisted of a drop of motivation coupled by a loss of energy and an increase of fatigue. In severe cases, the participants described a heightened sense of confusion and frustration.

The reported disappointment was worst when the participants expected to find interdisciplinary use for mathematics, such as coupled with science for the project *Andromeda*, only to have these expectations subverted.

Confusion was primarily increased when the participants were encouraged to involve mathematics in projects where they could not perceive a natural or intuitive connection between the subject matter of the project and traditional topics of mathematics.

Relating to the unintuitive connection of mathematics and project themes, the participants reported the worst confusion when they could receive few concrete examples of how mathematics could be involved, citing ambiguity as the source of their irritation.

The structural description concerns what contexts facilitated these negative experiences.

As already stated, the breach of expectations in the project *Andromeda* appeared to facilitate a loss of motivation for the students. The disappointment reportedly stemmed from an association of astronomic science and mathematics, possibly encouraged by popular science-fiction material consumed by the pupils. This implies that a certain caution and mentalization into pupil expectations is in order; a failure to fulfil the expectations of the thematic expectations of the pupils can render the entire participation in the project unpleasant for some.

In addition, being exposed to projects which demanded old mathematical subject matter from the participant appeared to induce a sense of confusion and despair in some, owed to the participants forgetting subject matter over time. Others were instead frustrated and displeased with the lack of novelty in revisiting old topics without new subject matter to cover.

7.7.5. Essential, invariant structures

The essential, invariant structure is a description of the experiences of the phenomenon which were shared among all participants. This study offers two such descriptions; one for the phenomenon of mathematical relevance in a project and one for mathematical irrelevance in a project.

Concerning the experience of mathematical relevance in a project:

It is invigorating. There is a rush when it all comes together, when one sees the usefulness of it all. Sees a glimpse of the network of mathematics, how it connects to different layers of *life, like a branching tree. One feels like one is doing something worthwhile. Something one might to later. Something other are doing, right now, elsewhere. It wakens interest. Like a hunger, one feels eager to have more. It brings joy, lightens the mood, and one feels like sharing the revelations, like spreading the joy.*

Concerning the experience of mathematical irrelevance in a project:

It is a torture, a slow, arduous slog with no rhyme or reason to it. One is sedated, as if breathing inert gases instead of oxygen. The longer one stays, the worse the sedation. Like a poison, it numbs the mind. From the numbness comes confusion, uncertainty, insecurity. Perhaps others see what one cannot; perhaps one is being stupid? The sedation gives way to frustration, and then anger. But one is stuck with the project. There is no escape from the drudgery. "How dare they waste my time with this?" The impotency breeds resentment.

8. Discussion

8.1. Introduction

Chapter 7 of this study has presented the findings and analysis of the interview data. This chapter discusses these findings in light of existing theory. It also brings up omitted answers which might be expected to be found based on the results of previous studies and attempts to provide potential explanations for their omission. Finally, it attempts to answer the research questions established in chapter 1.3.

8.2. Relevance-enhancing aspects

The interviews produced a diverse picture of the contributing factors to mathematical relevance, but some commonalities were discerned. This chapter will relate to the first research question: *What aspects of an interdisciplinary project made participants experience mathematical relevance?*

8.2.1. Future utility

Several components of mathematical relevance are identified in the literature, chiefly concerning motivational gain owed to the useability of the mathematical topics covered (e.g., Darby, 2008). This study adds further support to this component, as all participants reported a motivational boost from the feeling of relevance and all participants mentioned future utility as a relevance-governing factor. What the participants associated with future utility varied depending on their future goals, much in line with previous research (e.g., Hernandez-Martinez & Vos, 2018; Sealy & Noyes, 2010; Michelsen & Sriraman, 2009). Some considered future utility to pertain to their everyday lives, while others focused on vocational application, and some yet considered future academic achievement.

Developing projects which allow the students to approach a project from different angles may be necessary to ascertain that as many as possible find the project mathematically relevance. One way of ensuring that the pupils are allowed to approach the project from different angles is to allow them to pick their own thesis questions to answer. This may allow them to direct the project either towards more academic and abstract topics, more vocational topics, or more general topics.

This *approach-differentiation* may be a relevance-boosting aspect of interdisciplinarity.

Some pupils struggle with mathematics and become easily overwhelmed by a too wide variety of covered topics — and others yet are easily bored by repetition. Therefore, it is implied that a good project is one which allows for easy and extensive differentiation on part of the pupil. The diverse responses to the interviews imply that a good project is open in terms of the problems it exposes to the pupils. If a project can be differentiated such that vocationally inclined pupils are allowed to use methods mimicked in their favoured vocation, while simultaneously granting academically inspired pupils the opportunity to delve deeply into novel theory, all parties can be expected to be more satisfied. This, in turn, allows mathematics to become relevant to the individual pupil, while also highlighting the relevance of mathematics for the group.

Complexity-differentiation is another relevance-enhancing aspect.

The interviews also suggest that tying mathematical concepts to practically oriented projects appears to increase student motivation. A possible reason for this could be that the act of solving a problem practically highlights how the mathematical topics can be applied and used in real-life contexts and therefore be useful in the future.

Practicality might therefore be considered a relevance-boosting aspect of an interdisciplinary project.

8.2.2. Relevant topics and recency

Miettinen (1999) emphasized the value of tying mathematics to the everyday experiences and goals of the pupils. With this in mind, it is no surprise that the mathematical topics considered relevant to the participants of this study varied. There were, however, two clear favourites in arithmetic and personal economy. Hernandez-Martinez and Vos's (2018, pg. 253) description of the goal-orientedness of relevance reads: "[...] a wider perspective on the relevance of mathematics at large will yield a more complex picture, in particular as the subject of mathematics also may contain topics that are irrelevant to many students." It is then no wonder that arithmetic and personal economy were found to be favoured topics in this study, as the participants are all young adolescents. Though a heterogenous group, most adolescents this age are many years from situations which require more advanced mathematics of them, e.g., engineering or finances; and so, it is likely that they favour topics which instead relate to their immediate everyday concerns. More abstract topics are, simply put, more likely to be considered "irrelevant to many students".

Statistics was also favoured by most of the participants, which could be attributed to the prevalence of graphs both in political contexts and relating to the COVID-19 pandemic. These topics are often covered by the media, frequently with striking graphs of different kinds (see Figure 1).

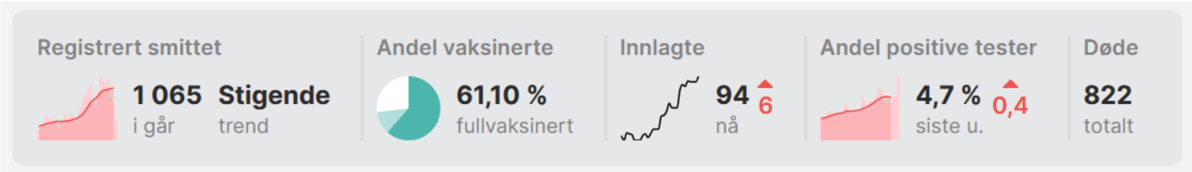

Figure 1. The Coronavirus-banner of "VG", a popular Norwegian newspaper, showing different graphs. A potential source for the relevance of statistics in the minds of the particiapants? (VG, 2021).

Basing projects around one of these three topics — arithmetic, economy, or statistics — may be an aspect which boosts mathematical relevance in projects.

Concerning the topics of *equations* and *functions*, only pupils with explicit goals of continuing studies in STEM described these as relevant — in the context of future academic studies. This may imply that while *arithmetic, economy* and *statistics* have the broadest range of application for enhancing the feeling of mathematical relevance, differentiation is key to reach as many pupils as possible. Topical differentiation — such as allowing other mathematical topics to be used in the same project — can be an important tool in allowing other pupils to tailor their education in accordance with their future goals.

Topical differentiation can therefore be considered a relevance-boosting aspect of an interdisciplinary subject.

Beyond the mere subject matter of a given mathematical topic, recency also appears to play a large role in determining whether a topic feels relevant to a given project. Pupils expectedly appear to prefer projects which concern mathematical topics which they have recently been instructed in.

This study tentatively concludes that *recency of instruction* is another relevance-enhancing aspect of an interdisciplinary project, though more research into this topic is necessary to establish its importance.

