Cogent Education

ISSN: 2331-186X (Online) Journal homepage: www.tandfonline.com/journals/oaed20

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To cite this article: Oliv G. Klingenberg, Anne H. Holkesvik & Liv Berit Augestad | (2019) Research evidence for mathematics education for students with visual impairment: A systematic review, Cogent Education, 6:1, 1626322, DOI: 10.1080/2331186X.2019.1626322

To link to this article: https://doi.org/10.1080/2331186X.2019.1626322

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Published online: 10 Jun 2019.

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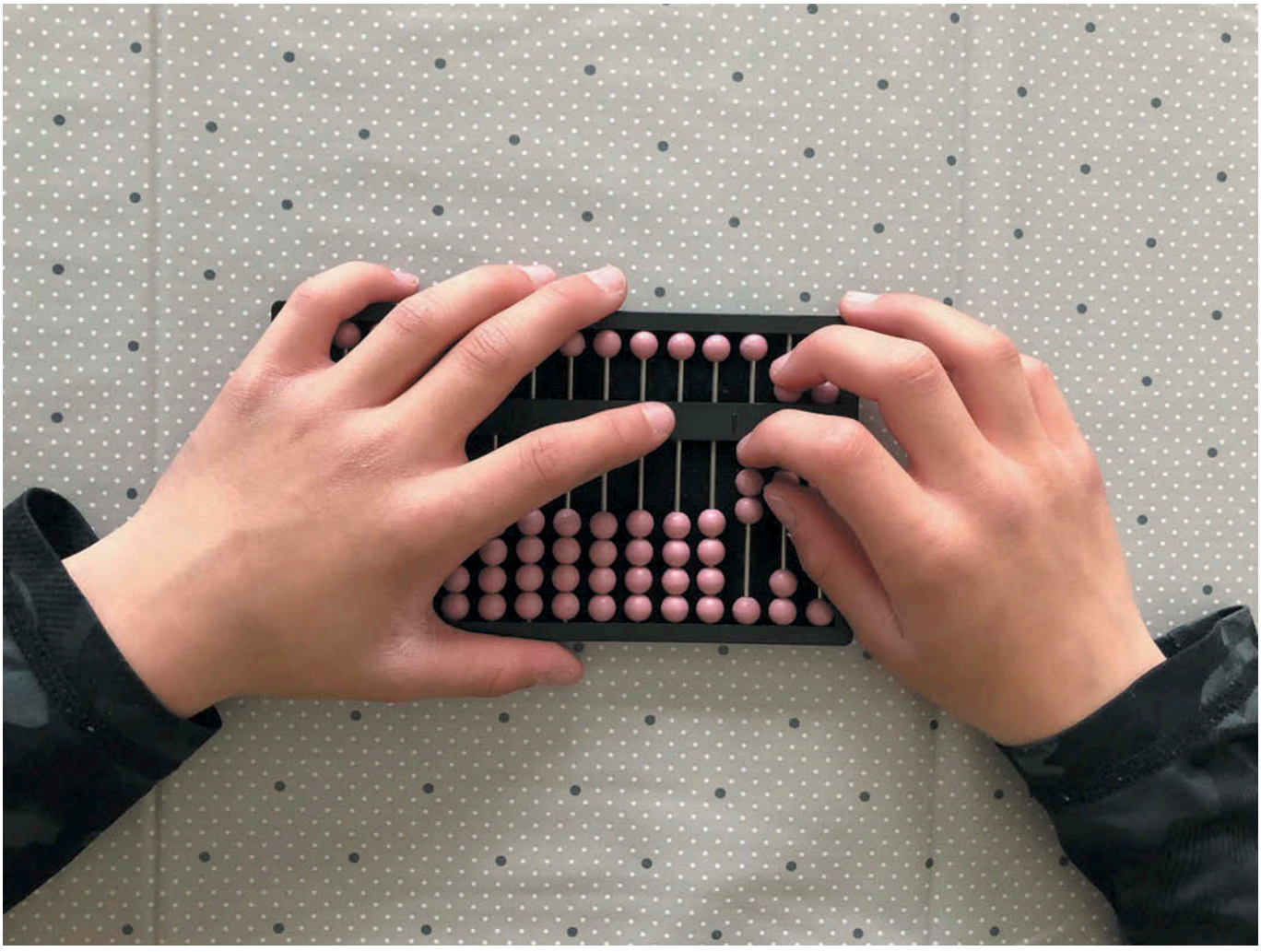
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EDUCATIONAL ASSESSMENT & EVALUATION | REVIEW ARTICLE

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EDUCATIONAL ASSESSMENT & EVALUATION | REVIEW ARTICLE

Research evidence for mathematics education for students with visual impairment: A systematic review

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Received: 07 February 2019
Accepted: 24 May 2019
First Published: 02 June 2019

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Reviewing editor:
Emrullah Erdem, Adiyaman University, Turkey

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Abstract: The aim of the study was to conduct a systematic review in order to synthesize the evidence-based literature on mathematics education among students with visual impairment (VI). Studies were identified through searches of electronic databases (SCOPUS, PubMed, ERIC, and Web of Science). The authors included articles published between 1 January 2000 and 31 October 2017. Eleven publications met the inclusion criteria, and seven studies had observational designs. The studies focused on teachers' attitudes and experiences, the use of abacus, tactile graphics, and the development of mathematical concepts. The results showed that the studies had different aims and methods, and only four studies reported eye disorder diagnoses. The ability to choose suitable teaching strategies that involve individual instructions requires qualified and enthusiastic teachers who allow students to experience a sense of accomplishment and success. Additionally, it is important to gain information on eye disorder diagnoses and possible learning disabilities. The authors conclude that it is to be expected that students with VI but without cognitive disabilities will follow their grade level in mathematics. The findings highlight the need for more randomly



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ABOUT THE AUTHORS

Oliv G. Klingenberg was awarded a PhD from NTNU for her research on mathematics education and Braille reading pupils. Her research interests focus on teaching and learning mathematics, particularly on understanding how children with VI learn to think mathematically.

