COGNITIVE SCIENCE APPROACHES IN THE CLASSROOM: A REVIEW OF THE EVIDENCE Cognitive science approaches in the classroom: a review of the evidence 2 This report summarises the contents of a longer systematic, evidence and practice review produced by a team from the University of Birmingham, England. We would like to thank all those who have contributed or provided advice in the production of the original review, and this teacher facing summary. Review team: Dr Thomas Perry, Dr Rosanna Lea, Clara Rübner Jørgensen (University of Birmingham), Prof. Philippa Cordingley (CUREE), Prof. Kimron Shapiro, Prof. Deborah Youdell (University of Birmingham). Additional support in writing this practitioner summary was provided by Jonathan Kay and Harry Madgwick (EEF). We would also like to thank the advisory panel who assisted the review team. Advisory panel: Dr Robin Bevan, Prof. Robert Coe, Dr Iroise Dumontheil, Dr Amy Fancourt, Dr Davinia Fernández-Espejo, Julia Harrington, Dr Niki Kaiser, Mark Stow, Prof. Hillevi Lenz Taguchi, Sonia Thompson, Prof. Sam Twiselton. About the Education Endowment Foundation The Education Endowment Foundation (EEF) is an independent charity supporting teachers and school leaders to use evidence of what works—and what doesn't—to improve educational outcomes, especially for disadvantaged children and young people. July 2021 Cognitive science approaches in the classroom: a review of the evidence 3 CONTENTS Foreword 3 Executive summary 4 Introduction 9 Different aspects of cognitive science and how they might be applied in the classroom 1 Spaced learning 15 2 Interleaving 19 3 Retrieval practice 21 4 Managing cognitive load 25 5 Working with schemas 31 6 Multimedia learning (including dual coding) 37 7 Embodied learning 42 Overarching findings 46 Glossary of terms 49 Cognitive science approaches in the classroom: a review of the evidence 4 One of the most important questions educational research can ask is how children learn. If we know how they process and retain information, we can adapt our approach to teaching accordingly and in turn, increase effectiveness. At the Education Endowment Foundation (EEF), our mission is to ensure that pupils, regardless of their background, are able to reach the full extent of their potential. Developing our understanding of memory and how to balance cognitive load, and then applying this understanding in the classroom, has the potential to improve outcomes for all children. This is why the EEF has produced this evidence summary on the impact of cognitive science approaches when applied in the classroom. Our hope is that by providing a transparent summary of the evidence that shows both the strengths and weaknesses of the current research, we can support schools as they consider how principles might make a difference to their pupils. As with much evidence, the key message here is the importance of nuance. Principles from cognitive science are neither myths to be discounted, nor silver bullets that directly translate into accelerated progress. There are still many questions to be answered on how principles from cognitive science can be applied in order to make the biggest positive difference for all young people. We need to know more about the effectiveness of approaches when used in different subjects, phases and their impact on disadvantaged pupils. The future research work of the EEF can help fill some of these gaps. We will continue to work to generate and accurately summarise evidence on the approaches that can make a difference for all pupils, particularly the most disadvantaged. Professor Becky Francis Chief Executive FOREWORD Cognitive science approaches in the classroom: a review of the evidence 5 EXECUTIVE SUMMARY The role of cognitive science in the classroom Cognitive science is being used increasingly to inform interventions, practice, and policy in education. Of particular interest to education has been research into motivation and reward, working memory and long-term memory, and cognitive load. Findings from two areas of cognitive science have been especially influential: cognitive psychology, which is underpinned by interpretive, behavioural, and observational methods, and cognitive neuroscience, which is underpinned by brain imaging technologies. Many theories of effective learning have been derived from these research areas, including: • spaced learning—

distributing learning and retrieval opportunities over a longer period of time rather than concentrating them in 'massed' practice; • interleaving—switching between different types of problem or different ideas within the same lesson or study session; • retrieval practice—using a variety of strategies to recall information from memory, for example flash cards, practice tests or quizzing, or mind-mapping; • strategies to manage cognitive load—focusing students on key information without overloading them, for example, by breaking down or 'chunking' subject content or using worked examples, exemplars, or 'scaffolds'; and • dual coding—using both verbal and non-verbal information (such as words and pictures) to teach concepts; dual coding forms one part of a wider theory known as the cognitive theory of multimedia learning (CTML). These theories are already having an impact on teaching policy and practice in England. For example, the evidence review underpinning the Ofsted inspection framework draws significantly on approaches inspired by cognitive science: 'It is, for example, becoming increasingly clear that using spaced or distributed practice, where knowledge is rehearsed for short periods over a longer period of time, is more effective than socalled massed practice.' Our survey of teachers found that over 85% of respondents said that cognitive science strategies were central to their own approach to teaching. In addition, all early career teachers will be taught about memory and cognitive load as part of the Early Career Framework. Cognitive science approaches in the classroom: a review of the evidence 6 The approach taken in this evidence review Many recent reviews have examined and explained the principles of cognitive science and how these principles might be applied in the classroom. Much of this evidence comes from studies in the psychology laboratory or from researcher-led trials. This evidence summary looks at the impact of these principles when they have been applied in the classroom. All of the studies included and summarised have taken place within schools. In other words, this summary is focused on applied cognitive science. Applied research reveals many problems not encountered in laboratory or tightly controlled conditions. Classrooms are 'messy' and complex, with teachers needing to balance a wide range of considerations, both practical and pedagogical. Findings from the lab do not always translate into effective teaching and learning in the classroom and they may not apply across different pupil age groups, subject areas, and school contexts. With any educational approach, implementation in the classroom and variation in how the theories are translated can have a massive influence over whether the expected impacts are achieved. By examining studies taking place in the classroom it is possible to build a picture of whether cognitive science principles work in practice, how they might be applied most effectively, and begin to understand the barriers and misapplications that mean that they sometimes have a weaker than desirable, or even negative, impact. This report summarises the key findings and implications from a substantial evidence review; the full report can be found here. The review comprises a theoretical review of cognitive science, a practice review on how approaches have been applied and received in English classrooms, and a systematic review of studies that have rigorously tested the impact of approaches. 