A Systematic Review on The Definition of Children’s Number Sense in the Primary School Years

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Abstract
The definitions serve the purpose of communication and preservation of knowledge in scientific inquiry. However, it is quite often to perceive number sense concept without well-accepted definitions in the field of mathematics education research. Despite the mentioned issue, the current literature on children’s number sense provide a glean for introducing, implementing, and even measuring the number sense using the specific and contextualized indicators in early mathematics. Consequently, this phenomenon offers to bridge a gap in the literature concerning definitions of number sense and its indicators. This article systematically reviews on the indicators in measuring children’s number sense based on the past research guided by the PRISMA statements. The metadata were analysed using open-coding and were further re-coded through axial coding and selective coding to form a definition of number sense. This article discusses on limitations, implications, and the future research directions for studying children’s number sense in the primary schools’ mathematics.

Keywords: systematic review, number sense; numeracy; definition; mathematics education

INTRODUCTION
The term “number sense” is widely used in recent years’ curricula reforms, as reported in the Encyclopedia of Mathematics Education (Pitta-Pantazi, 2014). The significance of number sense in mathematics curricula is well recognized; however, its description and definition are somewhat elusive. For instance, the National Council of Teachers of Mathematics (NCTM) refers the “students with number sense naturally decompose numbers, use particular numbers as referents, solve problems using the relationships among operations and knowledge about the base-ten system, estimate a reasonable result for a problem, and have a disposition to make sense of numbers, problems, and results” (NCTM, 2000). As compared to the broad aspect that the number sense is in the mentioned definition, the number sense also referred to a very confined terms. To illustrate, Reynvoet, Smets, and Sasanguie (2016) suggests that the “number sense is the ability to represent the number of both non-symbolic and symbolic stimuli” innately. However, the argument stated by Reynvoet et al. (2016) was contradicted with the study by Leibovich, Katzin, Harel, and Henik (2017) who claimed that number sense is not innate and automatic as previously thought. The challenges in defining number sense also highlighted by other researcher (Ghazali, 2004; Lee & Lembke, 2016; Yang, Li, & Lin, 2008).

The lack of consistent definitions does not only weaken the significance of research findings, but this also contributes to obstacles in academic communication and consequently produces the misunderstanding of what number sense is. The concept of number sense studied in animal and infant, cognitive psychologist, neurologist, and mathematical educationalist were differently conceptualized (Dehaene, 2011). In regard of mathematics education, the complexities and variation of how number sense is acquired were also rooted in student’s development of cognitive abilities (Yılmaz, 2017). It means that the current literature agreed that the misunderstanding of what number sense is derived from the field the number sense is notably studied in mathematics education - is the age of the students.

Even though the definition of number sense is ambivalent, the importance of number sense is prevailed (Kuldas, Sinnakaudan, Hashim, & Ghazali, 2017).
Contribution to the literature

- This paper systematically reviewed the concept of number sense in the primary years’ mathematics education.
- From the reviews, this article carefully proposed the operational definition, imposed definition, inductive definition and verbal definition of number sense by synthesizing the possible indicators of number sense in the past studies.
- This study also developed a flowchart for definition formulation using SLR+PRISMA through three coding stages.

Hence, the research on children’s number sense ability in primary school years are well documented. The past studies have applied different indicators to conceptualize the number sense in primary mathematics education. This article seeks to formulate a definition of number sense inductively from the indicators (i.e., construct, criteria, attribute, and isolates) which were used to measure the number sense in primary school students. Therefore, this study aims to formulate a definition of number sense based on indicators documented in previous studies in the perspectives of primary year’s mathematics education. As compared to the common practice of formulating definition from theoretical or literal interpretation, the formulation of definitions of number sense in this article is by synthesizing the possible indicators of number sense in the past studies.

The grasp in the definition of number sense specifically in primary year’s mathematics education is crucial to make possible verification and reproduction of the observations by others and checking the findings. The insight of the number sense definition and its indicators serve as a general guideline for researchers and teacher alike. The intensive analysis of indicators of number sense has directed to an informed decision and evidence-based sound plan to create and inform the current practice, center upon primary mathematics education.