Anne H. Holkesvik is a librarian. In 2015, the Norwegian Directorate for Education and Training assigned NTNU Social Research to perform research reviews of learning outcomes for children and adolescents with visual impairment. Holkesvik was co-author of the reviews and assisted in the systematic searches that formed the basis for the reviews.

Liv Berit Augestad is a professor at NTNU. Her main research area is physical activity and health, and mental and physical health among people with visual impairment. She has published handbooks and peer-reviewed articles in international journals, as well as the results of population-based epidemiological studies and systematic reviews in the field of vision and health.

PUBLIC INTEREST STATEMENT

Visually impaired students, particularly those who use Braille, are less likely to participate in advanced mathematics classes compared with students without VI. They also tend to have below grade-appropriate skills in mathematics. Ophthalmology diagnosis onset, comorbidity, and residual vision are all variables that may affect the development of their mathematical understanding. However, students with VI and without any other known cognitive disabilities should perform at grade level in mathematics if they are exposed to appropriate forms of stimulation and good teaching strategies. Development of e-learning in school systems may present additional challenges for students with VI. The graphic materials used to communicate relationships between variables are often visual in nature. The experiences of teachers of students with VI are that students need individual instructions on how to access such information. The aim of the study was to summarize scientific knowledge related to mathematics education among students with VI.

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controlled, high quality trials in order to obtain more evidence and knowledge of mathematics education among students with VI.

Subjects: Teaching mathematics for students with visual impairment; Mathematics education; Mathematical skills

Keywords: visual impairment; Braille; mathematics education; abacus; tactile graphics; students; systematic review

1. Introduction

Vision enables important access to information that supports students' development of mathematical concepts and procedures (Emerson & Anderson, 2018; Hershkowitz, Markovits, Rosenfeld, Ilani, & Eylon, 2018). Many basic mathematical concepts take the form of words that describe visual phenomena (Jones, 2018). Concepts such as big (or bigger), long (or longest), and between are comprehensible to sighted children because vision helps them to group objects according to their overall similarity. Sighted children can see relations between objects at a glance. For children with visual impairment (VI), such object relations are mental, because their hands can only explore ("look at") one object at a time. Accordingly, their awareness or understanding of spatial concepts and directional concepts are more challenging to grasp compared with children without VI (Hatwell, 2003). Consequently, it is natural that many children with VI are offered fewer experiences of how mathematical concepts are used in daily-life communication than are sighted children (Bateman et al., 2018; Emerson & Anderson, 2018).

In the field of visual impairment, researchers have traditionally studied students with VI as one group of students, despite the fact that visual impairment can be caused by a variety of conditions (Warren, 1994, p. 2). Some students have congenital disorders, and some have lost their vision partially or completely during the course of their lives. Ophthalmological diagnoses, age of onset, comorbidity, and residual vision are significant variables that may influence the development of mathematical understanding. In addition, as among all students, cognitive function and personal interest are important factors in learning to think mathematically as well as to develop grade-appropriate skills.

Our experiences are similar to the results reported by Rapp and Rapp (1992), namely that students who use Braille are less likely to participate in advanced mathematics classes. In addition, as a population, students with VI tend to perform below their ability in mathematics compared with in other academic subjects (Beal & Shaw, 2008; Freeland, Emerson, Curtis, & Fogarty, 2010)

One factor that may limit the participation of blind and partially sighted learners in mathematics education may be what Emerson and Anderson (2018) call the trend toward more visually based mathematics materials. Many mathematics textbooks have visual images with important content information that is not transcribed or described in either Braille books or digital versions of the texts. This trend is making textbooks, which to some extent are already inaccessible to students with VI, even more challenging for blind and partially sighted learners.

Graphs, charts, diagrams, figures, and drawings are used as mathematical tools to communicate huge amount of data or relationships between variables in a simplified and concise way (Akar & Övez, 2018). An important mathematical skill is to gather information from such graphics and use it to solve problems (Rosenblum, Cheng, & Beal, 2018). However, curricular graphic materials are visual in nature and therefore many students with VI face considerable challenges in reading them (Rosenblum & Herzberg, 2015).

The provision of suitable learning materials is vital in mathematics education. The abacus is a tool for addition, subtraction, multiplication, and division by students with VI, in a similar way to

how pencil and paper are used for calculations by sighted students. Often, it is up to the teacher to decide whether the student should learn how to use an abacus. This may be a difficult decision because the effectiveness of the abacus has been questioned (Ferrell, 2011).

Technology can offer new opportunities and valuable access to information for students with VI by complementing the use of tactile devices, Braille, and large print with audio (Beal & Rosenblum, 2018; Pitchford, Kamchedzera, Hubber, & Chigeda, 2018; Supalo, Hill, & Larrick, 2014; Supalo, Isaacson, & Lombardi, 2013). Digitally enhanced learning tools may thus transform educational environments by making the learning process more encompassing, more engaging, and more collaborative (Bin Tuwaym & Berry, 2018; Metatla et al., 2018).

Self-esteem may play a profound role in all aspects of a child's development (Breckler, Olson, & Wiggins, 2006; Brooks, 1992). A student's self-esteem may be dependent upon his or her psychological adjustment, quality of life, adaptive behaviour, relationships with friends, motivation, school performance, and success in life (Augestad, 2017b; Brooks, 1992; Papadopoulos, Metsiou, & Agaliotis, 2011; Saigal, Lambert, Russ, & Hoult, 2002). In STEM self-confidence is one factor that contributes to a student's motivation to learn mathematics. Supalo et al. (2013, p. 196) state that "inadequate hands-on science experiences may inhibit development of self-confidence concerning one's capacity to independently function in scientific endeavors, and that low self-confidence in the sciences may be associated with consideration of nonscientific college studies rather than studies in the sciences". Another factor is inclusion in the student group and being able to learn together with peers, which may increase the student's sense of well-being and his or her learning process. However, there is a lack of evidence about inclusion and collaborative learning in mathematics for the students with VI.

