On the use of boardgames to develop young children's number sense

Andrea Maffia, Liliana Silva

On the use of boardgames to develop young children's number sense

Andrea Maffia[1] and Liliana Silva[2]

[1]University of Pavia, Italy; andrea.maffia@unipv.it

[2]University of Messina, Italy; liliana.silva@unime.it

With the aim of nourishing the discussion that has taken place during CERMEs in TWG13, we present a review of results presented in previous CERMEs about the possible roles of boardgames in developing young children's number sense. Several contributions in CERMEs have shown that difficulties related to teacher education and curriculum design emerge when analyzing the boardgames that are proposed and their management in classrooms. However, the discussion about the contribution of boardgames to preverbal number sense is still underdeveloped when compared to literature from research journals. Also, the potential of boardgames in providing challenging mathematical tasks seems still unresearched. Hence, possible future paths of research for the use of boardgames in early years mathematics emerge.

Keywords: Boardgames, number sense, literature reviews.

Introduction

Play can be considered as the main learning experience for young children in general, and for early years mathematics in particular (Schuler, 2011). Among the many possible playful activities in which children may engage, we can roughly distinguish between free play and guided play, the latter consisting of adults structuring of the play environment but leaving control to the children within the environment (Weisberg et al., 2013). In this contribution we will focus on guided playful activities, to which we will refer as games. There is a large body of research about the use of games in learning (game-based learning), but not all kinds of games have been studied with the same attention. While literature about videogames is getting larger and larger (e.g. Yong et al., 2021), boardgames were rarely researched (Ramani & Siegler., 2008). We consider as boardgames all those games that are played on a printed surface by one or more people usually sitting around a table (Parlett, 2018); they might include the use of cards or dice. As testified by the available literature, boardgames can play an important role in the teaching and learning of mathematics (see next sections). Such relevance might be even higher at early grades, as stated in some contributions from previous CERMEs (e.g. Schuler & Wittmann, 2009; Schuler, 2011; Tubach, 2015).

The aim of this paper is to nourish the discussion that has taken place during CERMEs in TWG13 by summarizing results presented in past proceedings. Such review of the literature is intended to suggest further limits and opportunities in using boardgames in early mathematics education. Our discussion is limited to number sense; the next session is devoted to explaining what we mean by that.

Number sense

The construct of 'number sense' is present since many years in the discourse of researchers in mathematics education in general, and in the ERME community in particular (Rezat & Ejersbo, 2018). Several definitions have been proposed, mostly in the form of a list of abilities that a child should develop in order to show number sense. Such lists are often not equivalent. In this contribution

we adopt the classification provided by Andrews and Sayers (e.g. Andrews & Sayers, 2015) who distinguish three categories of number sense.

Preverbal number sense includes the innate abilities necessary for quantitative understanding. Research literature (within and outside mathematics education) shows that very young children can discriminate small quantities (e.g. subitizing) and arrange them as a linear representation, called 'mental number line' (e.g. Deahene, 2001).

Applied number sense refers to competences that prepare the learners for the adult life. Applied number sense should enable a person to

> look at a problem holistically before confronting details, look for relationships among numbers and operations and […] consider the context in which a question is posed; choose or invent a method that takes advantage of his or her own understanding of the relationships between numbers or between numbers and operations and […] seek the most efficient representation for the given task; use benchmarks to judge number magnitude; and recognize unreasonable results for calculations in the normal process of reflecting on answers (Reys 1994, p. 115, as quoted in Andrews & Sayers, 2015).

Finally, there is a set of intermediate abilities that are developed thanks to instruction, usually between the end of preschool and the beginning of primary school; then they are particularly relevant for early years mathematics. This set of eight abilities, called *foundational number sense*, is listed in Table 1.

The distinction between preverbal, foundational, and applied number sense will serve as a framework for organizing our presentation of the reviewed literature. The next sections are devoted to describing if and how each of these three types of number sense was considered in past contributions to TWG13 about boardgames. Furthermore, we will list limits evidenced by researchers.