'Basic' cognitive science—seeks fundamental understanding of learning, memory, and the brain. It typically uses experiments in controlled conditions to establish knowledge that is likely to have wide applicability. 'Applied' cognitive science—seeks to apply knowledge from basic cognitive science to solve practical problems. Here we are focused on cognitive science that is applied in the classroom that aims to improve learning of children and young people aged 3–18. Key Terms Cognitive science approaches in the classroom: a review of the evidence 7 Main findings Cognitive science principles of learning can have a real impact on rates of learning in the classroom. There is value in teachers having working knowledge of cognitive science principles. Theories from basic cognitive science imply principles for effective teaching and learning. Principles include 'spacing' learning out over time, providing worked examples or 'scaffolds' to support problem-solving, and presenting information both verbally and visually. The applied evidence summarised does provide support for many of the principles of learning implied by basic cognitive science, albeit in specific contexts. For most of the strategies included in this review, cognitive science principles were significant factors affecting rates of learning and retention of information in the classroom. Most of the results could be explained using theories from basic cognitive science and practice-facing versions of these. The evidence for the application of cognitive science principles in everyday classroom conditions (applied cognitive science) is limited, with uncertainties and gaps about the applicability of specific principles across subjects and age ranges. Applied cognitive science is, so far, more limited and provides a less positive, and more complex, picture than the basic science. For many of the strategies that have been tested in practice, the evidence was restricted to particular age groups, subject areas, or learning outcomes. Applications of cognitive science outside of these, while plausible given the basic science, are yet to be tested and found effective in the classroom. Even approaches with indicative evidence of promise like retrieval practice, spaced practice, and the use of worked examples are, as yet, only supported by a few studies that examine their impact in everyday classroom conditions—delivered by teachers over long periods of time. • With some approaches—like interleaving—there are studies with promising results but they have almost exclusively been tested in one subject area (mathematics). More generally, there are serious gaps and limitations in the age ranges, subjects, and learning outcomes studied for most of the strategies we reviewed. These gaps make the extent to which strategies apply across all age ranges and subject areas unclear. • Some approaches—like combining verbal explanations with graphical representations, also known as 'dual coding'—are possible to implement poorly. While some studies show positive impacts on pupil outcomes, there are also multiple studies showing null or negative findings. It is important to note that a lack of evidence is not the same as evidence that an approach is not successful. We should be cautious about concluding that because a principle is found to be ineffective in the lab or in one classroom context that it cannot be deployed effectively elsewhere. Cognitive science approaches in the classroom: a review of the evidence 8 Applying the principles of cognitive science is harder than knowing the principles and one does not necessarily follow from the other. Principles do not determine specific teaching and learning strategies or approaches to implementation. Considering how cognitive science principles are implemented in the classroom is critical. Some accounts of cognitive science principles prescribe practice based on the strength of the underlying theory and claim that the behavioural or neuroscientific evidence justifies application across subjects and ages (see previous). These are inevitably interpretations of how principles apply in the classroom. The fact that many strategies have not been consistently tested in everyday classroom settings means that it is particularly important to think carefully about if, and in what circumstances, they are applicable and how we could implement them in a way that has a positive impact on pupil outcomes: • Teachers looking to apply cognitive science principles in the classroom will need to consider how, and in what conditions, approaches informed by cognitive science might improve learning. The effectiveness of strategies is likely to depend on factors including the age of learners, learner prior knowledge, the nature of the subject and learning outcomes, and whether the approach is practically feasible—and make sure that they are successfully enacted. • Special care should be taken to make sure that principles are successfully implemented, avoiding 'lethal mutations' when a practice becomes disconnected from the theory. For example, teachers have reported that dual coding sometimes means that irrelevant illustrations are added to presentations, which may be a distraction rather than a way of developing schemas and optimising cognitive load. Schools should consider how—and in which contexts—to give teachers high quality CPD around cognitive science approaches, and enough time to test and incorporate approaches appropriately into their practice and for their subject and learners. Many teachers report that their main form of engagement with cognitive science is independent study. Principles of cognitive science interact and should not be considered in isolation from each other, or without taking into account wider practical and pedagogical considerations. There are clear links between the different approaches summarised within this review. In particular there are relationships between: • approaches that consider how to optimise retrieval of information from the long-term memory: spaced learning, interleaving, and retrieval practice; • approaches that consider the balance between didactic instruction and the pupil's role in learning: strategies for working with schemas, learnerled strategies within