See, Hear! Exploring pattern understanding in music and mathematics

Sarah McCarthy[1] , Adam Ockelford[1], Sue Gifford[1], Helen Thouless[2] and Sharon Kirk[3]

[1]University of Roehampton, [2]St. Mary's University, [3]West Hill School

This co-designed exploratory study sought to test a theoretical taxonomy of visuo-spatial pattern understanding, mapped from the Sounds of Intent framework of musical development. Researchers developed classroom-appropriate pattern games that progressed in complexity. The games were played using objects or sounds or both together. Participants (N = 20) in a primary special school in England completed up to five sessions with a researcher or practitioner. Children's engagement and progress were videoed, then analysed using an adapted musical assessment. Findings indicated that children recognised patterns across musical and spatial domains, with the strongest benefits arising when games combined sounds and visuo-spatial elements. Early evidence suggests that the taxonomy and games are a useful tool for practitioners seeking to support children's understanding in mathematics and music. Future, larger-scale experimental work is needed to evidence the effectiveness of integrated pattern making in improving children's mathematical and musical understanding.

Keywords: pattern understanding; music; mathematics; special educational needs; Sounds of Intent

Introduction

Patterns appear everywhere, in a range of contexts and domains, in nature, in numbers, in functional and decorative designs, music and dance. Mathematically, a pattern may be described as "any predictable regularity, usually involving numerical, spatial or logical relationships" (Mulligan and Mitchelmore, 2009, p. 34). Musical understanding is based on identifying patterns of different levels of complexity, as outlined in zygonic theory (Ockelford, 2015). Mathematics curricula in the early and primary years focus on repeating, spatial, and growing patterns, in visuo-spatial and numerical contexts. This study investigated 20 children's responses to repeating patterns that developed in complexity, presented using sounds or objects, or both.

Literature review

Pattern understanding in mathematics

Empirical evidence indicates that a child's pattern-making ability is uniquely important for their general mathematical understanding (Kidd et al., 2014; Rittle-Johnson et al., 2017) and allows children to deepen their mathematical skills (Warren, 2005). Thus, providing practitioners with tools to develop children's pattern understanding should be beneficial for supporting their attainment in mathematics. Research to date has explored how children's pattern skills develop at specific ages (Borthwick et al., 2021; Larkin et al., 2021; Papic et al., 2011; Mulligan & Mitchelmore, 2009, 2013). Mulligan & Mitchelmore's research with five- and six-year-olds (2009, 2013) categorised pattern-making abilities into five stages: pre-structural, emergent, partial structural, structural, and advanced structural. Building on this Borthwick et al. (2021) identified a pedagogical and learning progression for three- and four-year-olds as: continue, copy, identify and fix errors, identify the unit of repeat, generalise to other contexts and modes, symbolise (e.g., ABB), own symbols.

Identifying the unit of repeat has been recognised as the key to understanding repeating patterns. It has been found that four-year-olds can do this, name the structure in letters, and translate a pattern into other contexts (Fyfe, 2015). For instance, a child, when told his pattern was an ABBC pattern, said, "So it could be, dog, cat, cat, sheep" (Borthwick et al., 2021 p.7). Lüken (2020) also found that requiring children to produce gaps between units is a more accurate assessment of pattern recognition. Research has mainly focused on patterns with objects. However, Adam Ockelford noticed a similarity in progression with the musical Sounds of Intent (SoI) framework (Ockelford et al., 2025).

Pattern understanding in music

Zygonic theory and the Sounds of Intent framework of musical development (Ockelford, 2015) assume that: music consists of many types of patterns, all of which are generated through repetition of one form or another, which vary in their levels of complexity. As these patterns become more intricate, they place increasing cognitive demands on the learner. Additionally, the ability to perceive and understand such patterns develops progressively in childhood, becoming more complex as the brain gains more sophisticated processing skills. The Sounds of Intent framework is a universal model of musical development, with six levels from pre-birth to teenage years, across three domains: reactive, proactive, and interactive. In this study, we wanted to see if children could translate patterns between sounds and objects and if the progression in understanding was the same across the auditory and visuo-spatial domains.