Selection of papers

The papers selected for the presented review are taken from proceedings of the last six editions of CERME. A mapping review of all the abstracts of the paper presented in the working group about 'Early Years Mathematics' (TWG14 in CERME6, when it was founded; TWG13 in the following edition) served for a first phase of selection. Among the 124 contributions, we selected those explicitly referring to numerical abilities and to a playful/game context. We then realized a second phase of selection by reading the full text; only papers specifically including boardgames were left. We ended up with the four papers listed in Table 2.

The fact that a low number of contributions were selected sustains the claim that research about boardgames is still underdeveloped. Surely, TWG13 is not the only TWG interested in boardgames and number sense (e.g. Sensevy et al., 2001), however as we will discuss later, we believe that this topic is particularly relevant for TWG13. We can notice that papers about these topics appeared in this working group during several editions of CERME; we may then affirm that a discussion has started, and there is still room to widen it. The four selected papers have been categorized referring to the framework introduced above. Results are presented in the following sections.

Boardgames and preverbal number sense

Research on preverbal number sense usually focuses on children aged 0–6 and then this stream of research should be considered as part of research in early years mathematics education. Indeed, TWG13 has collected contributions about subitizing (e.g., Schöner & Benz, 2017), but none of them included the use of boardgames. One of the selected papers refers to subitizing (Schuler, 2011), but it is not the main focus of research. Surely this fact does not depend on the impossibility of using boardgames to assess or develop preverbal numbers sense. For instance, we may notice that many traditional boardgames (like Shut the Box) include the use of dice. Traditionally, cubic dice show quantities through dots arranged in a canonic way. Research shows how subitizing gets easier when children recognize patterns in the arrangement of dots; furthermore, developmental dyscalculia can cause a deficit in the estimation of canonically arranged dots (Ashkenazi et al., 2013). This fact suggests that playing boardgames can help in recognizing specific difficulties that might depend on inexperience with canonical arrangement of dots or on learning disabilities.

Table 1: Components of foundational number sense (Andrews & Sayers, 2015)

(1) Number recognition	Recognition of number symbols; their vocabulary and meaning. Ability to identify a particular number symbol from a collection and name a number when shown.
(2) Systematic counting	Counting systematically to twenty and back or count upwards and backwards from arbitrary starting points; knowing each number's position in the sequence of all numbers.
(3) Awareness of the relationship between number and quantity	Not only understanding the one-to-one correspondence between a number's name and the quantity it represents, but also that the last number in a count represents the total number of objects.
(4) Quantity discrimination	Understanding magnitude and comparing of magnitudes. Use of language like bigger than or smaller than.
(5) Understanding of different representations of number	Understanding that numbers can be represented differently, including the number line, different partitions, various manipulatives and fingers.
(6) Estimation	Estimation, whether the size of a set or an object. Moving between representations of number; for example, placing a number on an empty number line.
(7) Simple arithmetic competence	Performing simple arithmetical operations, transformation of small sets through addition and subtraction.
(8) Awareness of number patterns	Extending simple number sequences and identification of a missing number in simple number sequences.

Another clear example is given by research conducted on the development of the mental number line using linear boardgames (boardgames with linearly arranged, consecutively numbered, equal-size

spaces, e.g. Chutes and Ladders, Game of the Goose) – we are here referring to research that was not presented in CERME proceedings, but in research journals. According to Siegler and Booth (2004) and to Ramani and Siegler (2008):

> In such games, the greater the number in a square, the greater (a) the distance the child has moved the token, (b) the number of discrete moves the child makes, (c) the number of number names the child has spoken, (d) the number of number names the child has heard, and (e) the amount of time since the game began. The linear relations between numerical magnitudes and these visuospatial, kinesthetic, auditory, and temporal cues provide a broadly based, multimodal foundation for a linear representation of numerical magnitudes. (Ramani & Siegler, 2008, pp. 376–377)

Research shows that playing these boardgames strengthen preschoolers' number line estimation, magnitude comparison, numeral recognition, and counting skills (Siegler & Booth, 2004; Ramani & Siegler, 2008). Also, evidence shows that playing boardgames correlate positively with numerical knowledge, while this is not the case for videogames and card-games. Children from middle-income backgrounds reported playing more boardgames, and fewer videogames, than age peers from low-income backgrounds. This is considered as one of the possible explanations for differences in the development of preverbal number sense in relation to socio-economic status (Ramani & Siegler, 2008). Whyte and Bull (2008) have compared linear boardgames with card-games and found that card-games can improve some aspects of children's number sense, but not numerical estimation (evaluated as positioning on a number line). Playing with linear boardgames helps children to shift from a logarithmic to a linear representation of numerical magnitudes (Whyte & Bull, 2008).