managing cognitive load, cognitive theory of multimedia learning, and embodied learning. Little research has effectively explored how distinct and similar strategies interact but it is clear that careful consideration is required to optimise mergers between approaches, for example, combining retrieval approaches with appropriate spacing. The survey of teachers, review of the underpinning science, and the applied evidence in areas such as embodied learning suggest that social, emotional and physical aspects to cognition are also important for teachers to consider. Cognitive science approaches in the classroom: a review of the evidence 9 INTRODUCTION What is cognitive science? Cognitive science is gaining increasing influence in education and many existing and developing educational approaches are described as 'inspired by cognitive science'. Many of these approaches have been long practiced or described as effective pedagogy, without any reference to cognitive science—for example, quizzing pupils on topics has been common even without this being thought of as a form of 'retrieval practice'. The principles of cognitive science are typically derived from two areas of research: • cognitive psychology—which is underpinned by interpretive, behavioural, and observational methods and in cognitive science has commonly derived principles from 'lab studies' in which different ways of influencing learning are tested and their results observed for individuals or small groups; and • cognitive neuroscience—which is underpinned by brain imaging technologies such as functional imaging (fMRI) and tests principles by examining the physiological response of the brain rather than the behavioural response of participants in experiments. One of the appealing prospects for both these approaches is that they might reveal something fundamental about learning, memory, and the brain. These understandings might be applicable across many contexts—to the extent to which humans share the same basic processes of learning and memory. Cognitive science approaches in the classroom: a review of the evidence 10 Important concepts and theories from cognitive science Perhaps the most important concept used from cognitive science concerns the processes by which all of us commit information to our memories. Memory can be separated out into sensory, working, and long-term memory. The process of going from seeing or hearing something to storing it in your longterm memory goes through several stages: • an input (for example, hearing a teacher explain multiplication tables), the vast majority of which is forgotten (for example, the background noise, the clothes that the teacher is wearing, what is on the wall behind the teacher); • a fraction of the input enters the working memory (for example, 2 x 2 = 4); and • through attention and rehearsal, the information moves from the working memory to the longterm memory. Many of the strategies derived from cognitive science focus on the crucial interactions between working memory and long-term memory and the important observation from cognitive science that our working memories have limited capacity. Some strategies (reviewed in our section on managing cognitive load and also informing other areas such as dual coding and embodied learning) focus on the best ways of ensuring that the use of the working memory is optimised to focus on relevant learning content rather than distractions. Other strategies are more focused on practicing the process of retrieving information from the long-term memory (such as spaced learning, retrieval practice, and interleaving). Rehearsal Rehearsal Input (stimuli) Sensory memory Working memory Forgetting Long term memory Attention Retrieval Encoding 1. Learning requires information to be committed to long-term memory. 2. Information is processed through the working memory. 3. The working memory has limited capacity and can be overloaded. Key principles to remember Cognitive science approaches in the classroom: a review of the evidence 11 Theory and practice divide While discovering fundamental principles of memory or learning might be appealing precisely because they might be applicable to all pupils, the process of understanding whether a principle that works in the lab is also effective in the classroom—and the job of actually applying these principles—is far from straightforward. Understanding cognitive science and using lessons from cognitive science to improve teaching and learning are not the same thing. Applying a theory in the classroom requires understanding whether something found in artificial conditions applies in specific, realistic conditions. It also requires overcoming many barriers that can prevent positive results even if the theory itself is sound. Rather than reviewing the theories that underpin cognitive science, this review examines instances where these theories have been applied in real classrooms and how they have impacted the results of pupils. 1. Misunderstanding an important part of the theory Mr Bell has heard a lot about dual coding— and that learning can be enhanced by pictorial representations alongside information. He fills all of his classroom slides with quirky illustrations that he hopes will make the learning memorable. Unfortunately, the images end up distracting his pupils and increasing their cognitive load meaning that they struggle to remember the content itself. 2. Failing to equip teachers to deliver the theory The Ofsted inspection framework prompts senior leadership to book some staff training on cognitive science. While the twilight session covers some of the principles behind spaced learning, staff are given no guidance on how to apply the approach. Senior leadership are not keen on any changes to school timetabling or the curriculum. No follow-up training is provided. 3. Failing to target the theory effectively Mrs Rushby has heard that worked examples with incorrect information in them has been shown to be an effective way of teaching information while managing cognitive load. When she uses the examples in her Year 7 maths class, most pupils struggle to identify any errors—many of them end up reinforcing rather than addressing misconceptions and only a few of the top attaining pupils in the class respond positively to the task. 4. Or… the theory doesn't actually work in schools? It might be that none or all of these factors are in play and that the theory itself has only ever been shown to work in highly controlled laboratory settings or for particular age ranges or subject areas. In medicine, treatments are often shown to reduce in efficacy as they move from lab-testing, to larger trials, to the real world. Lost in translation: how to lose the power of a good theory Cognitive science approaches in the classroom: a review of the evidence 12 How close to classroom practice? One of the challenges when using evidence is understanding how close the research is to everyday classroom practice. We have consciously excluded any 'lab studies' from this review. If an approach has been