8.2.3. Relevant school subjects

There was no clear consensus of which school subjects were most suitable to pair with mathematics in an interdisciplinary context. This too can be interpreted in line with Hernandez-Martinez and Vos's (2018) subjectivity of relevance: with a heterogenous group with heterogenous interests, no one subject is likely to emerge as a clear favourite. Unlike mathematical topics, such as arithmetic, no one school subject is likely to be prevalent in the everyday lives of the participants. Instead, one can expect that their interests dictate what they determine to be useful to them — and therefore usefully paired with mathematics.

When conducting an interdisciplinary project, it is important to consider which school subjects will form the basis of the interdisciplinarity. Some school subjects appear to fit integration with mathematics more intuitively than others, with *science* and *social studies* being clear favourites.

While science was favoured by a cautious majority of the pupils, it was far from as ubiquitously favoured as the topics of arithmetic and economy was when discussing relevant topics. It may be that more pupils associate science with mathematics than not, or it may be a statistical fluke.

Differentiation of interdisciplinary subjects, meaning the pupils are allowed to choose subjects which are relevant matches to them, might therefore be concluded to be a relevant-boosting aspect of interdisciplinary projects.

8.3. Relevance-reducing aspects

This section covers the discussion related to the second research question: *What aspects of an interdisciplinary project made the participants experience a lack, or antithesis of, mathematical relevance?*

As has been done previously in this study, this lack of relevance or antithesis of relevance, will be denoted *irrelevance* for ease of discussion.

8.3.1. Theme

Projects carry with them themes which in turn inform expectations in the pupils who participate in them. Subversion of these expectations can result in a lower enjoyment and reduced sense of relevance in the pupils, as seen in the case of "Dave" and the issue he took with the *Andromeda*-project.

As described by Michelsen and Sriraman (2009), the relevance of mathematics is dependent on the pupils' identities. It may be that the identity informs the pupil of what to expect from certain themes. In the case of "Dave", a self-described "nerd" was forced away from the fantasy of science fiction space faring and placed in the role of a politician. This made the entire project's mathematical relevance wane for him, because he under no circumstances could picture himself becoming a politician. This waning interest manifested to such an extent that he could not appreciate the mathematical topics which were presented in the project.

When designing a project, special care should be taken to identify the theme or fantasy which the project attempts to capture. The answers from this study suggest that a *failure to deliver on the fantasy of a project* could be a relevance-reducing aspect for some pupils.

At the same time, pupils who profess a loathing of mathematics and who intend to actively avoid any professions wherein a reliance on mathematics can be found (like "Fred"), are unlikely to entertain "Dave's" notions of a relevant project. It may be that "Fred" would find no relevance in the *Andromeda*-project regardless of what mathematics were presented in it, as the project's themes are divorced from any future he could picture himself in.

This suggests that projects should take care to allow as many pupils as possible to approach the themes of the project from their own unique perspectives. By designing projects which cater only to a minority of the pupils, it follows that fewer pupils will find the project relevant. Demanding *approaches to themes which only support some pupil identities* can therefore be considered a relevance-reducing aspect. That said, more research should ideally be conducted to determine how great an effect this aspect has on relevance. It may for example be that most pupils do not care one way or the other, on account of their identity as *pupils doing schoolwork.*

8.3.2. Teacher hypocrisy

In the interviews with the participants, it became clear that several had had experiences with teachers wherein the premises of PBL and interdisciplinarity broke down. As stated by other studies (e.g., Duerr, 2008), a main motivator for interdisciplinary projects is the promotion of certain valuable skills, such as creative and critical thinking. PBL in general is expected to promote problem-solving skills through its use of complex, authentic problems (Chiang & Lee, 2016). In short, the principle behind an interdisciplinary project reliant on mathematics is that real world problems require mathematics.

When pupils are given dismissive remarks concerning the importance of mathematics by teachers, the perceived relevance of the mathematics is bound to drop. This hypocrisy, of promoting the usefulness of mathematics in officious-sounding instructions to the class, only to disparage it in off-hand comments later, is a relevance-reducing aspect.

The old adage of “show, don’t tell”, appears to apply to pedagogics as well as storytelling. If the pupils are to believe that mathematics is an integral and valuable part of society, they must see that it is treated in such a way by the teachers. Unfortunately, some evidence suggest that teachers struggle with mathematics, manifesting both in some math teachers without appropriate subject competence (Perlic, 2019) and in less than three quarters of all teacher students fulfilling the mathematics criteria for their education in 2019 (Kunnskapsdepartementet, 2019).

If the role of mathematics is to be emphasized in an interdisciplinary project, it is important that all teachers involved can use the mathematical skills emphasized by the project. Otherwise, mathematics risks being relegated to the math lesson, with no evident bridging into the real world, which is the opposite of the motivation for the interdisciplinary projects. Likewise, though no participant complained about it in their interviews, it stands to reason that if the math teacher is unable to speak of the benefits of the other subjects in the project, the perceived relevance of these projects is likely to drop. In that case, the perceived relevance of mathematics also risks falling, as the pupils will perceive that the math teacher has no use of their skills outside of the math lesson.

A potential remedy to the problem of this teacher hypocrisy could be to ascertain common values regarding interdisciplinarity in the teacher core responsible for the project. However, “show, don’t tell” might apply here as well. A way of ascertaining this common value among teachers of different subjects could be peer-to-peer instruction, wherein the teachers teach each other of their subject’s values and methods in advance of the project. This could allow the math teacher to teach the project-relevant skills to the (for example) social studies teacher, who in turn could impress upon the math teacher the techniques and values of their field, potentially resulting in better interdisciplinary cooperation.

8.3.3. Ambiguity

Part of the value of interdisciplinary education is the promotion of so-called 21st century work skills. These include the ability to tolerate ambiguity (Field, Lee, & Field, 1994).

Previous research (e.g., Duerr, 2008) has shown that interdisciplinary education improves tolerance to ambiguity compared to traditional methods.

However, this research has shown that certain kinds of ambiguity can be profoundly frustrating for many pupils. The answers from the participants have highlighted the need for certain ambiguity in the structure of a project to allow for differentiation of method, topics, and subjects used. In this regard, open questions are favoured, allowing pupils to define their own constraints, methods, and end product. “Eva’s” complaints towards ambiguity in chapter 7.4.3 highlights the bewilderment some pupils feel when exposed to math tasks with open constraints which are structured like regular, closed tasks. When set mathematical problems are integrated into projects, this study suggests that care should be taken when phrasing the problem text. Ambiguity regarding the constraints of the problem should be made explicit — for example by encouraging the pupils to research and make their own constraints — in order to avoid confusion and frustration.

8.3.4. Poorly matching interdisciplinary topics

If relevance is viewed as goal-oriented, as in the case of Hernandez-Martinez and Vos (2018), the disfavoured subjects are likewise expected: the participants clearly could not perceive mathematics as useful in history or language subjects. Thus, they regarded them as poor fits for interdisciplinary subjects with mathematics, seeing as the combination could seemingly not offer them any useful new perspectives or skills.

While these topics have been mentioned as poor fits by the participants, it should be noted that no participant expressed that a project was irrelevant because of them. They were mentioned only in hypotheticals, as examples of topics they predicted would make poor fits with mathematics.

Considering the potential importance of delivering on the fantasy of a project’s theme, it may be that pair-ups with unconventional subjects or topics require careful planning. The relevance of mathematics is dependent on the pupil’s identities and future goals (Michelsen & Sriraman, 2009). It may be that projects mixing mathematics with subjects described as poor fits, such as language, require special care in their description to avoid giving faulty impressions of their themes.

An example of potentially appropriate integration between math, language, and social studies, could be a project in which the pupils are expected to write a story set in a fictional world, inspired by a real-world culture. In developing the fictional setting, the pupil could be charged not only in expressing the norms of the fictional culture, but also determine such aspects as travel routes, using mathematical formulae for distance, time and velocity in the process. These routes would then need to be integral to the story they write, perhaps through the effects of fickle weather patterns on the road, scarcity of resources, or other hazards. The pupil might then make decisions on what to include in the story, as artistic licence to the formulae might be necessary to produce a sufficiently interesting story. This fictional setting, informed through mathematics, can be used to explore the nuances inherent in the interdisciplinary topics.

However, if this project is presented as a primarily storytelling project, pupils who identify as language-oriented, perhaps with the goal of becoming authors in the future, might take issue with the application of mathematics in the project. If the project is explained poorly, they may be disappointed with the project and find the mathematics therein irrelevant. Likewise, if the project is executed poorly, the mathematical aspects of it may feel disconnected from the whole, further hampering the perceived relevance of the mathematical topics.