Table 2: Selected papers from past CERME proceedings

Author(s)	Title	Edition
Dorier & Maréchal	Didactical analysis of a dice game.	CERME6 (TWG14)
Schuler & Wittmann	How can games contribute to early mathematics education? A video-based study	CERME6 (TWG14)
Schuler	Playing and learning in early mathematics education–modelling a complex relationship.	CERME7 (TWG13)
Tubach	"If she had rolled five, she'd have two more": Children focusing on differences between numbers in the context of a playing environment.	CERME9 (TWG13)

Boardgames and foundational number sense

All the contribution selected for our review focused on foundational number sense. The quality of the game and the role of the educators (parents or teachers) appear to be central for all the authors.

Foundational number sense needs explicit teaching (per definition) and thus the choice of a boardgame should be guided by the aim of a teaching intervention. Following Brousseau's Theory of didactical situations, an appropriate game is selected when it allows "bringing together a 'milieu' and a 'player', with this game being such that a given piece of knowledge will appear as the means of producing winning strategies" (Brousseau, 1998, p.57). The equilibrium between the game and the mathematical content seems hard to achieve, as has been shown by contributions to previous CERMEs. On one side, the game should be mathematically productive, meaning that the game materials should be reinterpreted as representations of mathematical relationships (Tubach, 2015).

On the other side, it is important that the game is an actual game to children for exploiting the game's idea and affordance (Schuler & Wittmann, 2009). However, there is also the risk that a game remains just a game. As reported by Schuler (2011, p. 1920) while referring to a boardgame about counting and comparison of numbers:

> Mathematical potential develops through the educator's comments on the game's course, through questions that stimulate explanations, reflections on actions and thoughts, and reasoning. She has to communicate individually challenging rules through stimuli, comments, questions and requests what requires a sensitivity for possibilities and variations in the games course.

Dorier and Maréchal (2009) refers about teachers selecting games based on the pleasure they are supposed to give to students, while the mathematical content remains secondary. They analyze a game called 'Turn the Dice' proposed for first grade in the official curricular material of the French-speaking Switzerland. By their analysis, to play correctly, students should know how to make sums correctly. However, if they do not, they may play anyway, because nothing in the managing of the game is organized to provide any feedback. In their words "nothing is organized didactically for them to learn sums, they have to know, but they can make errors without being corrected, except if the other player knows better or the teacher is there to correct" (Dorier & Maréchal, 2009, p. 2580). They also observed a teacher conducting the game in one of her classes and found how she had probably underestimated the difficulty of the game.

While research elsewhere as shown how boardgames may provide a good opportunity for the development of foundational number sense (Peters, 1999; Stebler et al., 2013), the discussion going on in TWG13 has pointed out possible limits for the exploitation of such potential.

Boardgames and applied number sense

Potentialities of boardgames for developing applied number sense are as many as the different representations of numbers, calculation algorithms, and so on. In the context of TWG13, the interest could be in understanding how boardgames may help, in the context of early years mathematics, to foster the development from foundational to applied number sense. In one of the selected papers, Dorier and Maréchal (2009) note that even simple games can hide interesting opportunities for introducing more complex mathematics. For instance, they show how, by slightly changing the rules of the game, 'Turn the Dice' shows strong similarities with the famous game 'Race to 20' which offers interesting opportunities to introduce the Euclidean division (Sensevy et al., 2001).

This example helps us in introducing an opportunity provided by boardgames that has been studied scarcely. In their paper from the *Journal für Mathematik-Didaktik*, after analyzing children playing the game Shut the Box, Stebler and colleagues conclude that:

> This first exploratory analysis leads us to the hypothesis that boardgames like Shut the Box can provide a high-quality teaching and learning arrangement, offering cognitively activating and challenging learning tasks, adaptive for different levels of mathematical competencies and allowing for diverse strategies, embedded in a collaborative setting (2013, p. 172)

Such hypothesis needs confirmation, but the possibility of using boardgames as context for mathematical activity that is adaptive for different levels of competencies is proposed by other authors in research literature (e.g. Vogt et al., 2018). Some authors notice that the challenges that are posed by a boardgame are particularly effective for children with higher mathematical competences, while more traditional training program could lead to better results for low achievers (Vogt et al., 2018); other authors suggest using boardgames even in the case of disabled children since they prove to be successful with students of different ability levels (McConkey & McEvoy, 1986).