tested outside of a classroom setting, it has not be included. This still, however, leaves large scope for studies that take place in real classrooms but that are further away from the reality of everyday teaching. For example: • studies where the activity takes place in the classroom but the actual activities are delivered by a researcher rather than a teacher; • studies where a teacher delivers an activity but their teaching is scripted and/or the researcher is present and providing more assistance than would be possible in a usual classroom setting; • approaches that focus on very particular or narrow learning objectives or are tested for a very short period of time; • studies where the outcome measured is very close to the intervention—for example, testing knowledge of specific words taught by a vocabulary intervention; • studies that only look at a very small group of pupils in one particular school that may not be representative of all pupils; or • studies that include only a small number of teachers, or the teachers are cognitive science experts and enthusiasts. It is important to note that any of these studies might contain useful information on whether a cognitive science approach might be successful; for example, knowing whether the vocabulary intervention does actually teach the words intended is useful. But these studies do not necessarily mean that the approach will translate to similar results in every classroom. For example, if the approach is delivered by a researcher this conveniently sidesteps any issues with how easy it might be to train teachers to deliver the approach across a school. Most scientific studies are designed to isolate and test the effect of a single principle or strategy. This is also true of even most applied studies, where researchers are usually focused on how a specific change in the teaching and learning can affect the learner outcomes. Researchers tend to use experiments across many schools to 'control for' or 'average out' all the myriad factors that affect teaching and learning. Teachers, on the other hand, must necessarily consider a wide range of practical and pedagogical factors. These factors interact in complex ways and change momentto-moment in complex classroom environments. During the review, researchers examined the literature to identify possible factors that might influence whether cognitive science principles work and are successfully implemented in a particular teaching and learning context. The table below summarises a range of factors relating to teachers, learners, classrooms, and the curriculum that might influence the impact of cognitive science strategies. Possible factors affecting the impact of cognitive science techniques Teachers, teaching Pupil individual factors (potentially different for each student) • Extent of teacher professional development and learning for the cognitive science technique • Teacher general pedagogical and subject-specific knowledge and skills • Level of teacher experience • Teacher motivation and enthusiasm for the cognitive science technique • Extent to which technique replaces or improves teacher's existing practice • (Many of the pupil factors, right, also apply to teachers) • Prior level of knowledge, in general and for the topic being learnt (and extent to which the teacher takes this into account) • Working memory capacity • Nutrition and hydration • Alertness/activity level • Mood and emotional state • General and learning-specific motivation • Personality and temperament • Special educational needs, difficulties, or disabilities • Learning behaviours and strategies • Age and maturity Classroom/social environment Activity, topic, and subject • Relations in the classroom (teacher-pupil, pupil-pupil) • Culture of participation • Emotional environment • Disruption, noise, or distraction • Decoration and information • Access to learning resources • Subject or curriculum area (e.g., general differences in the nature of subject content and pedagogy) • Nature of specific learning content (e.g., complexity/ element interactivity, novelty, connection with other learning) • Nature of specific learning activity (e.g., student-led, length, structure, resources) This is not an exhaustive list. It is also important to note that whether or not a specific strategy (for example, dual coding) works in practice may be influenced by any one of these factors, and more likely most of them. As we describe above, even applied studies rarely study much of this variation. The best applied studies provide an authentic test of a strategy in realistic conditions; they are designed to take these into account and make sense of why and in what circumstances something works as well as providing a strong test of whether or not it does. Unfortunately, at present, well-designed applied studies are rare. This evidence summary aims to be transparent about these challenges. Each section describes the evidence behind an approach and makes clear where these limitations apply. As with any evidence base, it is important to remember that lack of evidence or lack of quality evidence is not the same as evidence of no impact. It is also possible, despite the complexity of teaching and learning, to identify guiding principles and 'best bets' for action. The evidence around cognitive science is evolving quickly and areas that rely on lab-based studies or studies with researcher delivery today may be tested in realistic classroom environments tomorrow. This evidence summary This evidence summary is based on a longer review, which can be found here. The review document contains full details on the methodology of the review, which combines a theoretical review with a practice review and a systematic review, from which most of the evidence summaries below are drawn. This summary document is split into seven sections based on different aspects of cognitive science and ways they might be applied in the classroom. 1. Spaced learning 2. Interleaving 3. Retrieval practice 4. Managing cognitive load 5. Working with schemas 6. Multimedia learning (including dual coding) 7. Embodied learning Where these sections contain multiple approaches— for example, spacing across lessons and within lessons—there are separate sections summarising the evidence for each approach in more detail. The final sections of the evidence summary discuss mixed approaches that combine the strategies listed above, and a discussion on some overarching findings from the review with regards to the promise of approaches based on cognitive science in general. Cognitive science approaches in the classroom: a review of the evidence 15 Key things to consider • There is evidence to suggest that spacing teaching and learning of material over time and between intervals of unrelated content has the potential to improve pupil learning. • More studies have examined the impact of spacing content across days and lessons than within individual lessons. Regarding the former, the evidence suggests a small positive impact across pupil ages and subject areas. • A