The purpose of our research was to examine the state of mathematics education research in the field of visual impairment. Following a literature search, we found a review published in 2006 in which the authors state:

Because no two interventions were alike, we were unable to establish distinct categories or apply meta-analytic techniques with any group of studies. Accordingly, our initial syntheses of the research in mathematics for students with visual impairments yield promising, but not best practices. Without replication, even promising practices are preliminary and perhaps misleading in the absence of further research (Ferrell, Buettel, Sebald, & Pearson, 2006, p. 11).

In a literature review published in 2013, the author focuses on STEM education (science, technology, engineering, and mathematics education) (Cryer, 2013), but we were unable to identify the results that focus only on mathematics education.

We found it relevant to conduct a systematic review and to evaluate the quality of the research and the effect of any intervention, with the aim of summarizing the evidence-based academic knowledge about mathematics education among students with VI.

2. Method

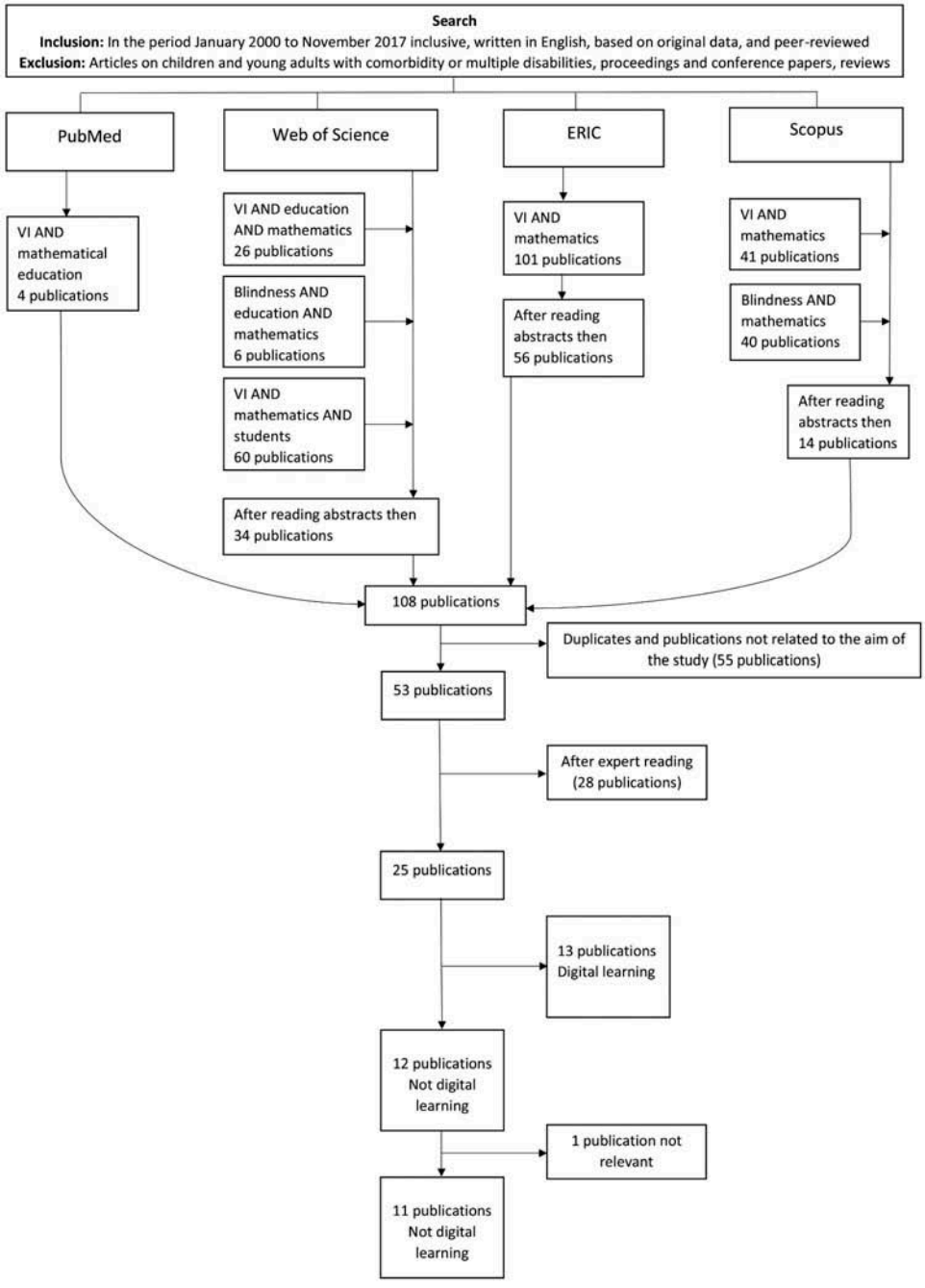
2.1. Design

We carried out a systematic review of pre-reviewed articles and described the study characteristics and major findings. In addition, we evaluated the quality of the studies and discussed possible interpretations of the results.

2.2. Search strategy

In order to identify relevant published articles, we searched the databases SCOPUS, PubMed, ERIC, and Web of Science using the following search terms: visual impairment, blind, low vision, mathematics, and education. We included articles published between 1 January 2000 and 31 October 2017 (Figure 1).

Figure 1. The review search strategy.



