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The potential of photography for mathematics education and research–A literature review

Susanna Maria Oksanen [1]*, Markku S. Hannula [1], Anu Laine [1]

[1] Faculty of Educational Sciences, Department of Teacher Education, University of Helsinki, Helsinki, FINLAND
***Corresponding Author:** susanna.oksanen@gmail.com

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ABSTRACT

This literature review examines the use of photography in educational research and in education, to learn how photography could be better used in teaching and learning mathematics and mathematics education research. The authors analyzed 125 publications published between 1975 and 2023 to identify different research methods and teaching solutions that utilize photography. Within educational research two main approaches that are often used combined were photo-elicitation (photographs are used in an interview as a stimulus) and photovoice (taking photographs is a way the participant communicates their perspective). Mathematics education research could also combine these methods, for example in identity research. Our findings regarding teaching show that photographs have an important role in connecting mathematics to the real world and for visualizing mathematics. The best way to engage students is when they take photographs of themselves as a starting point to mathematical activity. Based on this review we identify future exploratory directions and various research gaps.

Keywords: literature review, mathematics education, photo-elicitation, photography, photovoice

INTRODUCTION

Photographic images are increasingly present in everyday life as a medium of social interaction and commentary (Miles & Howes, 2015). Today, more people have access to cameras than ever before (Vellanki, 2022). Photography has become a substantial part of everyday life for many young people who take and share massive numbers of photos using their phones and applications such as Snapchat (Niemelä-Nyrhinen & Seppänen, 2023). In schools, photography can be an extremely powerful tool for both delivering curriculum goals and allowing for individualized exploration and expression (Groeneweg, 2014). In educational research, photography can engage research participants in representing and reflecting upon their own experiences and identity (Chao, 2014). To understand how photography is currently used and could be used in the future in mathematics teaching and learning and in mathematics education research we conducted a literature review. This paper provides an updated review on the use of photography in teaching and learning and educational research in general and extends it into the field of teaching and learning mathematics for the first time.

Development of Photography & Its Way to Education & Research

The first camera, camera obscura, was invented in the 1500s (Newhall, 1998). First, the development of the camera was relatively slow. After the first photographically illustrated books were produced in the 1800s, photojournalism developed. Those were the early years of portraiture, landscape and survey photography, war photography, and documentary photography (Theno, 1986). In 1889 Kodak brought portable cameras available to the consumers and amateurs. In 1947 Polaroid, the first instant camera was introduced. As cameras became more accessible in the 1960s, they were also introduced in research: participatory photography projects were first used in the social sciences (Miles & Howes, 2015). In the 1970s the researchers noticed that the use of cameras helped to increase students' motivation and gave possibilities for innovative teachers to integrate different areas such as language arts, social studies, science, and mathematics in their teaching (Brumbaugh & Hynes, 1979, p. 440). Also, pictorial representations in textbooks were considered beneficial for learning (Janko & Knecht, 2013). Evaluation of nonverbal elements in mathematics textbooks shows the importance of photographs in situations when it is difficult to represent the learning content verbally (Gunzel & Binterova, 2016).

In the late 1980s the early digital cameras were introduced. The rise of digital cameras has gone along with the expansion of personal computers. Besides using photographs in textbooks, technology has made it possible for teachers to use photos with computers and mobile devices. Using digital images for teaching mathematics became practical in the beginning of 2000, when digital technologies were becoming feasible for regular classroom use (Pierce et al., 2005).

Since the launch of the first digital camera phone in 2000, nowadays nearly everyone carries a mobile camera, the number of photographs has increased exponentially and with just a click of a button a photo can be shared (Groeneweg, 2014; Miles & Howes, 2015). Because students, digital natives, are comfortable taking photographs, photography is a familiar and natural way to integrate visuals for teaching and learning (Cappello & Lafferty, 2015; McCracken, 2015). As social media use has risen, teachers have also taken up the medium in specific ways, for example sharing their life in Instagram using the hashtag #teachersofinstagram (Angelone, 2023). The nature of personal photography has changed from taking visual memories to ephemeral communications (Niemelä-Nyrhinen & Seppänen, 2023).

Photography in Educational Research

Photography belongs to visual research methods and its origins in educational research are in the 1960s and 1970s (Prosser & Schwarz, 1998). Photography has strength as a methodology of representation and recognition (Miles & Howes, 2015). The camera is a flexible tool to collect data in various ways: research participants can take photographs themselves or the researcher can use photographs during an interview (Chao, 2014; Harper, 2002; Prosser, 1998). Photography is a representational system that provides three levels of information: denotation or material information, connotation or semantic information, and punctum or emotional information (Bautista García-Vera, 2023). For example, a form of participatory research, photo-voice, has helped students and their families to recognize mathematics in their lives outside the classroom (Hunter, 2022).

The research approaches that include the participants using cameras are classified under the methodological umbrella of participatory action research (PAR) (MacDonald, 2012). PAR is a qualitative research methodology considered as a subset of action research (Reason & Bradbury, 2006). Participatory photography often involves groups or individuals who would traditionally be the subjects of others' research in taking and interpreting their own photographs. The goal is to address and share important aspects of their lives and experiences (Wang et al., 1996). MacDonald (2012) summarizes that in PAR the participant is active in making informed decisions throughout all aspects of the research process.

Photography in Education

Photographs can be a powerful tool in enhancing teaching and learning in a variety of subjects. They can help to engage students, provide visual aids to support learning, and encourage critical thinking and analysis. For example, photographs can illustrate historical events, cultures, and landscapes.