very limited number of studies examined spacing within lessons. These suggest promise but there is too little evidence to have confidence in this result. • Implementing a spaced approach across days or lessons may present significant challenges, requiring careful integration with existing curriculum planning. Spacing within the confines of the existing curriculum and timetable may therefore be a more feasible application for classroom teachers to implement themselves. What is the theory? Spaced practice (also referred to as spaced learning, distributed practice, distributed learning, and the spacing effect) applies the principle that material is more easily learnt when broken apart by intervals of time. Spaced practice is often contrasted with 'massed' or 'clustered' practice, whereby material is covered within a single lesson or a linear and sequential succession of learning. While spaced practice is thought to make learning more challenging for pupils as it prohibits information being held in the working memory, it may be able to increase the likelihood of knowledge being embedded in pupils' long-term memory. In having pupils revisit key concepts, ideas, or skills over longer periods of time in which content is almost forgotten, teachers may be able to improve learning retention. 1. SPACED LEARNING Cognitive science approaches in the classroom: a review of the evidence 16 How do teachers use spaced practice in the classroom? When adopting a spaced practice approach, teachers will fill spaces of time with learning content or activities that do not relate to the concept, idea, or skill being spaced. Where material is learnt across more than one lesson in a subject, spacing can be a natural consequence of the timetable with lessons in different subjects occurring in between the spaced learning. Within-lesson spacing is built into lessons plans and activity sequencing. This is similar to the practice of interleaving, which also involves the use of spacing in a sequence of learning. This said, where spaced practice uses intervals consisting of unrelated content to encourage pupils to temporarily forget information before recalling their long-term memory, interleaving is more likely to be used to systematically switch between concepts and learning that are interrelated, encouraging learners to make distinctions and connections between similar yet slightly different learning material. Some teachers also report using spaced practice as a form of retrieval practice, testing pupils' knowledge of previously taught content. This approach to spacing may be used as a form of revision as teachers utilise strategies such as multiple choices questions, recall grids, quizzes, or homework tasks to help pupils identify gaps in understanding and recall information from long-term memory. Such practices may be embedded into teachers' lesson planning, meaning that a portion of every lesson or time of day is dedicated to revisiting content. Teachers might apply spacing principles to many aspects of teaching and learning. For example, spacing could be applied to instruction, practise, or assessment. This review identified two forms of spaced practice that have been evaluated through research: 1. spacing across days or lessons; and 2. spacing within lessons. Cognitive science approaches in the classroom: a review of the evidence 17 What is it? Spacing across days or lessons might see pupils revisit a specific concept, idea, or topic several times over the course of one week, or once or twice a week for many weeks. The alternative to spacing is usually referred to as 'blocked' or 'massed' practice, where content is studied in a single learning session. Spacing is frequently combined with retrieval practice, often known as spaced retrieval practice. What does the evidence say? There are a significant number of studies showing that spacing across days and lessons can have a small positive impact on learning outcomes. There are, however, some important limitations to the evidence. Substantial variation is found between study results with a significant number showing either no impact or a negative effect. Also, while spaced practice principles were tested in real classrooms within these studies, the approaches were rarely delivered by classroom teachers. Those that were designed and had the lesson materials provided by researchers. Implementation Planning and implementing spacing across days and lessons takes careful curriculum planning that may present challenges. A pressure to cover lots of learning material within limited timeframes can lead to teachers feeling that there is little opportunity to reintroduce previously taught content. Curricula are also often organised in blocks to accord with school timetables, school textbooks, and prescribed by school leadership teams: this means that applying a spaced approach across days or lessons can sometimes be an organisational challenge beyond the remit of individual classroom teachers. The evidence also highlights the value of considering how spacing can be informed and enhanced by classroom feedback and assessment. Teachers can use assessment to decide how often learning material should be revisited and the best time to increase the challenge or move on. An example approach After teaching her class a new word, Ms Begum always makes a note of when she will revisit the word in other lessons throughout the coming week. Whether asking pupils to recall the definition of the word or designing tasks in which they must apply it in a new context, Ms Begum always ensures the word is returned to as this can help to embed it in pupils' long-term memory. The review found 18 studies of spacing across days and lessons. • The ages of children in the studies ranged from 6 to 17. • Studies covered several different subject areas including reading and vocabulary, science, and maths. • In only six of the studies pupils were taught by teachers rather than researchers or computer packages. For these six, the training, guidance, or materials were provided by researchers. What is the evidence based on? Strategy 1: Spacing across days and lessons Cognitive science approaches in the classroom: a review of the evidence 18 What is it? Spacing within lessons involves the same content being repeated many times within one individual lesson, broken up by short intervals of time (often ten minutes long) in which unrelated content is taught. Although it may be common for key concepts, ideas, or definitions to be reused or revisited within single lessons, spacing within lessons differs from 'massed' or 'clustered' practice through the teacher's choice to fill spacing intervals with unrelated learning or activities. What does the evidence say? The two studies on the impact of within-lesson spaced practice suggest it may have a positive effect on learning when compared with massed practice. There are, however, significant limitations to the evidence. The range in available studies is very small, both in scale of research and authorship. Results are also varied within