LITERATURE REVIEW

Number sense is a critical part of mathematics instruction and curricular globally. The existing evidence discussed that number sense forms an essential foundation for understanding mathematical concepts that will be needed in later life (Voroin, Ovcharova, Bezrukov, & Kovas, 2018). Despite the large volume of the published documents concerning number sense, to date, a much objective definition is still not formulated in the perspectives of primary school mathematics education. For instance, the existing research views different representations of numbers as a number sense strategy (Carroll, Fuson, & Diamond, 2000). Furthermore, another study investigated by Kerschen, Cooper, Shelton, & Scott (2018) lamented that the number sense partly identifies relative and absolute magnitudes of numbers. Whereas, some researchers tend to imply number sense as the composition and decomposition of numbers (Howell & Kemp, 2010). At much consecutive extend, some research denote the conceptual understanding of numbers (Yang et al., 2008) or even estimation as the conceptual definition number sense (Kim, Shin, & Lee, 2013). Number sense also refers to mental computations (Lee & Lembke, 2016) or the ability to make a judgment about the reasonableness of a calculation (Yang & Hsu, 2009).

The genesis of the term ‘number sense’ traced from historical perspectives indicated that indexed literature before 1800 about number sense “does not make any sense” as it was related to sociology, art, theology, and even politics. From the N-Gram viewer provided by Google, the linguistic link of number sense has been put upfront in the literature for more than 200 years since the 1890s. Several earliest works conducted by Crawley (1897), and Conant (1893) yielded the discussions regarding the origin of the numbering system and philosophical underpinning of number sense. Despite early notes in published works, this term first appeared in the Scopus database was a review paper written by Riess (1943). She compared several previous experiments and attempted to propose an early theoretical underpinning regarding the numerical quantification and number sense from behavioural perspectives. This classic article revealed that systematic research concerning numeric sense-making research interest during that time was to understand human abilities and capabilities as compared to animals. To date, the research in number sense has been revolutionized and embarked to uncover in different area of studies. The collective research approach across the historical timeline until present has revealed the multitude of research approaches and could be a remark of more scientific revenues in the future.

What is the definition of number sense? As discussed earlier, the cognitive scientist might already arrive to a much converged definition (Reynvoet et al., 2016), but the mathematics educationalists were quite diverged (NCTM, 2000). From the classical perspective of social sciences, ‘definition’ consists of ‘words, and words are symbols representing ideas or facts, that is, singled-out states of knowable reality’ (Timasheff, 1947). He further explained that the definition which covers scientifically relevant conjunction of attributes or a suitable isolate
considered must scientifically adequate. To illustrate, the
typology of definition provides distinction of definition
criteria, namely verbal, inductive, imposed, and
operational.

The verbal definition refers to the meaning of the
terms designated in speech or the word’s etymology. Gupta (2019) referred to the verbal definition as a
nominal definition. ‘Number sense’ is expressed as a
single concept in literature; the terms are absent in the
dictionary (i.e., Merriam-Webster, Cambridge, and
Oxford). Meanwhile, the inductive definition associates
with the formulation of definitions by forming logical
implications from inferences. Other researchers mention
the inductive definition as inductive conceptualization
(see, e.g., São José et al., 2019). Amongst all of the four
types of definition, the number sense referred in
literature is mostly either imposed or operational. The
imposed definition refers to deductive reasoning
accompanied by additional examples (see, e.g., Xinkui,
2019). The operational definition relates to observable
operations, measured variables, and underlying prior
assumptions (Shoemaker, Tankard Jr, & Lasorsa, 2003).

The past research embarked on the qualitative
paradigm, frequently utilizing the imposed definition as
compared to the quantitative research incline towards an
operationalized definition. These differences may derive
from the nature and limitation of the different research
paradigms. The in-depth research from qualitative
realms apt to deduce the concept of number sense.
Therefore, rather than a comprehensive one-fits-for-all
definition, number sense is segmented according to a
particular topic. For example, number sense concept was
narrowed spatially and temporally (Cheek, 2013),
arithmetic (Alsawaie 2012), and fraction (Rendell, 2008).
On the other side, the operational definition fits well
with the usage of the construct, or principles, scale which
contributed mainly by the norm-referred instrumentation such as TEMA in Clarke et al. (2018),
CBM-IPAM in de León et al. (2020) or contextually-
adapted-framework to assess school children’s number
sense asses (Zanzali & Ghazali, 1999). The findings from
advanced statistical analysis of the norm-referred quantitative data mostly applied to a broader context.
Therefore, the selection of definitions and tailored
research agenda are referred to the criterion of certain
indicator to measure the abstract concept of number
sense.