2.3. Criteria for inclusion and exclusion

We included studies of children and young adults with VI in the age range 5–25 years. The reason for the wide age range was that we wanted to include studies of students of school age. Students with VI may have major problems with accessing information, and it is possible they may need additional years to graduate from secondary or upper secondary school (Yurtay, Yurtay, & Adak, 2015). We included peer-reviewed articles written in English that report studies of humans. We identified 278 abstracts.

After expert reading of the 278 abstracts, we excluded publications on children and young adults who had VI as well as comorbidity or multiple disabilities. In addition, we excluded articles that describe analyses of the situation related to teaching tool and materials in a specific country, and articles that do not include separate data collection for individuals with VI. We ended up with 108 publications. After 55 duplications were excluded, the search process yielded 53 articles.

Two of us read the 53 publications. Some studies did not have original data collection. Due to the defined inclusion and the exclusion criteria, we decided that 25 of the publications fitted the aim of our study. We evaluated the 25 publications and found it natural to divide them into two separate groups according to length. The review of mathematics education for students with VI was thus based on 11 publications (Figure 1). The other publications will be presented in a separate paper related to digital learning among students with severe vision loss.

2.4. Data extraction

We used a standardized protocol and reporting form to abstract the following data from each publication: year of publication, first author's name, country in which the study was conducted, aim of the study, study design, age and number of persons in the study sample, number of persons with VI and number of sighted persons in each study, definition of VI, and main results of each study (Table 1). In Table 1, under the rubric study design, we include each study's dependent and independent variable. However, since the different studies did not have the same dependent and independent variables, we chose the main dependent variable and independent variables. The reason for this choice was number of words in the table and making the table optimal for reading. We used the date that the article was first published online as the publication year, not the date of the print edition.

2.5. Evaluation of the studies

We used the Quality Assessment Tool for Studies with Diverse Designs (QATSDD) to evaluate the selected studies (Sirriyeh, Lawton, Gardner, & Armitage, 2012). The tool, which was developed to assess the quality of studies with one topic but using different approaches or designs, has been found to have good reliability (Cohen's kappa, $\kappa = 71.5$) and good face validity (Sirriyeh et al., 2012). We used the version of QATSDD with 14 items related to quantitative studies. Each item was rated on a 4-point scale ranging from "not at all" (0), "very slightly" (1), "moderate" (2), to "completely" (3), with a maximum score of 42. The percentage score was calculated by dividing the actual score by the maximum score (i.e. 42). Studies scoring higher than 75% were considered "high quality", between 50% and 75% "good quality", between 50% and 25% "moderate quality", and below 25% "poor quality". The quality ratings are presented in Table 1.

3. Results

The 11 reviewed articles are summarized in Table 1.

After using the QATSDD, four studies were classified as "high quality", six as "good quality", and one study as "moderate quality".

The studies had somewhat different aims and methods, but they all focused on improvements in mathematics education among students with VI. Two studies focused on the use of the abacus as a tool in the education (3, 4), and three studies focused on tactile graphics (1, 2, 7). Five focused on competence in mathematics (1, 6, 7, 8, 11), and three studies concerned environmental factors in the classroom and mathematics achievement (5, 9, 10).

The result showed that seven studies had an observational study design (2, 3, 4, 5, 6, 9, and 11 in Table 1), two used interviews (1, 8), and two had a mixed methods design, including an experimental study (7, 10). Study No. 10 used an intervention approach to examine the attitudes and instructional changes in teachers throughout a year of contact with itinerant teachers of the visually impaired, as well as reflective narratives on the use of supplemental adaptive resources. The results of the study

Table 1. Characteristics of the 11 studies of digital mathematics learning among students with visual impairment (VI)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
1 2015 Rosenblum & Herzberg USA	1. According to students who are tactile readers, what qualities make a "good" tactile graphic? 2. Can students who are tactile readers accurately locate and identify requested information in tactile graphics?	Structured interviews about four different tactile graphics Participants were asked to complete a series of tasks and share their impressions regarding the clarity of the graphics. D: Tactile readers InD: Access to tactile graphics, accurately locate and identify requested information in tactile graphics	12 youths in grades 6–12 8 females, 4 males Public school (n = 11) Specialized school for the blind (n = 1) Grade level in mathematics (n = 9) Below grade level (n = 1) Above grade level (n = 2) LCA[3] (n = 4), ROP[4] (n = 3), SOD[5] (n = 2), CVI[6] (n = 1), Peter's syndrome (n = 1, and cancer of the optic nerve (n = 1)	Participants varied in their accuracy in locating specific information in the graphics. They all reported that what made a tactile graphic "good" was clarity of information. When inaccuracies of measurement occurred, all of the youths tended to report lengths longer than they were in reality. Youths reported that they could locate necessary information on the x-axis but reported difficulty in locating specific information on the y-axis, even though there were gridlines. (Good quality)
2 2014 Zebehazy & Wilton Canada and USA	To investigate the perceptions of teachers of students with VI[1] with respect to the quality, importance, and instruction in the use of tactile and print graphics	An online survey sent to networks via e-mail, e-discussion groups, and newsletter announcements The survey link remained open for 6 months. D: Perceptions of teachers of students with VI[1] InD: Quality of tactile and print graphics, to promote learning, direct instruction	306 teachers responded, of which 221 (72%) completed the survey in full Respondents (94%) worked with at least one student who used tactile graphics at some point in their career It is not stated how many individuals received the survey	Greater than half (n = 245) agreed or strongly agreed the importance of early exposure to tactile graphics. Only 22% agreed that they had adequate time with their students to teach the use of graphics. Close to one-third of the respondents indicated they did not teach their students how to make their own graphics in order to understand concepts. (Good quality)

(*Continued*)