When it comes to teaching and learning mathematics, photography can support visualization especially (Clements, 2014). Visualization, as both the product and the process of creation, interpretation, and reflection upon pictures and images, is an important aspect of mathematics education (Arcavi, 2003).The development of computers and software programs such as GeoGebra has allowed the creation of dynamic, interactive visualizations that can be used to teach complex mathematical concepts, for example, topics of shape recognition, spatial sense through ratio/proportion and measurement (Furner & Marinas, 2012).

Research Questions

This literature review aims to explore the existing literature related to the use of photography in education and educational research especially from the perspective of teaching and learning mathematics. Our goal is to identify research gaps and potential future directions regarding the use of photography in mathematics education research and practice. We wanted to answer these two primary questions:

How photography, i.e., cameras and photographs are used within

(1) educational research and especially within research in mathematics education? and

(2) education especially from the perspective of teaching and learning mathematics?

We look at the results first from the perspective of general education and then from the perspective of mathematics education.

METHODOLOGY

To answer the research questions and to understand the role of photography in an educational context, we conducted a literature review. The review is reported according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Page et al., 2021). The first database search was made in the beginning of 2020. Supplementary searches were made in September 2022 to include publications published between January 2020 and August 2022, in January 2023 to include publications published between September 2022 and December 2022, and finally in March 2024 to include publications published in 2023. See **Appendix A** for more detailed information. **Figure 1** summarizes the flow of the literature searches.

Selection of Keywords

First the relevant keywords were identified in English. We chose three words:

(1) photography,

(2) education, and

(3) mathematics.

Boolean operators were used to combine terms: photography AND education; photography AND education AND mathematics.

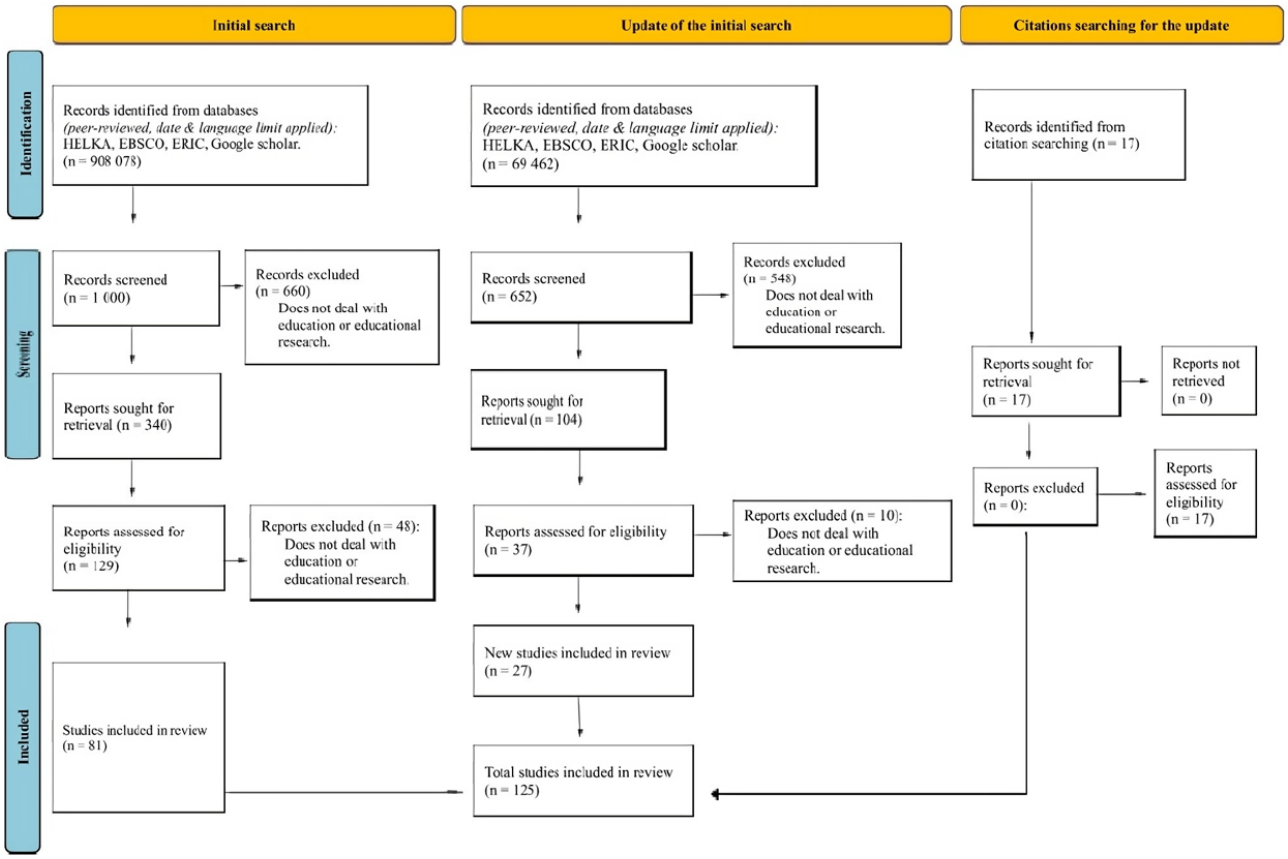

Figure 1. Flow of literature search (Page et al., 2021)

Selection of Databases

We chose four education-related databases to find relevant publications. The databases were examined in the following order:

(1) Helka-database is a shared collection and circulation service (helka.finna.fi). It has roughly two million publications from printed and electronic publications, e.g., books, journals, serials, theses, and electronic material.