In this article, number sense indicators refer to the
collective observable outcome from the number sense
concept implemented in the research as cases, attributes,
statements, variables, and embodied ideas of number
sense regardless of the research paradigm. It means that
the indicators of number sense portrayed as observable
features or measurable facets used in previous study to
learn the concept number sense in primary mathematics
education. In the formulation of the definition of number
sense, the procedure consists of suggesting a definition
by referring to some common and essential attributes or
a few typical and exact embodying the concept of
number sense. These instances are compared, and what
they have in common is abstracted. Inductively, the
definition of number sense is formulated.

**METHODOLOGY**

The Preferred Reporting Items for Systematic reviews
and Meta-Analyses (PRISMA) statement by Moher,
Liberati, Tetzlaff, and Altman (2009) was used as the
guidelines for this study. The detailed process of
PRISMA was summarized in the flow map (Figure 1).

**PRISMA**

PRISMA consist of four distinguish step
(identification, screening, eligibility and inclusion) in
selecting the best fit document for the purpose
systematic literature review (SLRs). Sierra-Correa,
Cristina and Kintz (2015) claimed that the PRISMA
statement were excellent guidelines in identifying the
research questions, addressing the inclusion and
exclusion criteria and framing the search. The detailed
process of PRISMA adapted from Moher et al. (2009) for
this review was summarized in the flow map (Figure 1).

**The systematic process of selecting the relevant articles**

Identification: The first step in PRISMA is the
‘identification’. The identification of relevant documents
involves searching in the selected database using the
best-fit term according to the purpose of the study. The
challenge in this study was to decide the right term in
the search string as number sense was worded
differently throughout the literature. For instance, ‘sense
of number’ or ‘representation of number’ or ‘numeracy’
or ‘numerical sense’ always refers to the similar concept
with number sense. In this review, 1) to avoid any
further confusions of the mentioned variation in the term
of number sense with other terms and 2) to specifically
refer the exact term used in national early mathematics
curriculum in Malaysia, the precise term- ‘number sense’
per se was searched. As mentioned in Shaffril, Krauss,
and Samsuddin (2018), specific keywords will result in
more accurate documents. Meanwhile, the other terms
that might referred as the similar concept was regarded
as the limitation of this review. The Scopus databases
were selected to perform this review considering the
advantage of this database as compared to others
(Burnham, 2006), which means that the other databases
were set as limitation of this review.

The relevant articles identified from the “number sense” string were oscillated around title, abstract, and
keywords. The total of 650 document appeared in the
database registry. Then, the search curtailed with the
sampling frame set for this review- the ‘primary’ year’s
students. The total of 283 documents were listed
including the other terms referred to primary including
The searching process was conducted on 5th December 2020.

**Screening:** The second stage was the 'screening'. Screening involved the filtering process of the identified articles based on the decided inclusion and exclusion criteria. The inclusion criteria for the type of literature were ‘open accesses’, ‘final publication stage’, ‘only article journal’ and language was ‘only English’. The exclusion criteria were irrelevant subject areas (i.e., medicine, neuroscience, agricultural and biological sciences, computer science, environmental science, and health professions) to narrow-down the article concerning the number sense studied in primary school children. Meanwhile, Table 1 shows the inclusion and exclusion criteria in this study. From the 283 articles retrieved earlier, a total of 224 unrelated articles were removed.

**Eligibility:** All the 59 documents were garnered. The review begun with skimming of the retrieved articles, proceed with tabulating the titles, abstracts, objectives, methodology, and conclusions remarks. Hereupon, 34 documents were excluded manually due to irrelevant population frame or field of study, i.e.,

1. deficient in sampling criteria mentioned in the article,
2. pre-service teacher, teacher or parents sampled population rather than the students,
3. the student sample aged between 2-6 years old or 13 years old and above,
4. other than mathematics education field of study (i.e., genetic, neuroscience),
5. non-research article (i.e., review or commentary),

In the end, 25 remaining articles were used as the source meta-analysis and synthesis of study (as illustrated in Figure 1).

**Meta-analysis and Synthesis of the Study:** The 25 retrieved articles were perused manually. The purposes
of coding were to organize data and summarize the unit of analysis which measure number sense or the components of the number sense in past research. The overall meta-analysis and synthesis of study based on general SLRs guide (i.e., Akcayir & Akcayir, 2018; Okoli & Schabram, 2010).

First, the possible codes were scored and listed according to the bibliographic information through open coding, forming an extensive meta-data. The meta-data were re-coded using dichotomous systemic analysis as reported by Tsvetkov (2014). The data-driven codes were constructed a posteriorily, isolated on words or phrases in the texts that refers as number sense or measure the number sense. The initial code serves as unit of analysis were the facets, cases, attributes, statements, variables, scale, and construct or criteria in the documents. The categories were revised, rectified, and refined forming comprehensive categories and several themes. These categories are highlighted in Table 2. The description of the coding process in this study was based on the guide by Vaismoradi, Jones, Turunen, and Snelgrove (2016).