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Table 1. (*Continued*)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
3 2013 Rosenblum et al. USA and Canada	To gather data that could be used to determine how much emphasis should be placed on abacus instruction within university teacher training programmes	An online survey advertised on local and national e-bulletin boards in the field of VI[1] D: Teachers use and beliefs about computation with abacus InD: Demographic data, proficiency or exposure to methods and ratings of belief statements, skills learned	196 individuals completed the survey, but not all of them completed all sections of the survey 122 had taught the use of the abacus to children in the past or were currently doing so	Statements with the highest level of agreement included one that indicated that when sighted individuals used pencil and paper for computation, an individual with VI[1] should be allowed to use an abacus. The data reported here support the concern that some teachers of the students with VI[1] were not taught specific computational skills that they may need to teach to students. Online webinars, an electronic bulletin board devoted to abacus skills and instructions, hands-on workshops, and interactive practice tools all have the potential to enrich teachers' knowledge of the abacus. (Good quality)
4 2013 Amato et al. USA and Canada	To report the experiences of teachers of students with VI[1] in teaching computations with an abacus, and their decisions about instructing their students	Online survey D: Teachers experiences of students with VI[1] in teaching computation with an abacus to their students InD: Demographic data, types of abacus skills taught to students with VI[1], instructing students in the use of an abacus	As for Article 3 (Rosenblum, Hong, & Amato, 2013)	Of the 168 participants, 121 (72%) reported that students could use an abacus on 'high-stakes' tests in their state. More than 112 began instruction between preschool and the second grade. The most frequently taught skills were the operations of addition and subtraction. A small number of participants reported they did not teach computation with an abacus to their students because of their own lack of knowledge. (Good quality)

(*Continued*)

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Table 1. (*Continued*)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
5 2012 McDonnall et al. USA	To determine whether PIS[7] and PIH[8] are associated with mathematics achievement for youths with VI in elementary and middle school To determine whether the effect of PIS[7] or PIH[8] on achievement differs according to grade level or the presence of a cognitive disability for youths with VI[1]	The SEELS[9] database was used. Data collection from several sources (i.e. parents, teachers, and school administrators) occurred up to three times for each student. Three waves, during 2000–2001, 2002, and 2004 Dependent: The Calculations subtest of the WJ-III ACH[10] measures mathematics computational skills, ranging in difficulty from simple to advanced. InD: PIS[7] a scale measuring the frequency of parent attendance at the school, PIH[8] a measuring the frequency of parental interaction with the child	All students with a primary VI[1] disability and who had scores available on the Calculations subtest of the WJ-III ACH[10] and parental involvement data were included in the sample (n = 341) 21 of the students had a cognitive disability in addition to VI[1]	Levels of PIS[7] were low for most students, with greatest levels when students were younger. PIS[7] was positively associated with mathematics achievement for students who began the study in elementary school. The effect of PIS[7] did not differ according to whether a cognitive disability was present. Levels of PIH[8] were high for most students, with successively lower levels reported at each wave except for students with a cognitive disability. PIH[8] significantly predicted mathematics achievement, and the authors conclude that students with VI[1] who are low achievers in mathematics may benefit most. (High quality)
6 2012 Klingenberg et al. Norway	To estimate the number of Braille students who were educated according to their grade-level progression in mathematics, and to analyse the association between eye disorder diagnoses and progression in mathematics	A retrospective study design of clinical data, consisting of educational and medical information D: Students following grade level in mathematics: yes/no InD: Demographic data, eye-related variables, reading media	All students who had received Braille education in Norway between 1967 and 2007 (n = 248) 45 principal eye diagnoses	141 students (57%) had been taught mathematics at grade level. In 19 of the 45 principal eye diagnoses, all of the students were educated according to the normative grade progress in mathematics. There were no statistically significant associations between gender and the abstracted variables or between mathematics education and reading media. (High quality)

(*Continued*)

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Table 1. (*Continued*)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
7 2012 Klingenberg Norway	To investigate the ways in which two students who read Braille completed geometry tasks and how they constructed mental representations of the shapes of objects	Educational experiment conducted as a four-day geometry course for Braille students D: Two Braille-reading students and mathematical skills InD: Scoring in learning performances, completing geometry tasks and how they constructed mental representations of the shapes of objects	Case study of two students aged 10 and 11 years, both of them blind due to ocular VI One was congenitally blind, although earlier in life he had light perception but had not been able to recognize shapes. The other student had sight during the first year of his life.	The students complemented their multiple manual explorations with body movements and postures that corresponded to characteristic features of the shapes of objects. They used their whole body as an explorative instrument They typically rotated small three-dimensional objects and experimented with the objects' point of balance, and "played" with the physical characteristics of environments. They continually measured geometric properties, such as length, area, and volume, as part of their way of "seeing" the shapes of objects. (High quality)
8 2012 Jones et al. USA	To document the reported experiences of students with VI[1] with respect to estimating measurements, as well as the students' conceptualizations of linear distances and accurate estimations	Interviews The participants were asked to perform a series of measurement tasks Test items were pilot-tested with youths with VI[1] to determine their appropriateness for the study. D: Participants' conceptions of linear distances and accuracy of estimation of linear distances InD: Accuracy of estimation of object orientation (vertical versus horizontal) and units (centimetres and inches) for the wooden dowel rods	15 middle school students who were legally blind (9 of them from birth) One student had no vision, but all students were Braille readers. 3 girls and 12 boys Average age 12.4 years	The results showed that the students lacked skills in making linear estimations and had difficulty in estimating metric lengths. The results indicated that the students with VI[1] might not have connected informal estimation experiences with the skills required in formal scientific inquiry. Across the tasks, the students were able to make better estimates when measurements were close to the human scale, but the difficulty extended to measurements of centimetres. (Moderate quality)

(*Continued*)