(2) Academic Search Complete EBSCO is a multi-disciplinary database (ebsco.com).

(3) ERIC (ProQuest) is an international database of educational publications, which provides coverage of journal articles, conferences, and other education-related material (eric.ed.gov).

(4) Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines (scholar.google.com).

Choosing Relevant Publications from Databases

We used the following inclusion criteria for the publications to be included in the review:

(1) the study was published in English,

(2) the study was peer-reviewed,

(3) the study focused on photography, i.e., the use of cameras or photographs in educational research, or/and

(4) the study focused on photography, i.e., the use of cameras or photographs in teaching and learning.

We started with database number one (Helka) and continued the process until database number four (Google Scholar). In the first phase, if the title or the abstract of the publication did not correspond to criterion (3) or vrtiterion (4), the publication was excluded from the review. The review continued until the number of publications addressing the designated scope became fewer and fewer and finally ended. This usually happened after 60-80 publications, but the first author always read the title and abstract of approximately 100 publications from each database. If the same publication was found in several databases, it was only counted once.

We received over 977,000 publications from the databases when using our keywords (see **Appendix A**). The first author read 1652 titles and 461 abstracts. Finally, 173 publications were read, and 108 publications chosen. We found another 17 relevant publications in their references leading to 125 publications in this literature review.

Coding Procedure

When reading the publications, the first author collected selected key information into the data extraction sheet in Excel:

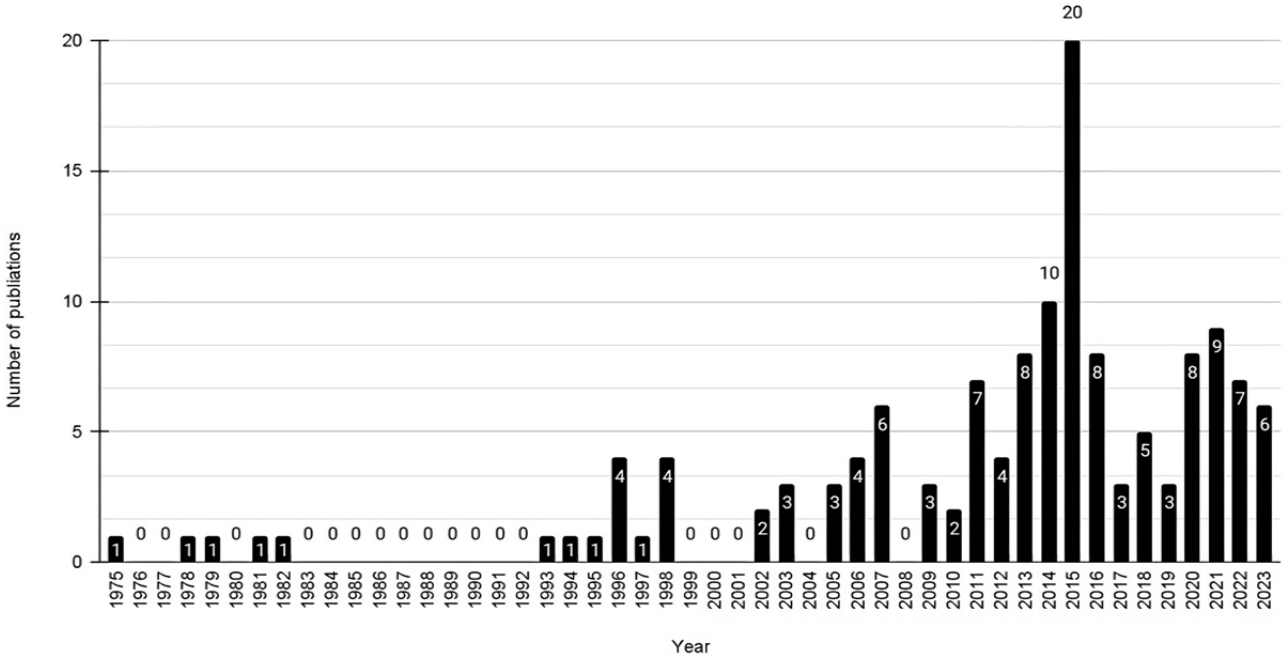

Figure 2. Distribution of year of chosen publications (Source: Authors' own elaboration)

(1) study information including authors, year of publication and title,
(2) publication type,
(3) country in which the research was conducted,
(4) participants grade level and age,
(5) subject,
(6) research questions / aim of the study,
(7) study methods or research design,
(8) how photography was used in the study,
(9) results, and
(10) ideas for further research.

Characteristics of Selected Publications

The selected publications highlight a broad range of countries, publication types, participant demographics, research designs, and different ways to use photography. The publications are from all over the world from various countries such as Ethiopia, England, Cyprus, Sudan, Australia, Taiwan, Canada, Sweden, Spain, Kenya, New Zealand, Denmark, Finland, China, Poland, Malaysia, Jordania, Zambia, Italy, Portugal, France, USA, and Romania. Participants in the studies cover a wide range of age groups. Examples include elementary and secondary school students, high-school students, student-teachers, and various other groups from early childhood to higher education. All detailed information about the chosen publications is available upon request from the first author. This document contains in-depth information on various aspects and serves as a valuable reference for obtaining a comprehensive overview of the chosen publications.