New taxonomy of pattern making in the visuo-spatial domain

Ockelford and colleagues (2025) integrated research on musical pattern structure, preference rules and visuo-spatial repeating patterns to propose a new taxonomy for pattern making in the visuo-spatial domain. Using an algorithm, the 'Structural Processing Load' (SPL), to provide an objective measure of the complexity of different pattern types, simple-to-complex musical patterns were mapped onto patterns used in mathematics. Levels 3 and 4 of the Sounds of Intent framework were aligned with early pattern-making behaviours typically seen in children aged 9 to 33 months. This approach enabled the definition of earlier stages of mathematical patterning than hitherto. The resulting progression of visuo-spatial patterns differed from the usual mathematical progression (e.g., Mulligan & Mitchelmore, 2009), where repeating patterns are presented as continuous patterns without gaps and growing patterns of units are presented after repeating patterns. The current study aimed to explore the validity of the proposed taxonomy of visuo-spatial pattern making.

Methodology

This was an exploratory study, co-designed by the mathematics lead in a special school, early childhood mathematics researchers and applied musicologists. The project took place in a primary special school in England to allow the researchers to identify the probable gradual progression in children's understanding of repeating patterns from early stages to more complex patterns. Among the research questions were whether empirical evidence supports the proposed Sounds of Intent framework, incorporating auditory and visuo-spatial pattern understanding, and what differences and similarities are there between pattern understanding in the auditory and visuo-spatial domains?

Participants (N = 20) were children with a range of learning support needs from years 3 to 6 (ages 7 to 11). Children were mostly accessing National Curriculum content equivalent to Reception to Year 2 (ages 4 to 7). Consent to participate in the study was provided by parents and carers of the young people. The study received ethical approval from the University of Roehampton (EDU 23/ 247).