Table 1. (*Continued*)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
9 2012 Giesen et al. USA	To investigate whether an environment with more academic support in mathematics is helpful for students with VI[1]	Longitudinal The SEELS[9] database was used. D: Primary outcome measure of mathematical achievement, the applied problems subtest of the WJ-III ACH[10] InD: Extent of academic supports, the SEELS[9] Wave 2 School Characteristics Questionnaire, Cognitive disabilities	Data were limited to students with VI[1] (including blindness) and scores available on the mathematics achievement measure for at least one of three measurement time points (n = 292)	The data analyses do not show a simple overall relationship between extent of academic support in the school and mathematics achievement for either initial level or growth in achievement over time. Presence of a cognitive disability moderated a relationship between the extent of school support and mathematics achievement. The extent of academic support appeared to be positively related for VI[1] students without a cognitive disability. (High quality)
10 2011 Rule et al. USA	To examine the attitudes of secondary teachers towards students with VI[1] in their science or mathematics classes before and after a year-long funded programme that provided curriculum materials and adaptive equipment	Three types of data collections: Survey of teachers' attitudes towards students with disabilities in STEM[11] classes Pre-test and post-test questions regarding the teachers' anticipated and actual experiences during the project A narrative about the challenges and successes that the teachers and their students experienced during the year D: The attitude survey of science and mathematics teachers working with students with VI[1] I: Individual survey questions showing largest pre-post differences	15 science or mathematics teachers of 13 students with VI[1] (8 blind, 5 with low vision), in the age range 13–18 years, and who were performing at or above the level of their peers	Teachers expressed that teaching a student with VI[1] was less difficult than anticipated at the beginning of the course and they felt more prepared to meet the needs of such students. A total of 8 out of 15 teachers reported that they faced a struggle when they tried to implement the new materials and adaptive devices. Given appropriate tactile or auditory materials and/or enlarged visuals, 10 of 12 teachers reported that students with VI[1] were as successful as their classroom peers in science and mathematics. (Good quality)

(*Continued*)

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Table 1. (*Continued*)

Article number Year Authors Country	Aim	Method		Main results (QATSSD[2])
		Study design Dependent (D) Independent variables (InD)	Sample Definition of VI[1]	
11 2011 Crollen et al. Belgium and Canada	1. To determine whether blind children used their fingers to count and to show quantities 2. To determine whether blind children who did not use their fingers or used them comparatively less achieved the same level of performance as sighted children 3. To determine whether blind children used their fingers in the same way as their sighted peers when they were explicitly required to count and to show quantities with their fingers	3 test batteries: General cognitive abilities The spontaneous use of finger-counting Canonicity of the finger-based representations D: Blind children use their fingers to count InD: General cognitive abilities, characteristics of the children, working memory test	14 children (7 girls and 7 boys) age range 7–13 years (mean age = 9.9) 11 right-handed, 1 left-handed, and 2 ambidextrous All were born with VI and did not have any other disability. Principal ophthalmic diagnoses Sighted matched control group (mean age 9.3)	Compared with sighted controls, blind children used their fingers less spontaneously to count and in a less canonical way to count and show quantities. The absence of vision precluded the development of a typical finger numeral representation and suggested that the use of canonical finger-counting and finger-monitoring strategies relied on the visual recognition of particular hand shapes. (Good quality)

[1]VI—visual impairment; [2]QATSDD—Quality Assessment Tool for Studies with Diverse Designs; [3]LCA—Leber congenital amarosis; [3]ROP—retinopathy of prematurity; [5]SOD—septo-optic dysplasia, [6]CVI—cortical vision impairment; [7]PIS—parental involvement at school; [8]PIH—parental involvement at home; [9]SEELS—Special Education Elementary Longitudinal Study, a comprehensive study documenting the achievement, personal characteristics, and educational experiences of a sample of elementary special education students as they moved through the school system up to high school; [10]WJ-III ACH-Woodcock-Johnson III Tests of Achievement; [11]STEM—science, mathematics, engineering and technology

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conducted by Rule et al. (10) support the claim that "given knowledgeable, supportive teachers, and with appropriate accommodations such as tactile or auditory materials, students with visual impairments can be as successful and engaged as other students in science and mathematics" (Rule, Stefanich, Boody, & Peiffer, 2011, p. 865).

The age range in the study samples varied from 6–18 years (1, 5, 6, 7, 8, 9, 10, 11). Three studies included only teachers (2, 3, 4). Studies 1, 6, and 7 included students in the age group 6–12 years, studies 8, 10, and 11included students older than 12 years of age. The state-wide (USA) SEELS study included students in the age range 7–16 years (5, 9).

Four studies reported eye disorder diagnoses (1, 6, 7, 11). Four studies (5, 8, 9, 10) did not clearly define visual impairment, nor was visual function reported. In seven of the studies, the students were Braille readers (1, 2, 6, 7, 8, 10, 11), while print readers were included in two studies (2, 10). Five studies reported gender in the sample characteristics (1, 5, 7, 8, 11), but only 2 studies reported gender in the results (5, 7). Four studies reported teachers' attitudes and experiences (2, 3, 4, 10).

Seven of the eleven articles are published in the Journal of Visual Impairment and Blindness, two in the Journal of Special Education, one in the Journal of Disability Policy Studies, one in the International Journal of Science Education, and one in the Journal of Experimental Psychology.

4. Discussion

The purposes of our systematic review was to evaluate the quality of the research and the effect of any interventions, with the aim of summarizing the evidence-based academic knowledge about mathematics education among students with VI. Our findings demonstrate the dearth of intervention studies of mathematics education and students with VI. This shortage is problematic in the field of visual impairment and mathematics education because it has an impact on the understanding of the best practices of students with VI. In addition, due to the different aims, methods, and samples reported in the 11 articles, it is to some extent difficult to summarize them with respect to evidence-based knowledge about mathematics education among students with VI. However, to facilitate a more comprehensive understanding of what can be learned from the research carried out to date, we have summarized the results under the following categories: Learning environment, Realistic expectations, Explicit and individual teaching, and Embodied mathematics.