Altogether 56% (n=70) of the publications focused on photography as a research method, while 44% (n=55) on the use of photography in teaching and learning. They cover the use of photography in education and educational research in general (n=89) and specifically from the perspective of mathematics (n=36). **Appendix A** shows the distribution of publications found from different databases.

The earliest publication found for this systematic literature review was published in 1975. **Figure 2** shows the year of publication for each publication in this review. The high peak for the year 2015 can be explained by 15 articles from one book (Miles & Howes, 2015) published that year.

RESULTS

We present first the findings regarding the use of photography in general education research and then in mathematics education research. Second, we present the findings regarding the use of photography generally in teaching and learning and then specifically from the perspective of teaching and learning mathematics.

Photography in Educational Research

Over several decades the use of photographs as a research tool has been implemented widely. We identified two main approaches from the literature:

(1) photo-elicitation, where photographs were used in an interview as a stimulus and

(2) photovoice, where taking photographs was a way the participant communicates their perspective.

Photo elicitation is based on the idea of including photograph(s) into a research interview. The method includes either photographs that the researcher has pre-selected, or photographs taken by research participants to explore a phenomenon during an interview (Chao, 2014; Corcoran, 2015; Harper, 2002; MacDonald, 2012; McCracken, 2015; Miles, 2011; Pyyry et al., 2021, Romera Iruela, 2023). Photo elicitation has been used as a visual participatory research method since the 1950s (Harper, 2002; MacDonald, 2012). Photo-elicitation takes many differing forms including interviews with individuals, with groups, with children, and those who respond more easily to visual, rather than lexical, prompts (Prosser & Schwartz, 1998).

Photovoice involves giving participants cameras and asking them to a) take photos about certain phenomena or to b) document and tell their own stories and then these photographs are used as data in the research or to facilitate interviews (Ciolan & Manadia, 2017; Wang & Burris, 1994). In this paper we use photovoice as an umbrella term for all similar participatory photography methods such as photo novella and photo journals. The use of photovoice is not new in social sciences, but its use within education research is (Ciolan & Manadia, 2017). Photographic images are ideally suited to inclusive research, as they have their own unique expression or language, and are highly accessible (Wang, 2006).

Usually these two main approaches, photovoice and photo elicitation, were combined when using photography in research. The approaches were shown to be effective even in cases, where the communication between the researcher and the research participants is limited due to language barriers (Eliadou, 2015). The differences between photo-elicitation and photo-voice and their advantages and limitations when engaging with child voice were identified and appraised by Shaw (2021). Their study explored whether through careful, critical, and conscientious application, these tools might advance understanding of younger children's perceptions of matters affecting them.

Using photography related research methods with students

In research, photography has the potential to meaningfully engage children and young people (Miles & Howes, 2015). Several authors have noted that giving the children cameras increases the children's power because they can make a choice and pick out things that are of importance to them (Cope, 1981; Faria & Cunha, 2016; Harkness & Stallworth, 2013; Johnson et al., 2014; Kor & Lim, 2020; Lemon, 2013; Martin & Gourley-Delaney, 2014; Sapin, 2015). Also, university level students can benefit from the use of photographs: Kaplan et al. (2011) concluded that the use of participatory photography in university courses in education is new and untested, but their experience suggests that it can provide a potentially powerful means of engagement. During the COVID-19 pandemic students used photography for example to connect to themselves, their history, and the living world (Vaughan-Lee, 2021) or to document their lives (Jirásek & Stránský, 2022).

Because photography has the power to strengthen the voices of misrepresented pupils, the following groups of people benefitted much from using photography in educational research: students with disabilities (Newbury, 1996; Zehle, 2015), high-achieving students (Anderson, 2015), students with learning difficulties (Mamaniat, 2015), underserved students (Means & Hudson, 2019), LGBTQI+ students, i.e., individuals who identify as part of the diverse spectrum of sexual orientations and gender identities (Ashburn, 2007), deaf students (McCracken, 2015), and students, teachers and/or researchers who do not share a common language (Eliadou, 2015; Wolfenden & Buckler, 2015).

In mathematics education research photovoice has been used with students who have difficulties with mathematics (Harkness & Stallworth, 2013). Research has extensively explored the level of mathematics anxiety, gender differences, and its correlation with performance (Garba et al., 2020). To address this, the research group used the photovoice method to observe and record peers' behaviors and language, which can either increase or decrease mathematics anxiety. The study concludes that students' mathematics anxiety can be influenced by their daily interactions with peers. To understand female high school students' conceptions of mathematics and learning mathematics the researchers requested four girls who faced difficulties with mathematics to use photography to respond to three questions: what mathematics means to you, what does an ideal learning environment look like, and what obstacles do you face while learning mathematics (Harkness & Stallworth, 2013). The researchers' suggestion would be to use photovoice at the beginning of the school year as a tool to help teachers to understand the perspectives of their students. Also in a more positive manner, photovoice has helped researchers to find out what students perceive as a good mathematics lesson (Kor & Lim, 2020). In another study photovoice was used as an alternative method to explore what is a good mathematics lesson as conceived by the primary pupils (Kor and Lim, 2020). Result shows that photovoice did help to enhance learner's critical reflection and the presence of photographs encouraged young pupils to "recall and speak out their mind in detail" (p. 63).