8.4. Discussion of “missing” results

This section will discuss answers which might be expected from existing literature but which were missing from the interviews in this study — as well as potential reasons for why these answers might be omitted.

8.4.1. Effect on grades

Several other studies, for example that by Hernandez-Martinez and Vos (2018) and Deslauriers et al. (2019) have shown some resistance on behalf of the pupils towards non-traditional teaching methods. Chiefly, the resistance appears to stem from a sensation of reduced quality of education, both pertaining to actual learning and the influence of the education on the prospective grades of the students. In this study, the two first pariticpants in the pilot study voiced similar complaints, describing the interdisciplinary projects as “worthless” and claiming that they “learned nothing” during them. While some participants in the main study also had some complaints about the quality of education, claiming — in a similar vein to the students of Deslauriers et al. (2019) that they learned less during the project lessons — neither the participants in the pilot study nor the main study complained about the potential effects these projects might have on their grades. Put shortly, instead of extrinsically motivated concerns (grades will suffer), the pupils instead mentioned intrinsically motivated concerns (not learning as much).

It could of course be that the effects on grades is intrinsically linked to the quality of education in the minds of the participants, such that any effect on the quality of education will necessitate an effect on the grading level.

There could be many other reasons for the omission. For one, while the projects are treated as a separate subject in the school curriculum, the teachers made explicit mention of their subjects' involvement in the projects, often grading pupils in their respective subject based on their project performance. For instance, in the last two projects the pupils attended —*The Luxury Trap* and *Life, Plain and Simply* — the pupils were allowed to choose two subjects to be graded in and were tasked with selecting the relevant competency goals in each subject as part of the project preparatory work. This highlighting, coupled with the school's de-emphasis of traditional grading methods like standardized tests and essay deliveries, as well as the last project period being associated with explicit exam preparation, might explain the omission of grade-detrimental concerns among the participants.

Another potential cause for the omission might lie in the ongoing COVID-19 pandemic. At the time of the study, the pupils had experienced on-and-off lockdowns due to COVID-19, with several cancelled tests and national exams as a result. Several internal surveys at the school showed an increase in general fatigue among the pupils, including indifference towards their academic performance. It may be that regardless of the school's implementation of PBL, the pupils offered few complaints about the effects on their grades because of a general sense of despair and fatalism concerning their academic achievements. At the same time, the heterogenous group of participants contained several pupils with traditionally high attainment scores, who — according to their teachers — would typically be gravely concerned by their grades. It may be that a combination of these factors, or others hitherto unconsidered ones, explains the omission of grades as an explicit cause for concern among the pupils.

8.4.2. Soft skill acquisition

In connection with the concern for reduced quality of education is the benefit PBL has on so-called *soft skills*. As discussed in Chapter 3.2.4, one of the most promising aspects of PBL is the educative potential it offers for problem-solving skills (Anderson, Greeno, Kline, & Neves, 1981), interpersonal skills (Musa, Mufti, Latiff, & Armin, 2012), time management, etc. which are valued as highly important in the modern labour market. As was also touched upon in chapter 3.2.4, PBL is a natural fit for a socio-culturally focused education system. Yet, for all documented positive effects of PBL, no participant in this study mentioned soft skills as a potential benefit of the school's projects. Similarly, no mention was made in relation to soft skills and mathematical relevance, meaning no participant associated the projects and the solving of mathematical problems in groups through PBL as relevant.

This could potentially be highlighting a discrepancy in the participants' expectations of what constitutes realistic out-of-school experiences with mathematics and the values of PBL. Math education in Norway has previously been associated with traditional methods of education, focusing on individualist principles such as individual problem solving and test results (Alseth, Breiteg, & Brekke, 2003). It may be that similar expectations of math lives on in the cultural zeitgeist and that pupils associate cooperative and interpersonal skills with other subjects as a result.

Alternatively, it may be that the pupils do not associate PBL with the acquisition of such soft skills. Whether this is because of the specific implementation of PBL at the school or because of other factors, such as whether acquisitions of social skills without direct instruction is registered by the pupils as something *learned* through PBL remains out of scope for this study.

8.4.3. Algebra and probability as relevant topics

In contrast to economy and statistics, the topics of *algebra* and *probability* were not described as relevant by any participant, implying that they are more difficult to associate with daily or vocational life.

It might be expected that algebra would be mentioned as a relevant mathematical topic, as it forms the grammar upon which future mathematics is built (Seidlin, Adams, & Shuster, 1948). While some pupils mentioned the relevance of mathematics for future academic achievement, linking the topics of equations and functions to their academic future, no participant mentioned algebra as a topic which promoted a sensation of mathematic relevance.

The omission might be attributed to the abstract nature of algebraic instruction, with its reliance on mathematical symbols over concretes, but this interpretation is curious in the face of the topic of equations and functions being raised as relevant topic. Equations and their solutions are a subset of algebra and functions build on both topics for its implementations. Its omission might be explained by the lesson materials of the pupils, which was examined after the interviews were conducted.

At the school, the lesson material was structured to mirror the LK06 Norwegian math curriculum, which has a section titled *Numbers and algebra*. This section contains numerous competency goals, but only one of these explicitly mentions *algebra* by name. Other competency goals contain aspects inherently linked to algebra, such as the binomial formulae — but in the lecture material for the pupils, the material linked to these competency goals was positioned under different headlines (see Figure 1 for an example mock-up). It may be that this distinction produced the effect of associating algebra with basic and fundamental mathematics in the minds of the participants. If this is true, the participants would be unlikely to mention algebra as being relevant for future academic achievement in the same way that basic addition is not regarded as relevant.

Numbers and algebra

1. Algebra: notation
2. Algebra: variables & constants
3. Equations
4. Solving first order equations
5. Binomial formulae
    - 5.1 First binomial formula
    - 5.2 Second binomial formula
    - 5.3 Third binomial formula
6. Inequalities
7. Sets of equations

Figure 2. A mock-up of the OneNote structure for the lesson material for the mathematics subject from "Class α". Note how the chapter 'Numbers and algebra' contains two entries explicitly titled "Algebra". It is possible that this distinction might produce an impression in the mind of the pupils that "Algebra" only refers to the very basic notation and variables and constants, while the other entries are different topics.

As with algebra, probability was also omitted as a relevant topic. Given the participant's claims of economy being useful for its real-life applications of managing one's personal finances, one might expect to see probability mentioned as a relevant topic. After all, lotteries and casino games are driven by probability and a common source of economic loss. Indeed, many of the otherwise innocuous video games played by youth contain so-called *loot* *boxes* — items in the video game with randomized content — which follow the rules of probability, and which have been linked to problem gambling (Zendle & Cairns, 2019).

Because the participants had been explicitly lectured about the use for probability in real life scenarios, such as for determining the likelihood of success in games of chance, the non-inclusion is further notable.

Its lack of inclusion might be found in the project-clause of the study. The pupils were asked which projects they had experienced as mathematically relevant. None of the projects so far had been designed with probability in mind nor was probability a natural fit to any of the projects as described by the teachers at the school (see Table 5-1).

9. Conclusion

9.1. Introduction

This study has attempted to investigate some of the factors which contribute to make implementations of interdisciplinary project-based learning (PBL) feel mathematically relevant to the pupils. Fifteen participants from the same junior high school were interviewed about their experiences with mathematical relevance in association with the school's projects (PBL-implementation). Of these participants, thirteen were used to analyse the experiences, factors, and contexts associated with mathematical relevance by these pupils.

9.2. Thesis conclusion

The thesis question of this study was "*What makes an interdisciplinary project feel mathematically relevant to a pupil at the 10th grade junior high school level?*"

This study has chiefly found that because different pupils have different needs concerning the complexity, degree of openness, and practicality of their problems, a project should ideally allow for customization. This customization should be done by the pupil, that they may select the version of the project which feels most relevant to them.

Several avenues of differentiation exist which appear to promote mathematical relevance, as described in chapter 8.2. These avenues include *approach and complexity*, *degree of practicality*, *mathematical topics covered,* and *other school subjects used.*

Not all projects need to be maximally customizable. Instead, the avenues of differentiation may be considered potential offsets to other aspects of the project which may threaten to reduce the perceived relevance. These aspects include *alienating themes, failure to deliver on the fantasy of a theme, constraint ambiguity,* and *unconventional subject matchups*.