available studies. This means that the positive finding is merely indicative of potential rather than evidence of effectiveness. Implementation Fewer teachers report using spacing within lessons, suggesting spacing is more regularly considered as a method of revisiting content throughout a longer timescale. However, given that some teachers seeking to apply spacing across days or lessons highlight the challenge of spacing content within rigidly planned and time pressured curricula, spacing within lessons may be a more feasible method of drawing on the benefits of spacing without making major adjustments to the organisation of the timetable or curriculum. This said, given that spacing is thought to increase the difficulty of learning for pupils by challenging then to revisit almost-forgotten information, frequent use of spacing within lessons could detrimentally affect some pupils' motivation. An example approach In his Year 4 class Mr Coales regularly breaks up the teaching of key concepts in science with other activities that distract pupils from what they have been learning. For example, after teaching his class about the different components of flowering plants (roots, stem or trunk, leaves, and flowers), Mr Coales supports his class to revise their previous topic on forces for ten minutes. After this, the pupils revise and apply previous learning on plant parts by labelling a diagram. The review found two studies of spacing within lessons. • The ages of children ranged from 4 to 11 in one study and 13 to 15 in the second study. • The study with 4- to 11-year-olds involved the teaching of history and geography, whereas the older study only looked at the teaching of biology. Both studies were conducted in a single school in England meaning there is insufficient variation in the population to test for generalisable impact. What is the evidence based on? Strategy 2: Spacing within lessons Cognitive science approaches in the classroom: a review of the evidence 19 Key things to consider • Evidence suggests interleaving may be an effective strategy for developing upper primary to early secondary (age 8–14) pupils' ability to select appropriate methods for solving mathematical problems. • While plausible, there is little or no applied evidence of interleaving being applied to topics outside of mathematics or for younger or older pupils. • The rationale for interleaving is that it may support learners to discriminate between two similar concepts or methods. Teachers may be able to increase the level of challenge presented through interleaved tasks by introducing more similar items of learning. What is the theory? Interleaving involves sequencing tasks so that learning material is interspersed with slightly (but not completely) different content or activities, as opposed to undertaking tasks through a blocked and consecutive approach. While similar to spaced practice, interleaving involves sequencing tasks or learning content that share some likeness whereas a spaced practice approach uses intervals that are filled with unrelated activities. By repeatedly reintroducing pupils to similar but slightly different content or activities, interleaving is thought to assist the drawing of comparisons between related but discrete items of learning. When completing a series of related activities, pupils may refine their ability to select the more appropriate method for answering certain types of questions. Interleaving therefore draws on the use of spaced intervals thought to assist long-term memory retention, as seen in spaced practice, as well as the benefits of making comparisons to develop more complex schemas, as highlighted in working with schemas. How do teachers use interleaving in the classroom? The evidence we reviewed on interleaving in the classroom has, with the exception of only one study, examined its use in Key Stage 2 or Key Stage 3 mathematics to develop pupils' ability to select appropriate strategies to solve problems. In the wider literature and teacher accounts, many believe that the benefits of interleaving extend beyond strategy choice in maths. Some other topics of application include students learning different artists' styles, grammar in the language curriculum, physics equation practice, preparation for MFL oral exams (where 'students have to be ready to talk at length about a large number of topics'), maths teaching, and primary languages. 2. INTERLEAVING An example approach When teaching fractions to his class, Mr Hodiak likes to test his pupils as this can help to identify areas for improvement and gaps in understanding. To ensure that his pupils have to think hard about how to solve fractions, Mr Hodiak interleaves problems with different numerators and denominators. Mr Hodiak thinks that by requiring his pupils to identify the subtle differences between these varied types of problems, he can embed learning and improve pupils' ability to select appropriate strategies when solving fractions in the future. Cognitive science approaches in the classroom: a review of the evidence 20 What has been researched? The research focused mostly on interleaving mathematical problems that pupils independently solve through selecting appropriate solutions. Problems could be presented to pupils through computer software, workbooks, or via a teacher provided with a script, or researchers. What does the evidence say? When compared to a blocked or sequential approach, there is moderate positive evidence that interleaving can better support Key Stage 2 and Key Stage 3 pupils to select appropriate solutions when solving mathematical problems. There are, however, some important limitations to the evidence: 11 out of 12 studies were in maths, and within these many focused on interleaving tasks that required learners to select a solution strategy before implementing it. While the approach may be transferable across tasks or subjects, we have no evidence to support this. The evidence is also based on a set of highly scripted, research-controlled studies that use mostly workbooks or computer software for delivery, so we cannot be sure how applicable these findings are to teacher-directed interleaving. Implementation There is some evidence to suggest that interleaving is well suited to problem-solving tasks where pupils select strategies to generate solutions. It is possible that the more similar interleaved items are, the harder pupils must think to differentiate between them, increasing the level of challenge. As pupils become more able to discern the differences of tasks and select appropriate strategies, it may be appropriate to interleave more similar problems as this should require more nuanced discrimination. Some teachers express concern over confusing students through interleaving, particularly those with lower attainment who may take comfort in compartmentalising their knowledge. It is possible that some pupils need to have strong foundational knowledge of learning content prior to making effective comparisons between interleaved tasks or concepts, particularly