Conclusion

General education literature converges on attesting that game-based education can foster learning providing students with a high motivational context, and this is also confirmed in the case of mathematics (Yong et al., 2021). Research about motivation and games is widespread in journals and conferences, but we can recognize that the reviewed research focuses more on the cognitive and relational aspects that are specific to the development of number sense using boardgames. The focus on the different didactical variables, including the teacher's role, appears peculiar to TWG13.

Drawing on literature from research journals, we have noticed that linear boardgames and playing with dice can help in fostering preverbal number sense (specifically, the mental number line and the subitizing ability) and in assessing deficits, however research about boardgames and preverbal number sense is still missing in CERME. Contributions in CERMEs have shown that difficulties related to teacher education and curriculum design emerge when analyzing the boardgames that are proposed in mathematics classes. However, we believe that these difficulties do not constitute good enough reasons to avoid the use of boardgames in preschool or primary school, since there is evidence that these games can provide the context for challenging tasks. Downton and Sullivan (2017) have documented (in the context of word problems) how challenging tasks may prompt the use of more sophisticated calculation strategies and then flexibility. This could be particularly true in the case of strategic games. Further research is needed to prove this kind of conjectures. If any, positive results may serve as basis for a larger implementation of boardgames in mathematics classes.

Research literature testifies that teachers participating in experimental interventions involving boardgames are particularly enthusiast (Vogt et al., 2018), and such involvement is considered one of the possible causes of good results of these experiments (Ramani & Siegler, 2008). Enjoyment may lead teachers to propose tasks that are more challenging than those they are used to and then prompts an explorative approach that is often prevented by teachers' insecurities (Peters. 1999). However, as noted above, teachers may misjudge the mathematics involved in a boardgame (Dorier

& Maréchal, 2009). The design of teacher professional development programs appears as needed and may constitute an interesting context of research (Maffia & Silva, 2021).

Concluding, we can claim that boardgames show several potentialities in relation to the development of young children's number sense, however in TWG13's discussion there is still room for more research aimed at: (1) understanding the features of boardgames for developing and assess preverbal and foundational number sense; (2) developing teachers' education to help them in analyzing games and exploit their potential.

References

Ashkenazi, S., Mark-Zigdon, N., & Henik, A. (2013). Do subitizing deficits in developmental dyscalculia involve pattern recognition weakness? *Developmental Science, 16*(1), 35–46. https://doi.org/10.1111/j.1467-7687.2012.01190.x

Andrews, P., & Sayers, J. (2015). Identifying opportunities for grade one children to acquire foundational number sense: developing a framework for cross cultural classroom analyses. *Early Childhood Education Journal, 43*(4), 257–267. https://doi.org/10.1007/s10643-014-0653-6

Brousseau, G. (1998) *Theory of didactical situations in mathematics*. Dordrecht: Kluwer Academic.

Dorier, J.L., & Maréchal, C. (2009). Didactical analysis of a dice game. In V. Durand-Guerrier, S. Soury-Lavergne, & F. Arzarello (Eds.), *Proceedings of the Sixth Congress of the European Society for Research in Mathematics Education* (pp. 2577–2586). ERME.

Downton, A., & Sullivan, P. (2017). Posing complex problems requiring multiplicative thinking prompts students to use sophisticated strategies and build mathematical connections. *Educational Studies in Mathematics, 95*(3), 303–328. https://doi.org/10.1007/s10649-017-9751-x

Maffia, A., & Silva, L. (2021). Primary teachers' professional development about mathematics assessment using tabletop games. In L. Gómez Chova, A. López Martínez, & I. Candel Torres (Eds.) *Proceedings of ICERI 14* (pp. 8408–8413). IATED Academy.