When possible, the subject matter of the traditional subjects should be planned carefully in tandem with the project. This is motivated by the loss of relevance participants described when faced with topics they had not engaged with in a long time.

9.3. Implications for PBL with the LK20 curriculum

Judging from the answers given by the participants, some implied trends towards best practices for crafting future projects emerge. These indications should be further explored and compared to existing design theories and tested in praxis to determine their usefulness to a wider audience than the thirteen pupils presented in this study.

This section will discuss the potential factors from this study worthy of future examination.

Some mathematical topics appeared easier associated with relevance than others in this study. Similarly, some school subjects appeared more naturally associated with relevance when combined with mathematics than others.

A potential exclusivity occurs between topic and subject: not all topics covered by mathematics are equally fitting integration with other subjects. For example, statistics fit social studies well, such as when considering population growth, demographic distributions, or the economic factors of nations. Similarly, functions can readily be used in tandem with the same social studies topics, as functions can be inferred from the statistical data and be used to make some rudimentary predictions of the future. Other topics are not as easily interwoven. As an example, while there are ways to tie history and geometry, the topics are likely not as intuitively linked as that of demographics and statistics. When planning for interdisciplinary projects, care must be given to combine subject matters which fit naturally with one another, to avoid accidental cross-disciplinary or multidisciplinary instruction. Which topics in math intuitively fit which topics in other subjects could be a fruitful point of future research for developing best practices.

Projects inherently have an underlying theme. In the case of the new Norwegian curriculum, these themes are *health and life skills*, *democracy and citizenship*, and *sustainable development* (Utdanningsdirektoratet, 2020). Different school subjects fall more or less naturally in line with these themes. When examining these interdisciplinary topics, special care must be given to tie the inclusion of mathematics to something worthwhile and integral to the project. The math must, in essence, be truly useful in the completion of the project. It should be well-integrated in the problem and allow for a mathematical perspective of the solution. For a truly interdisciplinary project, mathematics must not only be a tool for the solution — as this would make it cross-disciplinary in nature. An example of this could be a problem wherein some knowledge of statistics is necessary in order to collate and interpret social studies data. Mathematics, then, becomes a tool through which the pupils can form opinions about a given social studies topic — which is useful, but not sufficient for a truly interdisciplinary problem.

Identifying which topics of mathematics are valuable to which subjects, as well as which project theme, can allow for a smoother project creation process, and may lead to an enhanced sensation of mathematical relevance as per the *future utility*-aspect mentioned in this study.

For this integration to be given full weight, it is important that all teachers involved comprehend the material. The Norwegian curriculum promotes interdisciplinarity (Utdanningsdirektoratet, n.d.f). Beyond algorithmic thinking, meant to be enhanced through mathematics (Utdanningsdirektoratet, 2019), the ability to calculate is also considered a fundamental skill, which is meant to be expressed in all other subjects (Utdanningsdirektoratet, n.d.e). It forms the backbone on which knowledge is built in quantitative fields, both in science and the humanities. Knowing various aspects of mathematics are applied is therefore essential for all teachers where interdisciplinary cooperation is considered. Therefore, time allotted for planning projects should ideally include some peer-to-peer instruction of the topics covered where necessary. Whether such peer-to-peer instruction is actually feasible within the already hectic schedules of teachers — and whether it has the desired outcome — is a potential topic for future research.

Developing such modular and readily differentiable projects is no trifling feat. Teachers require adequate time to plan and prepare projects. Of the projects used by the school in this study, the ones which allowed the pupils to choose which subjects they desired grading in seemed to partially serve the need for this differentiation. At the same time, the participants complained of too ambiguous problems, warning against a detrimental effect on their experience of relevance associated with them. It may be that explicit instruction must be given to the pupils on how to constrain ambiguous problems.

Further studies on what constitutes a successful project for mathematical relevancy are needed to ascertain both positive learning opportunities for the pupils and a comfortable working day for the teachers. A tremendous amount of work of discovering good practices is currently underway within Norwegian schools following the implementation of the LK20 curriculum. At the school studied for this thesis, no less than eight projects are produced every year. This leaves a fertile field for further research, phenomenological or not, with ample opportunities to test theoretical design principles against the unforgiving necessities of teaching.

This study hopes to have illustrated which future avenues are worth examining first.

Reference List

Adam. (2021). *WallStreetBets GameStop Short Squeeze*. Retrieved from KnowYourMeme Web site: https://knowyourmeme.com/memes/events/wallstreetbets-gamestop-short-squeeze

Alseth, B., Breiteg, T., & Brekke, G. (2003). *Endringer og utvikling ved R97 som bakgrunn for videre planlegging og justering.* Notodden: Telemarksforskning.

Amin, M. E., Nørgaard, L. S., Cavaco, A. M., Witry, M. J., Hillman, L., Cernasev, A., & Desselle, S. P. (2020). Establishing trustworthiness and authenticity in qualitative pharmacy research. *Research in Social and Administrative Pharmacy*, 1472-1482.

Anderson, J. R., Greeno, J. G., Kline, P. J., & Neves, D. M. (1981). Acquisition of Problem-Solving Skill. In J. R. Anderson, *Cognitive Skills and Their Acquisition* (pp. 191-230). New York: Psychology Press.

Audet, É. C., Levine, S. L., Ezelbahar, M., Koestner, S., & Barcan, S. (2021). Zooming their way through university: Which Big 5 traits facilitated students' adjustments to online courses during the COVID-19 pandemic. *Personality and Individual Differences, 180*. doi:10.1016/j.paid.2021.110969

Barton, B., Poisard, C., & Domite, M. D. (2006). Cultural connections and mathematical manipulations. *For the Learning of Mathematics, 26*(2), 21-24. Retrieved from https://halshs.archives-ourvertes.fr/halshs-00856440

Birt, L., Scott, S., Cavers, D., Campbell, C., & Walter, F. (2016). Member Checking: A Tool to Enhance Trustworthiness or Merely a Nod to Validation? *Qualitative Health Research, 26*(13), 1802-1811. doi:doi:10.1177/1049732316654870

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist, 26*(3 & 4), pp. 369-398. doi:https://doi.org/10.1080/00461520.1991.9653139

Booth, S. (2007, June 7). Learning and teaching engineering mathematics for the knowledge society. *European Journal of Engineering Education, 33*(3), pp. 381-389. doi:https://doi.org/10.1080/03043790802090232

Bossio, D., Loch, B., Schier, M., & Mazzolini, A. (2014). A roadmap for forming successful interdisciplinary education research collaborations: a reflective approach. *Higher Education Research & Development, 33*(2), 198-211. doi:10.1080/07294360.2013.832167

Buabeng-Andoh, C. (2019). Students' Attitudes Toward Mathematics In Vocational Education: From Perspectives Of A Developing Country. *International Journal of Scientific & Technology Research, 8*(7), 43-49.

Chen, C.-H., & Yang, Y.-C. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educational Research Review, 26*, 71-81. doi:10.1016/j.edurev.2018.11.001

Chiang, C. L., & Lee, H. (2016, September 9). The Effect of Project-Based Learning on Learning Motivation and Problem-Solving Ability of Vocational High School Students. *International Journal of Information and Education Technology, 6*(9), pp. 709-712. Retrieved October 5, 2020, from http://www.ijiet.org/vol6/779-EP00028.pdf

Chohan, U. W. (2021, February 4). Counter-Hegemonic Finance: The Gamestop Short Squeeze. *SSRN*. doi:10.2139/ssrn.3775127

Cresswell, J. W. (2013). *Qualitative inquiry & research design: choosing among five approaches* (3rd ed.). Los Angeles: Sage.

Darby, L. (2008). Making mathematics and science relevant through story. *Australian mathematics teacher, 1*, pp. 6-11. Retrieved from http://hdl.handle.net/10536/DRO/DU:30046641

Davis, R. A., Conroy, J. C., & Clague, J. (2020). Schools as Factories: The Limits of a Metaphor. *Journal of Philosophy of Education, 54*(5), 1471-1488.