if this content was originally covered in a different unit of work. The review found 12 studies of interleaving. • The ages of children in the studied ranged from 8 to 14. • Studies covered mostly maths topics such as fractions, algebra, subtraction, and geometry. One study was in physical education. • In five of the 12 studies pupils were taught by teachers or with some (mostly scripted) teacher What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 21 3. RETRIEVAL PRACTICE Key things to consider • Short, low-stakes tests or 'quizzes' in various formats can be a cheap, easy-to-implement way of recapping material that might strengthen pupils' long-term ability to remember key concepts or information. • Planning test difficulty is particularly important— pupils should be able to retrieve at least some of the content they are tested on. • Quizzing or low-stakes testing may also reveal misconceptions. How will you ensure that where these emerge pupils are supported to overcome them? What is the theory? Retrieval practice describes the process of recalling information from memory with little or minimal prompting. Low stakes tests (such as individual questions or quizzes) are often used as methods of retrieval practice as these require pupils to think hard about what information they have retained and can recall. When used in this way, tests can be a strategy for learning in addition to being an assessment of learning. The retrieval practice evidence base (both basic and applied) suggests that testing learning is often a better strategy for learning than restudying or recapping the same information. Cognitive science informs us that memory has a 'strength', referring both to how easily something can be recalled and how deeply information is embedded. When content is studied and recalled, both types of memory strength increase, meaning that information is more easily accessible and that this accessibility is more durable. It is thought that by testing for knowledge of previously learnt content, retrieval practice encourages pupils to strengthen their memory on key concepts or information. Also, the testing process makes pupils aware of weaknesses in their memory and gaps in their understanding, thereby supporting self-monitoring of learning that can lead to the development of strategies for improvement. How do teachers use retrieval practice in the classroom? The most common application of retrieval practice in the classroom is using low-stakes quizzes to encourage learners to retrieve information from their long-term memory. Retrieval practice is often contrasted with recapping material—where the teacher reminds pupils of previous learning rather than asking learners to recall it themselves. The low-stakes quizzing can take many forms including: • multiple choice questions; • short-answer fact questions; • short problem-solving; • true/false questions; • labelling diagrams; • image recognition; • recitation of quotes or definitions; and • list creation. Retrieval practice might be combined with other approaches—for example, providing targeted feedback on the outcomes of the low-stakes quizzes. An example approach At the beginning of German class, Mrs Key asks the class to think back to their learning from the previous week and to list as many of the German words for animals as they can on a sheet in front of them. Cognitive science approaches in the classroom: a review of the evidence 22 What has been researched? The research summarised here examines any activity that requires students to recall information from memory rather than recapping, revising, or restudying the information. This can include partial recall of information supported by hints, cues, scaffolds, or other contextual information. A common way of achieving this in a classroom is through low-stakes quizzes, questions, and tests. What does the evidence say? When compared to no recap activity at all, the evidence for using quizzes is moderate and generally positive. Most studies that compare quizzing to forms of re-study or recap have a positive impact—though there are high levels of variation in the evidence and some negative results. One of the weaknesses of the evidence is that many of the approaches are designed and delivered by researchers rather than classroom teachers. There are examples of teacher-delivered quizzing having a positive impact but given the lack of studies, a firm conclusion is not possible. There are also questions about whether retrieval practice is as effective for more complex or subtle learning beyond rote factual recall. Despite these limitations, the positive impact of the retrieval studies, the good theoretical grounding of the practice, and the low cost of implementing lowstakes testing and quizzing generally mean that it is a promising approach that teachers should consider. Implementation Teachers have identified numerous ways that retrieval practice can be implemented and very few barriers to implementation were identified. Practices identified by teachers included: • use of knowledge organisers to rehearse learning points; • retrieval grids; • labelling diagrams with gradual reduction of information; and • true or false, multiple choice, cloze procedure, and finish the sentence. At present, the evidence is uncertain about which activity formats are most effective and whether retrieval practice can help students learn 'higherorder' or more subtle learning content beyond factual recall. There are, however, a number of factors that teachers should consider when implementing retrieval practice—particularly around whether additional support is required for pupils that struggle. When one provides a test to a group of students, they will—to varying proportions: • successfully retrieve some answers; • be unable to retrieve others; and • erroneously retrieve some answers (for example, misconceptions). Cognitive science approaches in the classroom: a review of the evidence 23 A key consideration when implementing retrieval approaches should be how to determine optimal task difficulty. If pupils are unable to retrieve information successfully then this is unlikely to increase memory strength, however, the evidence is currently uncertain about optimal level of challenge. It should be noted that quizzing has other potential benefits beyond encouraging pupils to retrieve information. For example, testing might identify gaps in knowledge and where pupils erroneously retrieve wrong answers, feedback might be used to support learning and help pupils overcome misconceptions. An interesting challenge is how to combine retrieval practice with spaced learning. Spacing lessons might make pupils less able to retrieve information. If teachers are implementing both approaches together, they could carefully monitor whether the approaches are additive and check that spacing does not reduce the ability of pupils to retrieve information successfully. Spaced retrieval can also potentially answer questions about which learning content to prioritise in a crowded curriculum.