4.1. Learning environment

Three articles report environmental factors that affect the mathematics learning process (Giesen, Cavenaugh, & McDonnall, 2012; McDonnall, Cavenaugh, & Giesen, 2012; Rule et al., 2011). McDonnall et al. (2012) recommend that both schools and parents should strive for continued high levels of parents' involvement in schools. Nevertheless, learning independency is a main goal for students with VI, and the balance between self-determination and involvement can be a challenge.

In many cases, students with VI attend mainstream schools and are often the only student with vision impairment in their class (Augestad, 2017b; de Verdier, 2018). Rule et al. (2011) found that teachers' experiences were that many mathematics lessons were difficult to teach when a student had vision loss. Nevertheless, many teachers experienced that an advantage of having a student with VI was that all students in the classroom benefited from using the tactile or electronic enlargement adaptations and receiving more modified and descriptive explanations.

The results of the study by Rule et al. (2011) support that given knowledgeable, supportive teachers and appropriate mathematics materials, students with VI can participate more fully in class activities. To choose the appropriate teaching strategies in mathematics requires highly qualified teachers, with enthusiasm and interest in achieving the curriculum goals set for their students. Rule et al. (2011, pp. 875–876) claim that teachers showed great motivation to modify their teaching strategies based on appropriateness for their students. The development of self-

evaluation skills is important for all students because it increases their self-esteem. Teachers who have both been made aware of and assisted in the purchase or creation of adaptive materials and activities have reported positive experiences for their students with VI, their classmates, and for themselves (Rule et al., 2011).

Giesen et al. (2012) similarly emphasize the consequences of well-educated teachers for academic support in schools regarding mathematics achievement for students with VI. However, the extent of school support and mathematics achievement is moderated when a student has a cognitive disability. One possible explanation for this surprising result is that students with VI and mental retardation, autism, traumatic brain injury, or multiple disabilities may have more varied needs for support (Giesen et al., 2012). This suggestion is supported by de Verdier (2018).

4.2. Realistic expectations

The findings from the review confirm that students with VI are a heterogeneous group with respect to achievement in mathematics (Klingenberg, Fosse, and Augestad (2012); Rule et al. (2011). In a longitudinal sample studied over 40 years, Klingenberg et al. (2012) found that the majority (57%) of blind and partially sighted learners were taught mathematics at grade level (i.e. the same level as their sighted peers). In addition, there is evidence that blind and partially sighted learners performed well in STEM subjects and in some cases excelled in them. Rule et al. (2011) report that when students with VI were given appropriate curricular materials, 10 out of 12 were as successful in mathematics as their peers. These results show that it is important to expect that students with VI will perform as well as their sighted peers. However, we agree with Warren (1994, pp. ix–x) that teachers must provide appropriate learning environments and methods in order to ensure an optimal developmental course for their students.

The limited amount of explicit advice on either teaching methods or teaching materials is challenging for teachers of students with VI. The least ambiguous advice that emerged from our review is that the competence and attitudes of teachers improve significantly when they reflect on their own practice together with a supervisor.

If students with VI struggle with mathematics, teachers must consider whether they have cognitive difficulties. Loss of vision may not be the primary reason for learning difficulties in the subject. Erin and Koenig (1997) point out that visual disabilities and learning disabilities have many similar symptoms and that early identification of a visual disability often masks the presence of a learning disability. Some visual diagnoses have a neurological origin and may coexist with a learning disability.

4.3. Explicit and individual teaching

The use of graphics is one example of a curriculum theme for which students who are tactile readers may need additional time and direct instruction in order to learn specific skills and strategies (Rosenblum & Herzberg, 2015; Zebehazy & Wilton, 2014). Such students need accurate information and specific feedback about their skills to know whether they have completed a task accurately. Their efficiency may improve if new types of graphical materials are introduced systematically (Rosenblum & Herzberg, 2015), and it is important for them to have early exposure to new tactile materials (Zebehazy & Wilton, 2014).

The abacus can be a good learning aid for all students and its usage can be taught for a whole class of students. However, Rosenblum et al. (2013) support the findings by Ferrell (2011), as they found inconsistency in the teachers' opinions on the use of the abacus as a valuable tool for computing in mathematics. However, most of the teachers considered that training in the use of the abacus should be included in their proposed list of teacher training competencies.

Abacus instruction is often introduced between preschool and second grade (5–7 years of age), but division with two-digit divisors is taught only to a relatively small number of students (Amato,

Hong, & Rosenblum, 2013). Amato et al.'s finding is in line with our personal experiences of the Norwegian school system, in which some teachers have not mastered the computation skill. They found that when teachers lacked knowledge about the use of abacuses, they hesitated to introduce them in their teaching (Amato et al., 2013; Rosenblum et al., 2013).

4.4. Embodied mathematics

Amato et al. (2013) recommend the use of an abacus to teach the concept of one-to-one correspondence. Their interesting recommendation relates to the study conducted by Crollen, Mahe, Collignon, and Seron (2011), who conclude that compared with sighted students, students with VI develop an understanding of numbers through different strategies. In their study, students who were blind did not spontaneously use their fingers to count and show quantities, probably because finger-counting and finger-counting strategies rely on visual recognition of particular hand shapes (Crollen et al., 2011).

Although fingers may not play a functional role in the development of a mature counting system in students with VI, Klingenberg (2012) and M. G. Jones, Forrester, Robertson, Gardner, and Taylor (2012) have observed how students with VI use their bodies as a measurement tool when making linear and spatial estimations. Their findings indicate there is an unconscious and intrinsic way of "seeing spatial object information", but it is likely that the perceived distances are different from those measured in metric units. Hence, teachers must help a student with VI to connect informal experiences with the measuring skills required in formal mathematics. M. G. Jones et al. (2012) conclude that research is needed to document how students who use tactile learning media are able to form concepts of metric units and apply them in concrete and abstract contexts. This finding is in accordance with Klingenberg's conclusion that students must be challenged to use measuring units and spatial concepts in many different activities and contexts (Klingenberg, 2012).