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019, September 24). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences of the United States of America, 116*(39), pp. 19251-19257. doi:https://doi.org/10.1073/pnas.1821936116

Dillon, P. (2008). A pedagogy of connection and boundary crossings: methodological and pistemological transactions in working across and between disciplines. *Innovations* *in Education and Teaching Internationa, 45*(3), 255-262. doi:10.1080/14703290802176121

Dinç, E., Memnum, D. S., & Aydın, B. (2018). Teaching Mathematics at Vocational High Schools and Student Attitudes and Approaches Towards This Course. *PEOPLE: International Journal of Social Sciences, 4*(1), 507-524. doi:10.20319/pijss.2018.41.507524

Drolet, A. L., & Morris, M. W. (2000). Rapport in conflict resolution: Accounting for how face-to-face contact fosters mutual cooperation in mixed-motive conflicts. *Journal of Experimental Social Psychology, 36*, 26-60.

Duerr, L. L. (2008). Interdisciplinary Instruction. *Educational Horizons, 86*(3), 173-180. Retrieved from http://www.pilambda.org/horizons/publications%20index.htm

Duncan, A. (2010, November 17). *The New Normal: Doing More with Less*. Retrieved from U.S. Department of Education: https://www.ed.gov/news/speeches/new-normal-doing-more-less-secretary-arne-duncans-remarks-american-enterprise-institute

Field, M., Lee, R., & Field, M. L. (1994). Assessing Interdisciplinary Learning. *New Directions for Teaching and Learning, 1994,* 69-84. doi:10.1002/tl.37219945806

Flegg, J., Mallet, D., & Lupton, M. (2012). Students' perceptions of the relevance of mathematics in engineering. *International Journal of Mathematical Education in Science and Technology, 43*(6), 717-732. doi:10.1080/0020739X.2011.644333

Fuchs, L., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., . . . Fletcher, J. M. (2006). The Cognitive Correlates of Third-Grade Skill in Arithmetic, Algorithmic Computation, and Arithmetic Word Problems. *Journal of Educational Psychology*, 29-43. doi:10.1037/0022-0663.98.1.29

Furunes, H. H. (2020, September 9). *Skolesystemet har blitt som en fabrikk der det skal produseres gode varer og resultater*. Retrieved from Varden: https://www.varden.no/meninger/skolesystemet-har-blitt-som-en-fabrikk-der-det-skal-produseres-gode-varer-og-resultater/

Gebremichael, A. T., Goodchild, S., & Nygaard, O. (2019). *Students' perceptions of the relevance of mathematics in an Ethiopian preparatory school.* Doctorial Dissertation, University of Adger, Faculty of Engineering and Science, Adger, Norway. Retrieved from http://www.cerme7.univ.rzeszow.pl/WG/10/CERME7_WG10_Gebremichael.pdf

Glanfield, F., & Sterenberg, G. (2020). Understanding the landscape of culturally responsive education within a community-driven mathematics education research project. In C. Nicol, J. A. Xiiem, F. Glanfield, & A. J. Dawson, *Living culturally responsive mathematics education with/in indigenous communities* (pp. 71-90). Leiden: Brill | Sense. doi:10.1163/9789004415768_004

Greer, B., Verschaffel, L., & De Corte, E. (2002). “The Answer is Really 4.5”: Beliefs About Word Problems. In P. E. Leder G.C., *Beliefs: A Hidden Variable in Mathematics Education?* (Vol. 31, pp. 271-292). Dordrecht: Springer. doi:10.1007/0-306-47958-3_16

Hannon, J., Hocking, C., Legge, K., & Lugg, A. (2018). Sustaining interdisciplinary education: developing boundary crossing governance. *Higher Education Research & Development, 37*(7), 1424-1438. doi:10.1080/07294360.2018.1484706

Heckman, J. J., & Kautz, T. (2012). Hard evidence on soft skills. *Labour Economics, 19*(4), 451-464. doi:10.1016/j.labeco.2012.05.014

Helle, L., Tynjälä, P., & Olkinuora, E. (2006, March). Project-Based Learning in Post-Secondary Education: Theory, Practice and Rubber Sling Shots. *Higher Education, 2*, pp. 287-314. doi:https://doi.org/10.1007/s10734-004-6386-5

Heppner, P. P., & Krauskopf, C. J. (1987). An information-processing approach to personal problem solving. *The Counseling Psychologist, 15*(3), 371-447. doi:10.1177/0011000087153001

Hernandez-Martinez, P., & Vos, P. (2018). “Why do I have to learn this?” A case study on students’ experiences of the relevance of mathematical modelling activities. *ZDM Mathematics Education, 50*, 245-257. doi:https://doi.org/10.1007/s11858-017-0904-2

Heylighen, F. (2007). Accelerating Socio-Technological Evolution: from ephemeralization and stigmergy to the global brain. In G. Modelski, T. Devezas, & W. Thompson, *Globalization as evolutionary process: Modeling global change* (pp. 284-335). London: Routledge.

Holtzman, D. M., & Kraft, E. M. (2011). Skills Needed in the 21st Century Workplace: A Comparison of Feedback from Undergraduate Business Alumni and Employers with a National Study. *Business Education & Accreditation, 3*(1), 61-76. Retrieved from https://ssrn.com/abstract=1948629

Ishartono, N., Nurcahyo, A., & Setyono, I. D. (2019). Guided discovery: an alternative teaching method to reduce students' rote learning behavior in studying geometric transformation. *Journal of Physics: Conference Series, 1265*(012019). doi:10.1088/1742-6596/1265/1/012019

Jehlička, V., & Rejsek, O. (2018). A Multidisciplinary Approach to Teaching Mathematics and Information and Communication Technology. *EURASIA J Math Sci Tech Ed, 14*(5), 1705-1718. doi:10.29333/ejmste/85109

John, R., John, R., & Rao, Z.-u.-R. (2020). The Big Five Personality Traits And Academic Performance. *Journal of Law & Social Studies, 2*(1), 10-19. doi:10.52279/jlss.02.01.1019

Jones, C. (2009). Interdisciplinary Approach - Advantages, Disadvantages, and the Future Benefits of Interdisciplinary Studies. *ESSAI, 7*, 76-81.

Korsager, M. (2014, November 25). *Utforskende undervisning for bærekraftig utvikling*. Retrieved from https://www.natursekken.no/c2102092/artikkel/vis.html?tid=2097219

Korstjens, I., & Moser, A. (2017). Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing. *European Journal of General Practice, 24*(1), 120-124. doi:https://doi.org/10.1080/13814788.2017.1375092

Kunnskapsdepartementet. (2019, November 20). Avvikler forkurs i matematikk for lærerstudenter. Retrieved September 12, 2021, from https://www.regjeringen.no/no/aktuelt/avvikler-forkurs-i-matematikk-for-larerstudenter/id2678451/

Lattimer, H., & Riordan, R. (2011, November). Project-based learning engages students in meaningful work. *Middle School Journal, 43*(2), 18-23.

Liljedahl, P. (2008). *The AHA! experience: Mathematical contexts, pedagogical implications.* Starbücken, Germany: VDM Verlag.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry.* Beverly Hills, CA: Sage.

Mammadov, S. (2021). The Big Five Personality Traits and Academic Performance: A Meta-Analysis. *Journal of Personality*. doi:10.1111/jopy.12663

Mayer, R. (1998). Cognitive, metacognitive, and motivational aspects of problem solving. *Instructional Science, 26*(1/2), 49-63. Retrieved from http://www.jstor.org/stable/23371264

Megayanti, T., Busono, T., & Makun, J. (2020). Project-based learning efficacy in vocational education: Literature review. *IOP Conference Series: Materials Science and Engineering*.

Michelsen, C., & Sriraman, B. (2009). Does interdisciplinary instruction raise students' interest in mathematics and the subjects of the natural sciences? *ZDM Mathematics Education, 41*, 231-244. doi:10.1007/s11858-008-0161-5

Miettinen, R. (1999). Transcending traditional school learning: Teachers' work and networks of learning. In Y. Engestrom, R. Miettinen, & R.-L. Punamaki, *Perspectives on activity theory* (pp. 325-344). Cambridge: Cambridge University Press . doi:10.1017/CBO9780511812774.022

Moustakas, C. (1994). *Phenomenological Research Methods.* Thousand Oaks: Sage Publications.

Musa, F., Mufti, N., Latiff, R. A., & Armin, M. M. (2012, October 17). Project-based Learning (PjBL): Inculcating Soft Skills in 21st Century Workplace. *Procedia - Social and Behavioral Sciences, 59*, pp. 565-573. doi:https://doi.org/10.1016/j.sbspro.2012.09.315

Norsk Senter for Forskningsdata. (n.d.). *Barnehage- og skoleforskning*. Retrieved from NSD Web site: https://www.nsd.no/personverntjenester/oppslagsverk-for-personvern-i-forskning/barnehage-og-skoleforskning/

Oltedal, E. (2016, September 20). *Elever på rødt lys*. Retrieved February 24, 2020, from Skolen: Veksthus eller fabrikk?: https://fornyskolen.wordpress.com/2016/09/20/elever-pa-rodt-lys/

Perlic, B. (2019). *Lærerkompetanse i grunnskolen: Hovedresultater 2018/2019.* Oslo–Kongsvinger: Statistisk sentralbyrå.