Second, the refined data from the open-coded and meta-data were further organized through the axial coding and selective coding. The emerging individual code was then linked to form a schematic representation of the definition of number sense as stated in Table 3. The data from the axial and selective codes serves as the descriptor to formulate the definition of number sense in this article. As suggested by Brereton, Kitchenham, Budgen, Turner, and Khalil (2007), the thorough procedure from identification of article until the coding and meta-analysis were checked by all three of the research members.

**FINDING AND DISCUSSION**

As the result of open coding, five themes emerged from the indicator of number sense in primary school mathematics education, namely number composition, number identification, number magnitude, number operations, and make a judgment. The number of articles mentioning the codes was counted (n), and the percentage of articles referring to the identified codes was calculated as \( \frac{n}{N} \times 100 \), N=25, the total number of all articles reviewed. Table 3 indicates the emerging themes and category from the open coding.

Based on the finding, it could be analyzed that there were five themes that emerged from 48 categories. The first theme was the number composition which encompassed meaning of numbers, general knowledge of numbers, decomposing and recomposing. Second, number identification was among one the most common unit of analysis for number sense in primary years. Within the number identification category, there were three categories, namely quantity numerical recognition (from visual to verbal), numerical recognition (from verbal to visual), and numeral recognition (from verbal to manipulative). The numerical recognition of number sense from visual to verbal was in term of use context, the distance between, identify a number from pictorial representation, understanding the meaning of variable, structured counting and resultative counting. The numerical recognition from verbal to visual, involved identifying the visual number symbol, matching visual representation, pattern, visual quantity representation, space and space skills. Finally, manipulative utilization within a numeral recognition found as non-verbal number line, use a set of concrete objects, use a set of objects and backward digit span.

Next, third theme was the magnitude of number. Magnitude of number specifically referred to the number order, comparison, and place value. The magnitude of number included order numerals and quantities from least to greatest, symbolic or nonsymbolic comparison, speed and accuracy of identifying and processing number sets, absolute magnitude number, comparison of relative magnitude of numbers, select circle the largest number, cross out the larger, mark the position on a number line, correspondence, seriation (relational skills) and symbolic magnitude comparison. The fourth theme was the number operation. The number operation encompassed the arithmetic operations as the most central theme, among others either non-verbally or and verbally. This category made up with mental computation, pressing a key on a computer keyboard, simple operations, single-digit additions, single-digit subtractions, number relation, multi-digit computation (addition or subtraction), multiplication, division and mix operation. The last theme was the judgment making. The making of judgment included several skills such as subitizing, enumeration, measuring benchmarks, judging the reasonableness, estimates and problem solving using of numbers.

By breaking down the earlier meta-data and the thematic analysis of open coding, the five qualitative themes were fragmented and recoded to form the descriptor for the definition of number sense through the axial code and selective code. The refined codes were

| Category | Description |
|----------|-------------|
| Number composition | The words or phrases in the texts that measure the number sense (i.e., facets, cases, attributes, statements, variables, scale, and construct or criteria). |
| Number identification | The constructed conceptual code of number sense that represents the mutually exclusive units of analysis that is directly or indirectly expressed in the text. |
| Number magnitude | The indicator of the meaning of number sense. The themes synthesized from unified category. |

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**Table 2. The Description of Unit of Analysis, Category and Themes in This Study**

| Terms          | Description                                                                 |
|----------------|-----------------------------------------------------------------------------|
| Unit of analysis | The words or phrases in the texts that measure the number sense (i.e., facets, cases, attributes, statements, variables, scale, and construct or criteria). |
| Category        | The constructed conceptual code of number sense that represents the mutually exclusive units of analysis that is directly or indirectly expressed in the text. |
| Theme           | The indicator of the meaning of number sense. The themes synthesized from unified category. |

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**Table 3. The Emerging Themes From Open Coding**

| Themes          | Description                                                                 |
|-----------------|-----------------------------------------------------------------------------|
| Number composition | The words or phrases in the texts that measure the number sense (i.e., facets, cases, attributes, statements, variables, scale, and construct or criteria). |
| Number identification | The constructed conceptual code of number sense that represents the mutually exclusive units of analysis that is directly or indirectly expressed in the text. |
| Number magnitude | The indicator of the meaning of number sense. The themes synthesized from unified category. |
presented in Table 4. Then, the axial code was linked and represented in the schematic diagram.