Using photography related research methods with teachers

Photovoice has also been used with teachers to explore and reflect their lives and professional identity (Chao, 2014; Graziano & Litton, 2009; Kaplan et al., 2011; Mayer & Kroeger, 2005). When using photovoice as a method for teacher research, such methodology can reveal information that would not normally be uncovered by traditional forms of research (Graziano & Litton, 2009). Some characteristics of photography make it especially suitable for research questions that require participants to tell their own stories (MacDonald, 2012; Miles, 2011). Graziano and Litton (2007) concluded that participatory research is "an ideal theoretical framework for understanding the lives of teachers" (p. 16). Photographs can stimulate participants to comment not

only on the content of the photograph but what is intimate to the interviewees that is 'triggered' by the photograph (Prosser & Schwarz, 1998). When photographs were used as part of a research interview, the researchers felt that the photos sharpened the informants' memory and reduced the areas of misunderstanding (Harper, 2002).

Photography has helped teachers in a professional training context to reflect. (Howes, 2015; Meyer & Kroeger, 2005). In one study teachers were encouraged to take a series of photographs signifying changes in their practice over a period of several weeks (Wolfenden & Buckler, 2015). The use of the images enabled researchers to gain access to diverse moments of teachers' practice, the rich reality of teaching as embedded in the school and wider community. Engaging with images has also enabled teachers and other professionals to reflect critically on issues of representation and fairness within their professional relationships, and to see further possibilities for a pedagogy for justice and care (Miles & Howes, 2015). Regarding research related to mathematics education, the construct of teacher identity and how mathematics teachers think of themselves is crucial in understanding the complexities of teaching (Chao, 2014).

Limitations & ethical concerns identified in reviewed publications

We found some limitations for using photography in educational research. It is important to remember that a photograph is not simply a representation of reality, but rather a result of the photographer's artistic vision and decision-making process: this involves not only deciding when to capture the image, but also how to compose it within the frame to convey a specific message or evoke a particular emotion (Quinn & Manning, 2013). Furthermore, the researchers' underlying epistemological and methodological assumptions may orientate the way the researcher involves photography in their study (Prosser & Schwartz, 1998). That is because "researchers bring to any study, skills, knowledge, past experiences, abilities, personal values, beliefs, enthusiasms, which are embedded in a culture, which directs not only their visual perception and what they study, but the way they conduct that study" (p. 114). Another limitation is that without additional commentary one photograph is susceptible to multiple interpretations (Mamaniat, 2015).

We also noticed some ethical concerns when using photography in educational research. First, written authorization should be acquired from parents allowing the use and display of images of their children (Byrnes & Vasik, 2009). When research participants are taking photos themselves, they may include people in their photographs, whose consent is hard for the researchers to acquire. Also, Quinn and Manning (2013) consider the issues of consent and assent in the use of photography with children: schools should ask not only the consent of guardians, but also the permission of children.

Second, the potential parent intervention should be taken into consideration when children take photographs. Parents may feel the need to suggest subjects or even take pictures themselves (MacDonald, 2012). Third, in the context of education, power dynamics may differ, with children typically having less power than teachers, pre-service teachers having less power than field placement supervisors, teachers having less power than administrators, and all these groups having less power than state and national education departments or accreditation bodies (Quinn & Manning, 2013). Fourth, when offering the freedom to students to take photos in schools, there is often the risk of abuse, misuse, and manipulation of images (Kaplan & Howes, 2004). Fifth, like other qualitative research methods, photovoice has its own advantages and difficulties. One critical aspect of photovoice is to provide clear prompts to guide participants, which helps maintain their interest and enjoyment throughout the process (Ciolan & Manasia, 2017).

One more thing to consider is the European Union general data protection regulations. It has a direct impact on research activities, as it raises the awareness of personal rights not only among the scientists but also among the data-subjects scientists process information from (Siegert et al., 2020). Photographs not only identify the individual, but they may also include sensitive personal information such as racial or ethnic origin or religious beliefs (c.f. Hannula et al., 2022).

Due to differing licensing terms, we are unable to reprint illuminating examples of the photographs from other publications. However, we invite you to explore the original book (Howes & Miles, 2015), where you'll find relevant images to the field of this study from the perspective of photovoice.

Photography in Education

In the previous chapters we have looked at the use of photography from the perspective of educational research. We now move on to look at the use of photography in education. Especially in teaching and learning at school, photography is used as a didactical tool or in assessment and evaluation to evidence learning. In the following paragraphs we illustrate these approaches and ideas. We also identify the groups of students to whom photography as a teaching and learning method is best suited.

Photographs as a didactical tool

In classrooms, photography is often used as a pedagogical tool for making real-life connections. While all students learn differently, photography in the classroom can be "a unique and powerful tool for combining and achieving curriculum goals with creative exploration and expression" (Groeneweg, 2014, p. 51-52). When photographs are combined with written text, students can examine the relationship between their prior knowledge, real-life experiences, and new content knowledge (Madden & Dell'Angelo, 2016) This method of processing information creates pathways that are more likely to lead to long-term memory storage.