4.5. Gender

Lee and Kung (2018) found gender variations with respect to self-concept and achievement in mathematics. Boys had significantly higher score on self-concept compared with girls, whereas girls exhibited higher levels of achievement compared with boys. The finding is confirmed by the work of Ehrtmann and Wolter (2018), who report an interaction effect of gender and gender role orientation in mathematics. The presence of gender as a variable in a study design may therefore be important when students with VI are included in the study sample. However, the results in the reviewed articles did not show clear gender differences in attitude and skills in mathematics among the students with VI. Furthermore, the sample sizes were small in most of the studies.

4.6. Authors and journals

Most of the authors of the reviewed articles represent the academic fields of education and teaching. We consider it important that teachers with experience of practical teaching in schools should participate in study designs and report their knowledge. Their collaboration with members of other professionals may ultimately lead to mathematical education that is more beneficial for students with VI, since an academic background and competence may influence the focus of a study and the interpretation of published results.

Only 1 of the 11 articles is published in an open access journal. The results may therefore be more readily available for personnel in institutions with large journal subscriptions, but harder for educators and caregivers to access.

4.7. Eye disorder diagnosis

Students with VI are a heterogeneous group, not least because they have a wide range of visual functions. Therefore, it is important to account for visual diagnoses, visual condition, and visual history disorders (Augestad, Klingenberg, & Fosse, 2012; Rahi & Cable, 2003; Warren, 1994, pp. 196–203).

Four articles report eye disorder diagnoses (1, 6, 7, 11). The other articles do not define VI clearly. The diversity of eye pathologies implies that students differ in their preferences and possibilities concerning the choice of informatics tools (Carrière, 2012). In cases where information about sight functions were overlooked in the studies, the results reported in the articles have less validity. In addition, pupils with congenital VI often have multiple disabilities with coexisting neurodevelopmental disorders (de Verdier, Ek, Löfgren, & Fernell, 2018; Klingenberg et al., 2012), yet relevant information is lacking in most of the reviewed articles.

4.8. Quality of the studies

After using the Quality Assessment Tool for Studies with Diverse Designs (QATSDD) to evaluate the selected studies holistically, we classified only four studies as high quality. The included studies had a moderately explicit theoretical framework and did not include a representative sample of a target group of reasonable size. Additionally, for some of the studies, the rationale for the choice of data collection was scored as moderate. A further reason for the lack of high quality scores for the studies was the fit between stated research question and the format and content of the data collection tool. Most of the studies did not have good justification for the analytical method selected. We also registered that few authors discussed the strengths and limitations critically.

Ethical considerations are important in all scientific work. Seven of the 11 publications do not mention the word “ethics” and the authors do not inform about whether they had any approval from an ethical committee. This may be explained by different rules in different countries, and that the study design in some of the included studies did not require ethical approval.

4.9. Strengths and limitations

A strength of our search for literature was that the second author is an experienced professional librarian. A further strength is that we searched multiple databases, which resulted in articles from different academic fields. In addition, teaching mathematics for pupils with VI is the main field of interest for the first author, who has a PhD in the field and 40 years of work experience with special education for pupils with VI.

By contrast, a limitation of our literature search was that different definitions of VI were used in the studies. Most of the publications do not mention the diagnoses, progression of the disease, or the onset age of vision loss. In some of the studies, the age range of the participants was wide, which may have affected the results.

Confounding may have occurred in some of the studies. In addition, we strongly suspect there was bias in the studies that lacked randomization, especially those that included only a small convenience sample of children with VI. Unfortunately, most of the studies used this approach to obtain a more homogeneous sample. Thus, the study subjects might not have been representative of the target population. The conclusions drawn in some of the studies might not have been accurate in the cases where selection bias was not taken into account.

5. Conclusions

There is a lack of mathematics education research in the field of VI and much of the existing literature was published a long time ago (Ferrell, 2011; Holbrook, 2015). A lack of up-to-date research is problematic because it has an impact on the understanding of best practices of students with VI. To choose the right teaching strategies requires educated and enthusiastic teachers who enable students with VI to experience feelings of accomplishment and success.

The studies reported in the reviewed articles had different aims and methods, which made comparison and systematic analysis difficult. In general, it is challenging to conduct research on the education of students with VI. One factor is that visual impairment is a low-incidence disability and therefore it is problematic to identify an adequate and homogeneous group of study participants and to obtain enough

statistical power in a study (Ferrell, 2011). In addition, conducting research within the population is often expensive and logistically difficult (Ferrell, 2011; Holbrook, 2015). Convenience sampling was used in many of the studies reported in the reviewed articles, with a wide age range in the samples and small samples sizes. This finding is in line with findings of earlier reviews that included students with VI (Augestad, 2017a, 2017b). Our review highlights the need for increased numbers of randomized controlled trials of high quality to secure more evidence-based knowledge about mathematical education among students with VI.

Acknowledgements
The authors thank Per Fosse, Head of Department for Visual Impairment at Statped midt, for support and excellent motivation during the work in connection with this article. The authors thank Catriona Turner for valuable help in checking the language of the manuscript. NTNU (Norwegian University of Science and Technology) is thanked for a grant from the publication fund to cover the publication charge for this article.

Funding
The authors did not receive any financial support for the research or authorship of this article. The publication charge for this article has been funded by a grant from the publication fund of the Norwegian University of Science and Technology (NTNU).

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding this article.

Cover image
Source: Author.

Citation information
Cite this article as: Research evidence for mathematics education for students with visual impairment: A systematic review, Oliv G. Klingenberg, Anne H. Holkesvik & Liv Berit Augestad, *Cogent Education* (2019), 6: 1626322.

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