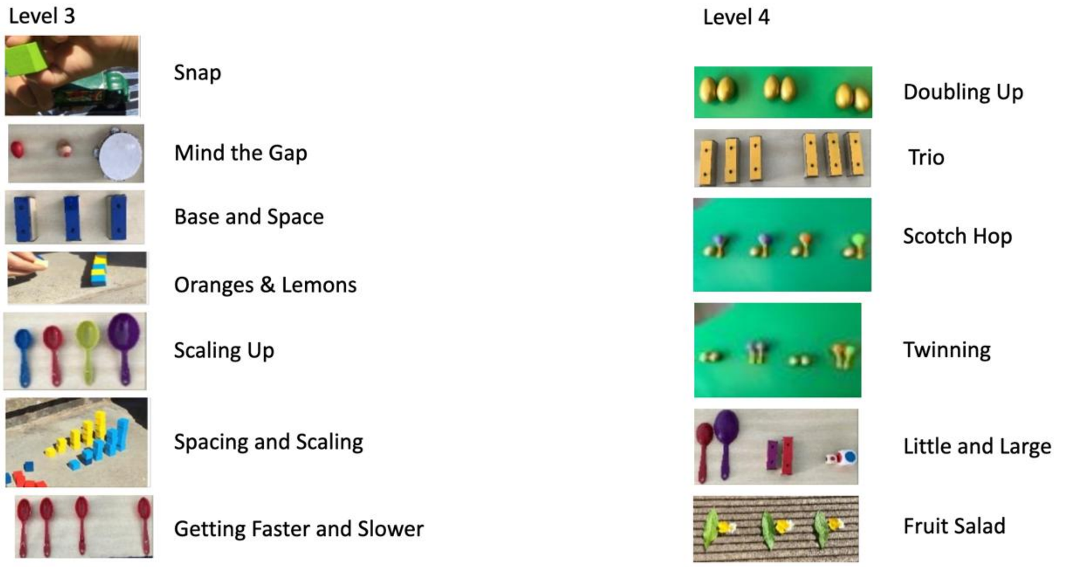
Procedure

Children played a series of 'pattern games' that increased in complexity (see Figure 1). Games were played in a classroom setting, working with a practitioner, a researcher or in small groups. Before each session, assent was checked with participants using a visual support. Games were played with few verbal prompts to allow full participation of non-speaking children. Participants completed up to five sessions each lasting between 10 and 20 minutes during a school term. Each session was video recorded for later analysis. In the first session, all children started at Level 3a – 'Snap' – playing the game across each domain (looking, listening, and looking/listening combined). Researchers judged children's base pattern understanding in the first session and played subsequent games from the framework accordingly. Sessions were fluid and followed the interests and abilities of each child. Subsequently, not all children played all the games in all the modes.

Materials

The pattern games were devised from the Sounds of Intent framework for visuo-spatial pattern making (Ockelford et al., 2025). For each sub-level (i.e., 3a, 3b etc.) of the framework researchers developed a game with a fun and accessible name such as 'Base and Space' or 'Fruit Salad' to engage participants and practitioners. Each game could be played with objects (visuo-spatial domain), with sounds (auditory domain) or with objects and sounds together (both domains). The games progressed in complexity, covering Levels 3 and 4 of the framework. All the games were in the 'interactive' domain of the SoI framework. Musically, the patterns varied in complexity of rhythm and pitch. Visuo-spatial patterns varied in complexity of the type of object, features of objects, and the positioning of the objects. For each game, the adult presented a sequence of sounds or objects, for example, 'Base and Space' was three of the same sounds or objects repeated with an equal spacing between them. The child then copied the pattern (reproduced it). If the child led the game, they were defined as 'producing' the pattern. If the child could create the same pattern with different objects or sounds, then they were deemed to have 'applied' the pattern.

Figure 1
Pattern Games



The pattern games were derived from the Taxonomy of Visuo-Spatial Pattern Making (Ockelford et al., 2025)

Analysis

Data were gathered for 80 sessions of pattern-game playing. Video analysis was completed by a group of researchers familiar with the Sounds of Intent three-level 'E-A-X' summative assessment scheme. A scheme was developed to account for the activities children were undertaking. The revised scheme classified children's pattern making across three categories: reproducing, producing, and applying patterns and rated them from 1 to 3 based on the accuracy of the pattern to the game requirements. For example, if a participant had copied a pattern with total accuracy, they would score R3. If a participant had attempted to apply a pattern to a different set of objects with some accuracy, they would score A2. Researchers independently coded the 80 sessions. Interrater reliability was strong ($k = 0.83$) (Warrens, 2015). The ratings were then converted to a quantitative score to examine children's progress.

Initial Results

Qualitative analysis of children's participation in the pattern games revealed that participants were able to reproduce, produce and apply patterns in both the auditory and visuo-spatial domains and when the domains were combined. This was observed in simple to more complex pattern games. Participants demonstrated that they could transfer their understanding of the pattern structure between domains. For instance, children were observed recreating visuo-spatial patterns using sounds and *vice versa*. Some participants were able to apply their understanding of the pattern structure into another domain without being prompted; for example, verbalising the colours of objects in a visuo-spatial pattern or playing a visuo-spatial pattern structure on a musical instrument such as a tambourine. High-performing participants were also able to extend their pattern structure across domains. One example is a participant who added an extra beat on the tambourine in his 'Trio' game pattern and then replicated this by adding an extra straw to the unit of repeat in his visuo-spatial 'Trio' pattern, unprompted. Quantitative analysis showed that most children (14 out of 20) scored more highly on the pattern games where the domains were combined than in either of the domains alone. A further five participants scored more highly with either sounds or objects than in the combined games, but more in these than in their weakest domain. This suggests that using both domains together could be more supportive of understanding repeating patterns in mathematics and music. This warrants further investigation as this could enhance pedagogical practice in these subjects.