When using photography in teaching and learning, some groups of students seemed to benefit the most. Especially in early childhood education the use of photography and photographs as a pedagogical tool is widespread (Quinn & Manning, 2013). Photographs have been used as a device to reflect upon pedagogy and for 'authentic' assessment of child outcomes. Study results by Boardman (2007) reveal that digital tools have the potential to enhance not only the young child's learning but also the teaching methods of early childhood practitioners. Byrnes and Wasik (2009) give guidelines on how to make picture-taking effective and

Mathematical Ideas	Photographs
Parabolas • Insert real-life examples by using arches. • Create a parabola in GeoGebra with parameters to curve fit the arches. • Explore how each parameter affects the shape of the parabola.	
Slopes • Insert real-life example by using slides of buildings and ladders. • Create a linear function in GeoGebra to explore the concept of slope.	

Figure 3. Sample examples of GeoGebra activities (adapted from Furner & Marinas, 2013, reprinted with permission)

fun in the early childhood classroom: their examples include using photographs to demonstrate different emotions or to build vocabulary with picture walks, matching games, personalizing pictures, classroom newsletter, pictures for storytelling and retelling, picture previews, and guessing games. Another group that seems to benefit when using photography in education is neurodivergent children. For example, many of the difficulties autistic children face can be eased using visual support aids (Dyrbjerg & Vedel, 2007).

During the past two decades several authors have noticed that when it comes to teaching and learning mathematics, photography can especially help students to relate mathematics "to the real world" (Furner & Marinas, 2012; Leonard & Guha, 2002; MacDonald, 2012; Meier et al., 2018; Munakata & Vaidya, 2012; Northcote, 2011; Pierce et al., 2005; Warrington, 2009). "When math has a purpose, students are willing to spend time exploring and understanding new concepts" (Furner & Marinas, 2014 p. 134). Through photography, mathematics can also be integrated with many other subjects such as physics, art, technology, or media studies (Pierce et al., 2005). When photography is used as a didactical tool at schools, students either a) use ready-made photos to learn or b) first take photographs themselves and then use them as learning material. In the following chapters we look at these two approaches in more detail.

Ready-made photographs used in teaching and learning: A study by Gunzel and Binterova (2016) presents a suggestion of how nonverbal elements in mathematics textbooks can be categorized and how we can compare mathematics textbooks using this categorization: photographs are one category among drawings, graphs, symbols, and signs**.** Another study noticed that the representation of scientists in textbooks is a crucial aspect of a student's school experience and serves as a measure of who is considered capable of pursuing a career in science (Murray et al., 2022). This has sparked ongoing interest in examining textbooks through a gender balance lens: "There was a tendency to show men in scientific and other occupational roles while women were less well represented in scientific roles and were pictured in domestic and buying activities" (p. 373).

In our literature review we found many examples on how photography was used to teach new mathematical concepts: many mathematical themes and topics were taught using photographic images such as numeric relationships for size comparison and angle measurements (Furner & Marinas, 2012), cartesian coordinates, linear functions, ratio, and Pythagoras' theorem (Pierce et al., 2005), abstract algebra (Warrington, 2009) and the concept of function (Venter, 2020). Photographic images supported the conceptual development of proportional thinking (Hilton et al., 2015). The teachers in this study found photography to be a valuable approach, not only for proportional reasoning but also for other mathematical topics and even beyond, suggesting its usefulness and versatility. Teachers observed that students were highly engaged and motivated when presented with photographs depicting real-life situations, which helped to bridge the gap between mathematics and the world outside the classroom. This powerful teaching strategy prompts students to connect visual images, mathematical concepts, and mathematical language, ultimately aiding in their understanding of the underlying mathematical relationships. Additionally, this approach minimizes the need for students to rely on algorithms or procedural approaches.

In literature one software stood out when it comes to using photographs in mathematics teaching and learning: GeoGebra (www.geogebra.org). Combining photographs and GeoGebra in teaching has covered a broad range of mathematical concepts, such as measurement and numeric relationships, numerical comparisons for size, constructing geometric shapes, measuring angles, developing spatial sense, understanding algebraic concepts, mathematical modelling, and measurement for distance and area (Furner & Marinas, 2012). When math teachers teach mathematics using GeoGebra and photography they show a purpose for math and practical applications to math in life. Sample examples of GeoGebra activities to teach mathematical ideas with photographs (**Figure 3**).

Students take and use photographs of themselves: Many teachers have used digital cameras, disposable cameras, and mobile phone cameras as tools for handing over control of a mathematics lesson to the children (Leonard & Guha, 2002; Martin & Gourley-Delaney, 2014; Northcore, 2011; Warrington, 2009). Usually, the photographs taken by the students are used to create tasks or classified using a mathematical criterion. For example, through open-ended problem photos, teachers and students will

see mathematics through a new lens (Bragg & Nicol, 2011). An important aspect of open-ended problem photos is that they create a curiosity in the students and a desire to explore possible solutions. In another study children from grade 2-grade 5 got disposable cameras and were asked to take pictures of interesting sites and people to create word problems (Leonard & Guha, 2002). The students were asked to select two or three of the pictures they took and prompted to think about all the mathematical concepts they could identify in the pictures. This task greatly motivated the students, who immediately began to discuss and share ideas. By identifying the math in their pictures, the students were able to apply mathematics in novel ways. In another study 35 sixth grade students were asked to take, view, and caption their own photos of mathematics and then view and comment on their classmates' photos and participate in a small group discussion. The results indicate that the students tended to focus on surface-level indicators such as symbols and coins, as well as the potential for mathematical action, when deciding whether a photo or activity involves math (Martin & Gourley-Delaney, 2014).