Polkinghorne, D. (1989). Phenomenological research methods. In R. Valle, & S. Halling, *Existential-phenomenological perspectives in psychology* (pp. 41-60). New York: Plenum.

r/FellowKids. (2014, May 18). Retrieved February 22, 2020, from Reddit: https://www.reddit.com/r/FellowKids/

Ravn, O., & Skovsmose, O. (2019). *Mathematics, Connecting humans to equations: A reinterpretation of the philosophy of mathematics.* Springer Nature.

Resnick, L., & Glaser, R. (1976). Problem Solving and Intelligence. In L. Resnick, *The Nature of Intelligence* (pp. 230-295). Hillsdale, NJ: Lawrence Erlbaum Associates.

Robinson, K. (2006, February). Do schools kill creativity? [Video]. TED Conferences. Retrieved February 2021, 24, from https://www.ted.com/talks/sir_ken_robinson_do_schools_kill_creativity

Raattkainen, P. (2005). On the Philosophical Relevance of Godel's Incompleteness Theorems. *Revue internationale de philosophie, 234*, 513-534. doi:10.3917/rip.234.0513

Sealey, P., & Noyes, A. (2010). On the relevance of the mathematics curriculum to young people. *The Curriculum Journal,, 21*(3), 239-253. doi:10.1080/09585176.2010.504573

Seidlin, J., Adams, L. J., & Shuster, C. N. (1948). The Grammar of Algebra. *Mathematics Magazine, 22*(2), pp. 83-99. doi:10.2307/3029270

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching, 77*, 20-26.

Smith, M. U. (1991). A view from biology. In M. U. Smith, *Toward a unified theory of problem solving: Views from the content domains.* Hillsdale, NJ: Lawrence Erlbaum Association.

Soldz, S., & Vaillant, G. E. (1999). The Big Five Personality Traits and the Life Course: A 45-Year. *Journal of Research in Personality, 33*, 208-232. doi:10.1006/jrpe.1999.2243

The Scratch Foundation. (n.d.). *Scratch*. Retrieved from https://scratch.mit.edu/

Trapmann, S., Hell, B., Hirn, J.-O. W., & Schuler, H. (2007). Meta-Analysis of the Relationship Between the Big Five and Academic Success at University. *Zeinschrift für Psychologie / Journal of Psychology, 215*(2), 132-151. doi:https://doi.org/10.1027/0044-3409.215.2.132

Utdanningsdirektoratet. (2006). *Formål: Læreplan i matematikk fellesfag (MAT1-04)*. Retrieved from https://www.udir.no/kl06/MAT1-04/Hele/Formaal

Utdanningsdirektoratet. (2013). *Læreplan i matematikk fellesfag (MAT1-04): Hovedområde*. Retrieved from https://www.udir.no/kl06/MAT1-04/Hele/Hovedomraader

Utdanningsdirektoratet. (2019, March 19). *Matematikk 1-10 (MAT01-05): Core elements*. Retrieved from https://www.udir.no/lk20/mat01-05/om-faget/kjerneelementer?lang=eng

Utdanningsdirektoratet. (2020). *Tverrfaglige temaer - overordnet del av læreplanverket*. Regjeringen. Retrieved October 5, 2020, from https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/

Utdanningsdirektoratet. (2020, Juni 3). *Hva er fagfornyelsen?* Retrieved from Webområde for Utdanningsdirektoratet: https://www.udir.no/laring-og-trivsel/lareplanverket/fagfornyelsen/nye-lareplaner-i-skolen/

Utdanningsdirektoratet. (n.d.a). *Matematikk 1-10 (MAT01-05): Kompetansemål og vurdering: 10. trinn*. Retrieved from https://www.udir.no/lk20/mat01-05/kompetansemaal-og-vurdering/kv14

Utdanningsdirektoratet. (n.d.b). *Matematikk 1-10 (MAT01-05): Kompetansemål og vurdering: 8. trinn*. Retrieved from https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/

Utdanningsdirektoratet. (n.d.c). *Matematikk 1-10 (MAT01-05): Kompetansemål og vurdering: 9. trinn*. Retrieved from https://www.udir.no/lk20/mat01-05/kompetansemaal-og-vurdering/kv15

Utdanningsdirektoratet. (n.d.d). *Core curriculum: The joy of creating, engagement and the urge to explore*. Retrieved from https://www.udir.no/lk20/overordnet-del/opplaringens-verdigrunnlag/1.4-skaperglede-engasjement-og-utforskertrang/?lang=eng

Utdanningsdirektoratet. (n.d.e). *Basic skills: Mathematics Year 1–10 (MAT01-05)*. Retrieved from https://www.udir.no/lk20/mat01-05/om-faget/grunnleggende-ferdigheter/?lang=eng

Utdanningsdirektoratet. (n.d.f). *Core curriculum -- Interdisciplinary topics*. Retrieved from https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/?lang=eng

Utdanningsforbundet. (n.d.g). *Core curriculum: Social learning and development*. Retrieved from https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/sosial-laring-og-utvikling/?lang=eng

Utdanningsforbundet. (n.d.h). *Relevance and central values*. Retrieved from https://www.udir.no/lk20/mat01-05/om-faget/fagets-relevans-og-verdier?lang=eng

Van Manen, M. (2016). *Phenomenology of Practice: Meaning-Giving Methods in Phenomenological Research and Writing.* London/New York: Routledge.

VG. (2021, september 6). *VG*. Retrieved september 6, 2021, from https://www.vg.no/

Vygotsky, L. S. (1978). *Mind in Society. The Development of Higher Psychological Processes.* Cambridge: Harvard University Press.

Wenglinsky, H. (2000). *How Teaching Matters: Bringing the Classroom Back Into Discussions of Teacher Quality.* Princeton: Educational Testing Service (ETS).

Zendle, D., & Cairns, P. (2019). Loot boxes are again linked to problem gambling: Results of a replication study. *PLOS ONE*, *14*(3). doi:10.1371/journal.pone.0213194

Appendix A: Audit trail

This list contains a record of changes done to the research project during its duration.

24.10.2020	Evaluation of study by NSD requested.
27.11.2020	Evaluation by NSD completed and study greenlit.
22.02.2021	Changed the questions used in the interview format after the pilot study, as this revealed significant negative bias in the participants.
11.03.2021	Requested to have the delivery deadline for the study extended until September following further restrictions related to the ongoing COVID-19 pandemic.
04.05.2021	Added additional comments for "Armin's" answers after feedback from the participant. These concerned practicality as a suitable trigger for experiencing mathematical relevance.
12.05.2021	Allowed "Dave" to participate without having his voice recorded. The interview was transcribed directly to a document.
14.05.2021	Added additional comments for "Dave's" answers after feedback from the participant. This concerned a feeling of general irrelevance when a social sciences teacher could not satisfactorily answer a scientific question relating to a project. Though not directly concerning mathematics, "Dave" wished it added to his account, speculating that similar experiences hold true for mathematics too.
11.06.2021	Added additional comments from "Mark's" answers after feedback from the participant. These concerned novelty as a suitable trigger for experiencing mathematical relevance.
14.06.2021	All participants have confirmed their satisfaction with the study.

Appendix B: Pilot Study quotes

This appendix contains the statements quoted from the participants in the pilot study in their original language.

Interview questions

1. Du har hatt prosjekt sånn åtte ganger siden åttene trinn. I noen av dem, som for eksempel i forrige prosjekt du hadde, kunne du bruke matematikk for å svare på problemstillingen. Kan du fortelle meg om du følte at matematikk var brukelig og relevant i noen av prosjektene?
2. Var det noe projsekt der du følte at matematikk var særlig lite brukelig og relevant?

Participant P1

P1: *Prosjekt er så verdiløst. Jeg beklager ass, men det er så bortkasta. Vi lærer ikke noe. Vi får ikke karakter en gang.*

Intervjueren: Hva med prosjektet du akkurat ble ferdig med, den med økonomi? Hva syns du om matte-relevansen der?