Conclusions and implications

This exploratory study aimed to test a new theoretical model of pattern understanding in the auditory and visuo-spatial domains. Working with 20 children in a special school, the research team observed that the proposed framework did mostly map pattern understanding accurately between the auditory and visuo-spatial domains. Researchers observed mainly similarities in pattern understanding between the two domains. Participants were able to play the pattern games using sounds and objects or both sounds and objects together. Any errors in pattern making also occurred across the domains, suggesting that there was an equivalence in pattern structure in sound and visuo-spatial repeating patterns. Some children's progress in the games was limited by their lack of cognition of the 'gap' between repeating units of a pattern, apparent in both domains. This aspect requires further investigation to unpick the drivers and consequences of their lack of awareness in developing their understanding of patterns. The proposed framework and pattern games were received positively by children and practitioners and present a promising tool for extending pattern-making skills, particularly for children with additional barriers to learning. The next step is to develop a larger-scale, quasi-experimental study to further explore the relevance and effectiveness of the taxonomy of repeating patterns in supporting children's mathematics and musical development.

Acknowledgements

The research team would like to thank the senior leaders and staff at West Hill School, Leatherhead, for their support during this project.

References

Borthwick, A., Gifford, S. & Thouless, H. (2021) *The power of pattern: Patterning in the early years* Derby: Association of Teachers of Mathematics

Fyfe, E. R., Rittle-Johnson, B. & McNeil, N. M. (2015). Easy as ABCABD: Abstract Language Facilitates Performance on a Concrete patterning Task. *Child Development,* 86(3), 927 – 935

Kidd, J. K., Pasnak, R., Gadzichowski, K. M., Gallington, D. A., McKnight, P., Boyer, C. E., & Carlson, A. (2014). Instructing first-grade children on patterning improves reading and mathematics. *Early Education & Development,* 25(1), 134-151.

Larkin, K., Resnick, I., & Lowrie, T. (2024). Preschool children's repeating patterning skills: Evidence of their capability from a large scale, naturalistic, Australia wide study. *Mathematical Thinking and Learning*, 26(2), 127-142.

Lüken et al.(2020). 'Patterning as a mathematical activity: an analysis of young children's strategies when working with repeating pattern'. In: Carlsen, M., Erfjord, I., Hundeland, P.S. (Ed.s) *Mathematics Education in the Early Years: Results from the POEM4 Conference, 2018* (e-book) Switzerland: Springer Nature, 79-92. https://doi.org/10.1007/978-3-030-34776-5

Mulligan J., Mitchelmore M. (2009). Awareness of pattern and structure in early mathematical development. M*athematics Education Research Journal*, 21(2), 33–49. https://doi-org.surrey.idm.oclc.org/10.1007/BF03217544

Mulligan J., Mitchelmore M. C. (2013). Early awareness of mathematical pattern and structure. In English L. D., Mulligan J. T. (Eds.), *Reconceptualizing early mathematics learning* (pp. 29–45). Springer Nature.

Ockelford, A. (2015). The Sounds of Intent Project: Modelling musical development in children with learning difficulties. *Tizard Learning Disability Review*, 20(4), 179-194.

Ockelford, A., McCarthy, S., Gifford, S., Thouless, H., Kirk, S., & Thorpe, M. (2025). Towards a New Taxonomy of Pattern-Making in the Visuo-Spatial Domain in Early Childhood Based on Zygonic Theory and the Sounds of Intent Framework of Musical Development. *Music & Science*, 8, 20592043241305939.

Papic, M. M., Mulligan, J. T., & Mitchelmore, M. C. (2011). Assessing the development of preschoolers' mathematical patterning. *Journal for Research in Mathematics Education*, 42(3), 237-268.

Rittle-Johnson, B., Fyfe, E. R., Hofer, K. G., & Farran, D. C. (2017). Early math trajectories: Low-income children's mathematics knowledge from ages 4 to 11. *Child Development*, 88(5), 1727-1742.

Warren, E. (2005). Young Children's Ability to Generalise the Pattern Rule for Growing Patterns. *International Group for the Psychology of Mathematics Education*, 4, 305-312.

Warrens, M. J. (2015). Five ways to look at Cohen's kappa. *Journal of Psychology & Psychotherapy*, 5.