Finding different forms of symmetry seemed to be a good way to use photography: a staff car park inspired students to examine and identify objects with rotational symmetry (Hancock, 2007). Also, another study used a photo classification method when designing a photographic assignment for abstract algebra and symmetry (Warrington, 2009). Students took digital pictures around campus of various examples of symmetry. They then classified these pictures according to which of the 17 plane symmetry groups they belong to. The researchers report that by relocating the source pictures from the textbook to a physical location within their everyday surroundings, two benefits arise. Firstly, it connects algebraic concepts to everyday objects that students can relate to. Secondly, this activity can be beneficial for students who enjoy photography or are struggling with the course, as it provides a welcome break from working with abstract symbols on paper.

Photo competitions are also one possibility in which photographs taken by students were used. Munakata and Vaidya (2012) used photography competition to encourage creativity in science and mathematics with undergraduate science and mathematics students and in-service mathematics teachers. The assignment challenged participants to see images of mathematics around them and to capture those images through photography. They were asked to take the photograph(s), analyze the mathematics underlying one of them, and develop questions that promote problem solving based on that photograph.

In-service teachers found many benefits when using cameras and photography during their studies. Meier et al. (2018) studied the effect of photography-based teaching in outdoor conditions. They asked in-service teacher students to go out, "find mathematics" and take ten pictures with their mobile phones. They report that this activity was successful in helping the students re-see familiar objects with mathematical vision.

Photography as assessment and evaluation tool

Besides using photography as a didactical tool, cameras and photographs can also be used as a tool for assessment and evaluation. Many researchers have reported growing understanding of the subject being taught when using photography as an assessment or evaluation tool. Photographs have helped teachers to uncover and analyze overlooked student work, document student understanding, and enhance lesson planning in mathematics (Roller et al., 2019).

For example, creating reflective photo journal entries in a science course helped college students to establish connections between science content and

(a) their personal lives and beliefs,

(b) their prospective careers, and

(c) global environmental issues (Madden & Dell'Angelo, 2016).

Consequently, the teacher had solid proof that the students not only acquired knowledge but also gained a comprehension of how that knowledge was related and integrated into a broader context. In the following example during an online course with undergraduate university students' participants used photographs in assessment submissions to evidence their learning (Sapin, 2015). After being introduced to photo-elicitation, which involves using photographs to spark discussion, students started using a variety of creative images to showcase their learning in assessment submissions, project proposals, and evaluations. Following some discussions about this technique during certain projects, it was adopted as a learning method in the course to encourage and stimulate participation in online text-based discussions.

DISCUSSION

In this literature review we have summarized how photography has been used within education and educational research with a specific interest in mathematics. In teaching and learning mathematics, photography is often used as a didactical tool to activate students, visualize mathematics, to teach new concepts, facilitate learning, and to find real-life connections (Faria & Cunha, 2016; Warrington, 2009) or as a pedagogical tool for assessment and evaluation (Behrendt & Machtmes, 2016; Madden & Dell'Angelo, 2016). Photographs have an important role in connecting mathematics to the real world and visualizing learning content. We found vast possibilities in the existing literature on how different mathematical themes and topics, such as numeric relationships for size comparison and abstract algebra, can be taught using photographic images. Interactive technology, especially GeoGebra, helps students to relate and mathematise real-world photographs. Photographs bring mathematics closer to pupils' everyday lives. Many reviewed studies address the lack of research on how students think about and identify mathematics in contexts outside of school (MacDonald, 2012; Martin & Gourley-Delaney, 2014).

Student interest and motivation peaked when photography was part of the instructional strategies to teach new material and make meaningful connections to mathematical concepts (Furner & Marinas, 2012). Further research is needed to find out if

photography can support not just generating situational interest but also developing a more sustained personal interest. Situational interest is spontaneous and context-specific, whereas personal interest is enduring and context-general (Schraw & Lehman, 2001).

Within educational research we identified two main approaches from the literature on how photography was used: photo-elicitation and photovoice. Both photo elicitation and photovoice have been used as research methods with students of all ages and with pre-service and in-service teachers: when students are asked to take photographs, the research participants are active in making decisions during the research process (MacDonald, 2012). Students can reflect on how their prior knowledge, real-life experiences, and new content knowledge are related. By using photovoice researchers gain a deeper understanding of how students learn mathematical concepts and what aspects of the classroom environment they find important, all with the goal of enhancing the effectiveness of mathematics instruction (Seah & Wong, 2012). With the help of photography, teachers can explore and reflect on their lives, professional identity, and teaching practices (Chao 2014; Graziano & Litton, 2009; Kaplan et al., 2011; Mayer & Kroeger, 2005; Weng & Troyan, 2023). While both methods have been used also in mathematics education research, we see much potential to expand their use. These two main approaches, photovoice and photo elicitation, work best when combined (Chao, 2014; Kor & Lim, 2020; Miles & Howes, 2015). When the participant has the possibility to explain their view and reasons to take the photo(s) and to express themselves using their own perspectives and commentary, there is less misunderstanding between the researcher and the participant. Also conducting focus group interviews using the photographs taken by the participants as a basis for the discussion has proven to be a powerful method (Mamaniat, 2015). It is valuable for participants to share and compare their experiences and thoughts together. This method results in a more diverse and insightful exchange of ideas.