P1: *Det var forferdelig. Så kjedelig. Vi lærte oss ikke noe matte.*

Participant P2

P2: *"Prosjekt er det verste faget vi har. Du blir Alltid satt på gruppe med folk som ikke gjør noe. Du lærer ingenting. Ingen gjør noe fordi vi får ikke karakter uansett. Lærerne bryr seg ikke en gang."*

Intervjueren: *"Jeg skjønner at du er misfornøyd med prosjekter. Men, har det vært noen prosjekter I hele tatt som du føler har vært litt bedre enn resten? Mer relevante?"*

P2: *"Nei, det er bare søppel."*

Appendix C: Main Study quotes

This appendix contains the statements quoted from the participants in the main study in their original language.

Interview Questions

Introductory Question

Du har nå hatt rundt åtte prosjekter siden åttene trinn. Noen har vært bedre enn andre — kan du fortelle meg hvilke du har likt best?

Main Question 1

Matematikk har vært mer relevant for noen prosjekter enn andre. Tenk på det mest matematisk relevante prosjektet du kan huske. Hva gjorte at det føltes matematisk relevant?

Main Question 2

Var det et prosjekt som du følte burde vært matematisk relevant, men som ikke var det? Hvis ja, hva gjorte at det ble slik?

Optional Question

Hvordan og hvorfor ville du designet et prosjekt hvis du ønsket å få det til å føles matematisk relevant?

Armin

In 7.2.2 Mathematical irrelevance

"Armin": *Når det ikke er relevant, er det så kjedelig at du har lyst å bare sove.*

In 7.2.2 Mathematical irrelevance

“Armin”: *Når du har prosjekt skal du tenke deg inn da, hva ville du gjort i denne situasjonen. Og da ville mange tenkt hva ville du gjort i denne situasjonen? Da ville de tenkt mer da, og brukt matte på en relevant måte.*

Betty

In 7.2.1. Mathematical Relevance

“Betty”: *Det føles som om at du bare må gjøre det ferdig. Jeg kan bli helt opptatt av det om det er relevant. Jeg sitter timevis å bare jobber og jobber.*

“Betty”: *Det er gøy. Du liker å gjøre det. Du vil se hva som kommer etterpå.*

In 7.4.2 Project teachers with inadequate interdisciplinary expertise

“Betty:” *En gang spørte jeg [vikaren] hvordan man lager en graf over økonomien og han sa at han ikke visste og at det sikkert ikke var så viktig.*

Intervjueren: *I et prosjekt der du hadde valgt matematikk som en av fagene du skulle ha karakter i?*

“Betty”: *Ja! Og, altså, jeg vet at han tok feil. Men akkurat da fikk det hele greien å føles irrelevant.*

Intervjueren: *Hvorfor tror du at det føltes sånn?*

“Betty”: *Altså… hvis ikke han kunne gjøre det og ikke hadde noe bruk for det og han klarte seg fint, så virker det jo ikke nødvendig. Så det er liksom propaganda, du vet?*

Intervjueren: *Propaganda? At funksjoner og sånn kan være anvendbart?*

“Betty”: *Ja.*

In 7.5.1 Economy

"Betty": *Det økonomi-prosjektet var relevant. Man kan i hvert fall si at det er noe vi vil trenge – med renter og sånn. Det blir mer relevant. Folk blir oppmuntret til å gjøre det siden de vil trenge det.*

Cedric

In 7.2.2 Mathematical irrelevance

"Cedric": *Jeg er dum. Ofte skjønner jeg ikke poenget med matte. Hva snakker læreren om, du vet? Jeg blir sint på dem fordi de ikke forklarer bedre. Hva gjør vi og hvorfor gjør vi dette? Jeg blir også sint på meg selv fordi jeg er så dum.*

In 7.6.4 Unsuitable subjects and topics

"Cedric": *De eneste tallene vi ser i historie er årene. Så liksom, i beste fall kunne man regnet ut hvor lang tid noe tok, men det er ikke mye det.*

Dave

In 7.3.2 Novelty:

"Dave": *Jeg tror det blir kjedelig for kjapt. Vi gjør alltid bare det samme, samme, samme. Du kan egentlig ikke kalle det relevant fordi du har allerede gjort det. Det er bare kjedelig å gjøre det igjen. Det er bare relevant for meg når du må lære deg noe nytt for å løse det.*

In 7.4.2 Project teachers with inadequate interdisciplinary expertise

"Dave": *Det ødelegger litt av poenget med tverrfaglighet. Det skal jo være de her to fagene som kommer sammen. Men om læreren ikke vet mer enn om sitt eget fag, så er det ikke så troverdig.*

In 7.6.1 Science

"Dave:" *Jeg forventet noe likt Star Trek der man måtte late som om man løste problemer med romskippet og sånn. Kanskje med asteroider i veien*

men motorene har blitt ødelagde, noe sånn. Jeg vet ikke, det virket bare som en god mulighet å bruke fysikken vi lærte i naturfag i år. Type krefter og energi og mer om verdensrommet

Eva

In 7.3.2 Novelty

"Eva": *Det er kult når du får se det brukt. Ofte er det bare i boka. Og det er vel greit, liksom, men det er bedre når man kan se hvordan det blir brukt på ordentlig. Det beste var når jeg gjorte det økonomiprosjektet og vi brukte funksjoner for å spare penger. Jeg kunne allerede det fra mattetimene men vi hadde brutk det på blomster og sånn. Det var kult å se at detsamme plutselig kunne brukes for å spare penger.*

In 7.3.4 Complexity

"Eva": *Du får det ikke bare servert i virkeligheten. Du må aldri liksom bare finne hypotenusen. Du vil egentlig bygge et bord eller noe. Og hypotenusen er bare avstanden mellom beina som du må vite for å borre hullene eller sånne ting.*

In 7.4.3 Problem ambiguity

"Eva": *Vi hadde en oppgave om å betale for noe i butikken. Jeg tror det dreiet seg om brus og boller, typ to eller tre brus og fire boller, og sammen kostet de 50kr eller noe.*

Intervjueren: *Dette var et dårlig og tvetydig problem?*

"Eva": *Ja.*

Intervjueren: *Hva eksakt var oppgaven? Hva spurte den om?*

"Eva": *Altså, vi skulle finne ut hva prisen for en brus og en bolle ville bli.*

Intervjueren: *Ah, ok, jeg skjønner. Hvorfor var det dårlig, mener du?*

"Eva": *Det kunne være hva som helst! Altså, du kunne bestemme at brusene kostet ti hver og at bollene ville koste, uh, vent… [Eva bruker telefonen, sannsynligvis kalkulatoren]… syv og en halv. Ellers så*

kunne du sette brusene til femten hver og bollene til fem. Men det kunne være hva som helst! Det finnes ikke noen mate å finne riktige svar på. Du kan aldri vite det!

Fred

In 7.2.1 Mathematical relevance

"Fred": *Det er ikke mye jeg syns er relevant, men når det er noe så har du lyst å gjøre det. Altså, du gir ikke opp så enkelt selv om du normalt ville gjort det.*

"Fred": *Nei, jeg syns aldri matte er interessant. Men jeg overlever når det er relevant.*

In 7.3.1 Future utility

"Fred": *Det er ikke noen vits å lære seg grafer og likninger. Vi trenger det ikke. Jeg vil ikke sitte hjemme å lage en graf over maten jeg kjøper eller lage en likning om jobben min. Jeg vil ikke sitte der å si, 'ja, ok, vi trenger å betale x denne måneden', det er teit, jeg ville bare legge det sammen. Det er alt du trenger! Pluss og minus og ganging. Kanskje deling. Kanskje prosenter typ en gang i måneden når det er salg men selv da forteller de deg hva det koster i butikken.*

George

In 7.2.2 Mathematical irrelevance

"George": *Det er litt tullete når du blir vist noe på tavla og det virker helt ubrukelig [latter]. Jeg vet at det egentlig sjeldent er slik men av og til bare vet du ikke hvorfor de går gjennom noe. Det er skuffende. Du kan ikke vurdere hvor mye energi du skal legge i det. Er det viktig? Vil det komme på en prøve? Er det viktig for å lære noe annet i fremtiden? Eller er læreren bare rar på dette punktet? Jeg tror man ville hatt mye mindre frustrasjon hvis lærerne snakket mer om hva tingene er til.*