The identified emerging codes are labeled as cognition, logic proposition, communication mode, and thinking order which serve as the descriptors of the definition of number sense. The cognition refers to an acquired perception of number and its meanings such as quantity and symbols, in non-electronic form or analogue. Logic preposition is the linkages or interaction in sense-making through logic from the indicator of number sense. For instance, ‘conditional implication’ contextualizes in a new phenomenon, imparting the idea of number from the concrete to abstract and vice versa.

The communication mode was the route to receive and convey the concept of number sense; language (words, read, write), articulations (verbal, non-verbal) or actions (i.e., pressing key, sign, cue). Meanwhile, the thinking order refers to the verbs used in the hierarchy of the cognitive domain of thinking skills. Thoroughly, all the indicators include both orders of thinking skills, namely Lower-Order Thinking skills (LOTs) and Higher-Order Thinking skills (HOTs), according to the age-based cognitive development of the sampling frame in the respective articles.
Finally, throughout all the codes, the core themes emerged were labeled as the analogous numerical cognition. As the research in mathematics education has seemed to categorize the indicator of number sense complexity according to age, the analogous numerical cognition was a broad term referred as the biological or natural human perception of numerical conception acquired in primary school years. The emerging codes were then linked to form a schematic diagram of the formulation of number sense as in Figure 2—that consisted of cognition, logic proposition, communication mode, and thinking order.

Therefore, the definition of number sense was:
Number sense was an analogous numerical cognition, perceived via logical preposition and thinking skills through various communication modes.

From the analysis, the core theme identified throughout all the subcategories, categories, and themes was the ‘analogous numerical cognition.’ This core theme was anchored as the basis of all types of number sense. Thus, from the analysis conducted from this study, the definitions that encompassed operational definition, imposed definition, inductive definition and verbal definition. Thus, the typology of definition for number sense in this article were:

**The Operational Definition of Number Sense**

Number sense was an analogous numerical cognition collectively measured by any or all 48 units of analysis includes facets, cases, attributes, statements, variables, scale, and construct or criteria of number sense as identified in this article.

**The Imposed Definition of Number Sense**

Number sense is an analogous numerical cognition that includes number composition, number identification, magnitude number, number operation, and judgment making.

**The Inductive Definition of Number Sense**

Number sense is an analogous numerical cognition, perceived via logical preposition and thinking skills, channeled in/out through various communication modes.

**The Verbal Definition of Number Sense**

Number sense is an analogous numerical cognition that denotes a particular meaning to a group of vital mathematical abilities or the basic mathematical concept. In other words, number sense may also be used loosely to refer to an intelligible view of number implied or grasped rather than expressed.

**Discussion, Conclusion and Recommendation for Future Research**

This study carefully extracted five indicators and 48 unit of analysis of number sense that could further operationalize to serve as cases, attributes, statements, variables, and embodied ideas for future research in primary year’s education. Practically, the teacher could use the indicators in the teaching practice to create a sound-plan for better understanding of children’s acquiring number sense for primary school students, with the support of other research findings as well. Even though this study identified and accumulated the indicators in number sense in the past studies according to primary years schooling, it was an insufficient evident on which indicators that were relevant for each grade respectively. Bridging this gap in future studies would be able to provide a much comprehensive guide for teaching number sense systematically.

This study proposed the definition of number sense. Besides the induced definition, the imposed, operational, and verbal definitions were also formulated in conjunction to the primary years’ education. The finding from this review further supported the statement.
by Leibovich et al. (2017) who found that there was not enough convincing evidence to relate number sense theory exclusively with ‘innate and non-symbolic’ ability. In this review, the primary year’s number senses were extended into symbolic ability as well. In a similar vein, the reviews of past research the context of primary school years, found that number sense were rather acquired by students and facilitated by the means of early mathematics education. Another important signposting from this study is the emergence of cognition and logic prepossession as the descriptor of number sense.

Towards the completion of the definition formulation, this study also developed a flowchart for definition formulation using SLR+PRISMA through three coding stages. The proposed definition and flowchart of the process have important implications for advancing research on this topic. Even it is so, the definition of number sense in this article is limited for primary school years and there is a need to consider the underexplored forms of the definition of number sense related to several factors such as context, ageism, multiple intelligence, worldviews, and even biological factors. Moreover, number sense in young children should be studied carefully that denotes their budding development.

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