McConkey, R., & McEvoy, J. (1986). Games for learning to count. *British Journal of Special Education, 13*(2), 59–62. https://doi.org/10.1111/j.1467-8578.1986.tb00655.

Parlett, D. (1999/2018). *History of boardgames*. EPBM.

Peters, S. (1999). Playing games and learning mathematics: The results of two intervention studies. *International Journal of Early Years Education, 1*, 49–58. https://doi.org/10.1080/0966976980060105

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number boardgames. *Child development, 79*(2), 375–394. https://doi.org/10.1111/j.1467-8624.2007.01131.x

Rezat, S., & Ejersbo, L. R. (2018). Number sense in teaching and learning arithmetic. In Dreyfus, T., Artigue, M., Potari, D., Prediger, S., & Ruthven, K. (Eds.) *Developing research in mathematics education: Twenty years of communication, cooperation and collaboration in Europe* (pp. 23–31). Routledge.

Reys, B. (1994). Promoting number sense in the middle grades. *Mathematics Teaching in the Middle School, 1*(2), 114–120. https://doi.org/10.5951/MTMS.1.2.0114

Schöner, P., & Benz, C. (2017). “Two, three and two more equals seven” Preschoolers’ perception and use of structures in sets. In T. Dooley & G. Gueudet (Eds.), *Proceedings of the Tenth Congress of the European Society for Research in Mathematics Education* (pp. 1893–1900). ERME.

Schuler, S. (2011). Playing and learning in early mathematics education–modelling a complex relationship. In M. Pytlak, T. Rowland, & E. Swoboda (Eds.) *Proceedings of the Seventh Congress of the European Society for Research in Mathematics Education* (pp. 1912–1922). ERME.

Schuler, S., & Wittmann, G. (2009). How can games contribute to early mathematics education? A video-based study. In V. Durand-Guerrier, S. Soury-Lavergne, & F. Arzarello (Eds.), *Proceedings of the Sixth Congress of the European Society for Research in Mathematics Education* (pp. 2647–2656). ERME.

Sensevy, G., Mercier, A., & Schubauer-Leoni, M. L. (2001). A model for examining Teacher's didactic action in mathematics, the case of the game "race to 20". In J. Novotná (Ed.), *Proceedings of the Second Congress of the European Society for Research in Mathematics Education* (pp. 420–432). ERME.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75*, 428–444. https://doi.org/10.1111/j.1467-8624.2004.00684.x

Stebler, R., Vogt, F., Wolf, I., Hauser, B., & Rechsteiner, K. (2013). Play-based mathematics in kindergarten. A video analysis of children’s mathematical behaviour while playing a boardgame in small groups. *Journal für Mathematik-Didaktik, 34*(2), 149–175. https://doi.org/10.1007/s13138-013-0051-4

Tubach, D. (2015). "If she had rolled five, she'd have two more": Children focusing on differences between numbers in the context of a playing environment. In K. Krainer & N. Vondrová (Eds.), *Proceedings of the Ninth Congress of the European Society for Research in Mathematics Education* (pp. 2017–2024). Charles University in Prague, Faculty of Education and ERME.

Vogt, F., Hauser, B., Stebler, R., Rechsteiner, K., & Urech, C. (2018). Learning through play–pedagogy and learning outcomes in early childhood mathematics. *European Early Childhood Education Research Journal, 26*(4), 589–603. https://doi.org/10.1080/1350293X.2018.1487160

Weisberg, D. S., Hirsh-Pasek, K., & Golinkoff, R.M. (2013). Guided play: where curricular goals meet a playful pedagogy. *Mind, Brain, and Education, 7*(2), 104–112. https://doi.org/10.1111/mbe.12015

Whyte, J. C., & Bull, R. (2008). Number games, magnitude representation, and basic number skills in preschoolers. *Developmental psychology, 44*(2), 588–596. https://doi.org/10.1037/0012-1649.44.2.588

Yong, S. T., Karjanto, N., Gates, P., Chan, T. Y. A., & Khin, T. M. (2021). Let us rethink how to teach mathematics using gaming principles. *International Journal of Mathematical Education in Science and Technology, 52*(8), 1175–1194. https://doi.org/10.1080/0020739X.2020.1744754