In 7.3.1 Future utility

"George:" *Noen matte bare lærer du en gang og så ser du det aldri igjen. Andre ting, som Pytagoras, får du bruke igjen og igjen. Det hjelper når du lærer trigonometri, hva med sinus og cosinus-formlene og enhetssirkelen og så kan du bruke det i grafer for vektorer og vinklene mellom de. Funksjoner er også fine, siden det finnes så mange av de og de kan brukes for å lage mange modeller som gjør de brukelige. Så trenger du de for kalkulus. Du kan ikke drive med kalkulus uten funksjoner.*

Henry

In 7.2.1 Mathematical relevance

"Henry": *Du gidder når det er relevant. Når det ikke er relevant gidder du ikke.*

In 7.3.1 Future utility

"Henry": *Det er bortkastet tid om vi ikke får bruk for det.*

Ida

In 7.3.1 Future utility

"Ida": *Noen temaer er forvirrende. Kvadratsetningene var sånn. Men så skjønte jeg at du kunne bruke dem på andregradsfunksjoner til å skrive om dem til sånne parenteser. Altså du gjør om det til to parenteser ganget med hverandre. Så du lærer deg å skrive om dem slik at de er enklere å jobbe med. Det gjorte de kjempebra. Før det var de kjedelige. Men så ble de bare koselige. Det var helt sykt når den klikket.*

In 7.6.1 Science

"Ida": *Vi har allerede hatt masse prosjekter om politikk og egentlig bare en om vitenskap. Og det var lenge siden. For å være helt ærlig syns jeg det var litt bortkastet. Jeg hadde ikke lyst å gjøre det. [latter] Jeg*

mener, jeg gjorte det, det gjør jeg alltid, men det er bare... jeg vet ikke, det føltes skikkelig bortkastet.

Johanna

In 7.3.1 Future utility

"Johanna": *Det meste av det vi lærer er ubrukelig for oss. Du bare lærer det for den oppgaven og så glemmer du det. Jeg syns vi bare burde lære det vi trenger for å greie jobben.*

"Johanna": *Nei, det er ikke relevant. Altså, jeg vet at jeg ikke kommer å sitte å gjøre algebra hjemme. Det er latterlig. Ingen gjør det! Jeg kommer ikke bli matematiker eller lærer eller noe som helst av det så jeg trenger det ikke. Jeg trenger å vite hvordan jeg betaler regninger og skatt og hvordan jeg ikke blir fattig. Kanskje trenger jeg å lære hvordan man bruker Excel og sånn om jeg må bruke det i jobben.*

Kevin

In 7.4.1 Disorganization

"Kevin": *Hvis ikke en gang lærene gidder å gjøre det ordentlig er det vel ikke så relevant.*

In 7.5.1 Economy

"Kevin": *Økonomi er det mest relevante temaet fordi alle trenger å tjene penger for å ikke bli fattige. Det er masse triks ute å går. Altså, triks for å tjene penger gjennom å investere dem og sånn. Du kan ikke bare kjøpe Bitcoin og GameStop og hoppes på det beste. Det er gambling. Og så har du alle triksene de bruker for å ta våre penger også. Det er viktig å vite om det.*

Leo

In 7.3.4 Complexity

"Leo": *Det er ikke det at det burde trenge, liksom, en ny funksjon vi aldri har sett før. Men et relevant problem skal ikke løses på 1-2-3. Det kan være at du først må regne ut volumet til noe, og så massen, og så når du har massen, så får du akselerasjonen, og da kan du svare hvorvidt det ville koste for mye å gjøre noe.*

In 7.6.3 Programming and Art

"Leo": *Det er masse ting som er felles mellom Programmering og matte. For eksempel så jobber alle datamaskiner med tall uansett. Jeg tror matte lar deg skjønne mer.*

"Leo": *Datamaskiner er gode på å gjøre beregninger igjen og igjen. Så jeg tenker et prosjekt der du må gjøre en utregning kanskje hundretusen ganger. Noe sånn.*

Mark

In 7.3.1 Future utility

"Mark": *Vi vet ikke hvorfor vi må lære disse tingene. Altså, vi vet at det er brukelig. Men, det er bare brukelig for andre egentlig. Forskere kanskje, og matematikkere. Jeg tror ikke mamma sitter og tenker på funksjoner.*

"Mark": *Jeg vil bli elektriker. Må elektriker løse likninger hver dag? Jeg vet ikke. Kanskje de gjør det, men jeg vet bare ikke. Så jeg vet ikke om likninger er relevante for meg.*

Appendix D: Consent form

Vil du delta i forskningsprosjektet

"Relevant matte i prosjekt"?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å *finne ut hvordan matematikk kan gjøres mer relevant i prosjekt*. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Jeg ønsker å undersøke hva elever syns om matematikk i prosjekt. Det er en liten undersøkelse her på skolen for elever i 10. trinn.

Spesielt ønsker jeg å undersøke to ting: hva elever syns er relevant matte for dem, og hvordan elever mener at prosjektundervisningen burde være lagt opp for at den skal kunne gi relevant mattekunnskap.

Forskningsprosjektet er til en masteroppgave.

Hvem er ansvarlig for forskningsprosjektet?
Høgskolen i Innlandet er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?
20 elever har vilkårlig blitt trukket ut fra klasselistene i 10. trinn på skolen for å bli spurt om deltakelse.

Hva innebærer det for deg å delta?

Hvis du velger å delta i prosjektet, innebærer det at du deltar i et intervju med meg. Det vil ta deg ca. 45 minutter og gjøres på skolen.

I intervjuet kommer du få snakke om og svare på spørsmål om prosjektundervisning og hva du mener er relevant matematikk for deg.

Jeg kommer ta lydopptak og notater fra intervjuet, men ditt navn kommer ikke komme med i oppgaven.

Jeg kommer registrere deltakelse for å ta kontakt med deg når jeg er ferdig med prosjektet. Dette gjør jeg for at du skal få vite hva jeg har brukt fra intervjuet og hvilke slutninger jeg har trekket. Hvis du mener at du ikke har blitt rettferdig tolket, vil du få mulighet til å be om endringer.

Foreldre kan få se intervjuguide på forhånd ved åt a kontakt.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Deltakelse eller trekking fra prosjektet vil ikke påvirke din situasjon på skolen. Det vil ikke påvirke dine vurderinger eller ditt forhold til skolen/lærerne. Dette prosjektet er ikke en del av undervisningen på skolen.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- Kun student (Lars Thomas Bågenholm) og veileder (Reinert A. Rinvold) ved Høgskolen i Innlandet har tilgang på dine opplysninger.
- Opplysningene lagres sikkert og kryptert i Nettskjema.

Deltakere i prosjektet vil ikke kunne gjenkjennes i publikasjon. Ingen lydopptak publiseres, men intervjuene transkriberes (skrives av) til tekst. Du kan bli sitert fra avskrivingen, men du vil ikke kunne gjenkjennes. All data anonymiseres, slik at hvis du blir sitert i prosjektet så vil det skje med falskt navn.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er
5. mai. Da slettes alle personopplysninger og lydopptak fra intervjuet.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Høgskolen i Innlandet har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Veileder/Prosjektansvarlig:
  Reinert A. Rinvold
  E-post: reinert.rinvold@inn.no
  Tlf: 62 51 78 89

- Student:
  Lars Thomas Bågenholm
  E-post: 238516@stud.inn.no
  Tlf: 95 72 08 76

- Vårt personvernombud:
  Hans Petter Nyberg
  E-post: hans.nyberg@inn.no
  Tlf.: 62 43 00 23

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Reinert A. Rinvold (Forsker/veileder)

Lars Thomas Bågenholm

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *Relevant Matte i Prosjekt*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å delta i intervju

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

----

(Signert av prosjektdeltaker, dato)

Jeg samtykker at mitt barn, _____________________________________ kan delta i forskningsprosjektet og at mitt barns opplysninger behandles frem til prosjektet er avsluttet

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(Signert av foresatt til prosjektdeltaker, dato)

Abstract

The LK20 curriculum emphasizes three interdisciplinary themes which lend themselves well to project-based learning (PBL). Attempting to determine what makes such a project mathematically relevant, this study looks at the interdisciplinary PBL-implementation in a Norwegian junior high school.

Using a phenomenological analysis of interview data from 13 pupils at the school, the study identifies several aspects which may help improve mathematical relevancy in association with interdisciplinary projects for 14–15-year-olds. It also highlights potential negative aspects which may be detrimental to the perceived relevance of a project.