We identified some ethical concerns regarding the use of photography in educational research such as risk of abuse, misuse, and manipulation of images, issues related to consent and assent of the person who is being photographed, power-relations, and parent intervention (Kaplan & Howes, 2004; MacDonald, 2012; Mamaniat, 2015; Quinn & Manning, 2013). Based on our identification of the ethical considerations, it is essential to establish clear guidelines to mitigate potential risks. For example, Quinn and Manning (2013) discuss on how and when to ask for children's permission: "Asking for permission each time we use the camera, asking for permission each time we take a photograph, asking for permission each time we use a photograph in a portfolio, in a display, or in pedagogic documentation" (p. 275).

Many of the ethical issues concerning the use of photography in education are the same that are also concerning photography in educational research. In addition to the ethical issues, we found some limitations for using photography in mathematics teaching: taking good images for mathematical analysis requires thought, to overcome problems such as perspective distorting measurements and angles (Pierce et al., 2005). For example, to effectively convey geometric concepts, it is important to use photographs that showcase key features or interesting objects. Mathematics, as a science of abstraction, is often difficult to capture in photographs. For example, the symmetry in nature is seldom perfect. Yet, photography can have special power to find and connect real-life with mathematics. This distinction underscores the importance of selecting the most suitable visual aids when teaching different subjects (Gunzel & Binterova, 2016).

Limitations of This Study

We identified some limitations from each phase of the review process: determination of the databases, choosing the keywords, selecting publications, and finally making a synthesis of the chosen publications. First, we chose four education-related databases to find relevant publications. All the chosen databases offer free access to all the referenced sources. Even though the chosen databases were extensive, they may not have included all relevant publications on the topic. Second, after determining the databases, we chose keywords. This review focused on photography and thus we chose the word "photography" instead of "photograph". Relevant publications may have been excluded. Third, while reading the titles of publications offered by the database search engine, in all cases, it was not clear from the title whether the topic concerned teaching and/or learning with photography or teaching photography. Thus, with the help of the abstract, we checked what the publication was about. However, it did not necessarily appear from all abstracts that the article could be relevant for this review article. Articles that could have been relevant could therefore be left out because of this. The fourth and last step was to ensure that we found the main approaches and trends related to our research questions. To make sure all the information is available, the first author collected selected key information into one big table. After collecting examples related to research questions 1 and 2, we categorized and grouped the topics into upper categories and subcategories. The process of categorization and grouping was subjective and open to alternative interpretations.

CONCLUSIONS

So far, many potentially fruitful approaches are not yet used in mathematics education research. As a research method, photovoice could give voice to underrepresented student groups: high or low-achieving students, students with anxiety or neurological differences and young children might benefit the most from the use of photos or photography. Photography can also help mathematics teachers to explore and reflect on their lives, professional identity, and teaching practices. We found no examples of using photo novellas or other time-series of photographs that could capture processes, for example, related to mathematical modelling.

In this literature review we focused specifically on photography and left videography out. Photographs capture a single moment in time allowing researchers to focus on specific events, behaviors, or occurrences. Analyzing photographs can be more straightforward and less-time consuming compared to video, which often requires careful review of lengthy footage to find

relevant information. However, both approaches are valuable tools for researchers and further research is needed to help researchers to choose between photography and video as research methods. Sometimes combining both methods can provide the best outcomes.

Within teaching and learning mathematics one common purpose to use photography is to find real-life connections. We encourage teachers to ask their students to take photographs and use them as a starting point when creating tasks or part of assessment. Students can reflect on how their prior knowledge, real-life experiences, and new content knowledge are related using photography. The rapid development of technology enables the use of cameras in the future more as part of virtual reality, augmented reality, or artificial intelligence (AI). Image manipulation and AI-generated images can potentially revolutionize the use of images in mathematics education. In teaching, these technologies could provide a more interactive and engaging learning experience, allowing students to better visualize and comprehend complex mathematical concepts. For example, interactive visualizations could be used to illustrate functions, geometric shapes, and other mathematical objects. Additionally, AI-generated images and videos could be used to simulate mathematical scenarios: for example, to create visualizations of plane symmetry groups allowing students to explore and experiment with mathematical concepts.

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APPENDIX A

Table A1. Number of reviewed & selected publications

Database	Keywords	D1	Reading level				D2	Reading level				Total
		n1	Title	Abstract	Whole article	Chosen	n2	Title	Abstract	Whole article	Chosen	
1	P&E	63,237	200	120	50	36	3,355	120	19	10	10	46
1	P, E&M	11,154	200	50	15	12	62	62	20	6	3	15
2	P&E	4,080	100	15	10	6	968	110	13	5	5	11
2	P, E&M	62	50	20	8	4	15	15	3	0	0	4
3	P&E	2,168	100	20	15	6	442	105	13	5	5	11
3	P, E&M	22,977	150	50	10	5	20	20	12	2	2	7
4	P&E	744,000	100	15	13	7	32,400	120	15	4	0	7
4	P, E&M	60400	100	50	8	5	32,200	100	9	5	2	7
5	P&E			14	14	14						14
5	P, E&M			3	3	3						3
		908,078	1,000	357	146	98	69,462	652	104	37	27	125

Note. P&E: Photography AND education; P, E&M: Photography AND education AND mathematics; Database 1: Helka; 2: Academic Search Complete (EBSCO); 3: ERIC (ProQuest); 4: Google Scholar; number five refers to all additional publications that were found while reading chosen publications from four chosen databases; n1: total number of publications (<2020); n2: Total number of publications (2020-2023); D1: 1st database search; & D2: 2nd, 3rd, & 4th database & citation search