Moreover, revisiting previously-taught content as part of retrieval practice—while it is likely to be preferable to restudying or reteaching (assuming that the material was successfully learnt)—may also encroach on the time available to teach new material. The review found 21 studies that compared retrieval practice to restudy. • The studies spanned students from early years to older pupils aged 16–17. There was a good spread across primary and secondary pupils • Studies looked at a wide range of subjects including language, history, maths, science, and English. • Only one of the 21 studies was delivered by regular class teachers. Others were delivered by researchers (in keeping with the aim of this review, all studies did take place in school rather than lab settings). What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 24 4. MANAGING COGNITIVE LOAD Key things to consider • The evidence around strategies that seek to manage cognitive load is promising and indicative of the value and importance of teachers seeking to manage cognitive load. • While this typically involves reducing unnecessary information and providing additional structure and support, sometimes optimising cognitive load involves increasing the challenge and quantity of relevant information provided. • Worked examples are appropriate for learning with a defined, step-by-step structure. Their typical application has been in secondary science and maths, where all of the applied evidence we reviewed is located. • It is also possible to provide incomplete or partially incorrect worked examples to increase challenge and 'fade' out the support provided. • Other strategies for managing cognitive load include scaffolding through, for example, providing appropriate guidance, prompts, instructions, templates, and tools. • Collaborative group work can share—and thereby reduce—cognitive load, with peer support acting analogously to worked examples and scaffolds. The evidence suggests that optimising cognitive load in group-work settings is possible, albeit challenging. What is the theory? A key challenge for educators is that working memory is limited. There are lots of things that can cause it to be overwhelmed. An example is when problemsolving learners might be presented with a large amount of complex information and asked to follow a series of problem-solving steps. Where a student has limited prior knowledge committed to their long-term memory this might lead to their working memory being overwhelmed, impairing learning. The aim of strategies that focus on managing cognitive load is not to minimise cognitive load but to optimise it—minimising unnecessary load and ensuring that working memory remains focused on the information that is being taught. How do teachers manage cognitive load in the classroom? Understanding cognitive load has implications for general teaching practice—for example, avoiding distractions or anxieties that might overload the working memory. Teachers report practices aimed at managing cognitive load, for example, chunking content into manageable pieces of learning, creating frameworks and scaffolds to support understanding of key concepts, thinking about economy of language when giving verbal instructions, and decluttering presentation materials. This review has identified three specific practices that teachers might use to manage cognitive load: 1. using worked examples to support learners to apply and develop knowledge; 2. providing 'scaffolding' and other forms of support such as prompts, cues, or targeted instructions to help learners navigate the working memory demands of tasks; and 3. using collaboration between pupils so that they can share the demands of problem-solving tasks. Cognitive science approaches in the classroom: a review of the evidence 25 Strategy 1: Worked examples What is it? Worked examples provide students with step-by-step, or part-by-part, demonstration of a task that makes clear the required product (that is, answers or output) and the process of completing the task. They often include diagrams that illustrate each step. They relate to cognitive load theory because it is thought that they can support pupils in applying understanding and applying knowledge without overloading working memory by requiring pupils to solve problems while they are first beginning to understand an approach. Approaches will often 'fade' information—

gradually reducing the level of explanation provided by the examples. In some circumstances, pupils are given incorrect worked examples and asked to identify errors in the process. What does the evidence say? There are a large number of studies showing that using worked examples can have a positive impact on learning outcomes. There are, however, some important limitations to the evidence. No studies were found that tested using worked examples outside of maths and science. While the principles may be transferable, we have no evidence of the application outside of these subjects. The evidence is also very focused on older pupils. An example approach When teaching her class about titration calculations, Dr Turner demonstrates how to organise the information in a question within a grid format. This breaks down the steps involved in the overall calculation, helping to ensure pupils complete each step in the correct order. Dr Turner always models how to use the grid correctly when teaching it to pupils. The review found 22 studies on worked examples. Seven of these studies focused on the use of incorrect or incomplete worked examples. • Most studies took place with secondary age students. • All studies focused on maths and science. • In only eight of the studies were the worked examples delivered by regular class teachers rather than computers or researchers. What if the evidence was there? Image © Kristy Turner reproduced with permission Cognitive science approaches in the classroom: a review of the evidence 26 Implementation One of the biggest challenges identified around the use of worked examples was the 'expert reversal' effect. The structure and support provided by worked examples that appear to benefit learners in an unfamiliar and complex topic can be become redundant or even harmful as pupils become more familiar with the problem. It is important to pay close attention to pupil prior understanding and the progress being made. The evidence also shows that individual working memory capacity varies, and can be greatly affected by emotions such as anxiety. There is some evidence that using incorrect examples and asking pupils to identify errors in a worked example can have a positive impact as learning progresses. However, a key factor identified is matching levels of prior learning to the strategy. Strategies where pupils are asked to identify problems with incorrect worked examples need to be carefully tailored to the prior knowledge of the pupils. Several studies showed that these approaches had positive effects for advanced pupils but mixed evidence for pupils with low prior attainment. One of the biggest challenges identified around the use of worked examples was making sure that the exemplification itself is of high quality and does not introduce any new misconceptions, unless it is specifically designed to test their identification. Another challenge identified around managing cognitive load was that many existing materials from core textbooks contain designs that are likely to split attention and overload the working memory. There is a balance to be struck between breaking down information into manageable steps or 'chunks' and keeping related material in one place to avoid split attention. Where pre-prepared materials are poor, it can be challenging for teachers to have capacity to design worked examples that do not introduce misconceptions, that are well-tailored to the content, and do not contain extraneous design elements that overload the working memory (see cognitive theory of multimedia learning). Cognitive science approaches in the classroom: a review of the evidence 27 What is it? There are many common learning objectives and curriculum areas that can potentially overwhelm working memory, especially when learning a new topic. Not all lend themselves to step-by-step and defined solutions that can be supported through worked examples. There are many techniques teachers use to support students; many of these are designed to focus learners on key information, guide them through a process, or support them to record or organise information for reference. These approaches typically use some kind of guidance to support pupils while engaging in tasks, the aim being that the instructions reduce cognitive load and help learners navigate the working memory demands of the task. It might involve, for example, including prompts, cues, instructions, definitions, templates, and tools as resources to support a task.

Scaffolding is a general teaching strategy and concept. The evidence here focuses on a subset of this, specifically designed to optimise cognitive load. What does the evidence say? This approach covers a wide number of different practices. For example, some studies examined intelligent tutoring systems that automated support as learners went through tasks while another provided explanatory notes during reading comprehension activities. Despite the variety in approaches, there is consistent evidence that well targeted scaffolds, guidance, and schema-based support are an effective approach to support students to solve problems or learn from complex tasks in Key Stage 2 to Key Stage 4. Strategy 2: Scaffolds, guidance, and schema-based instruction An example approach Whilst reading aloud to class, Mrs Walker chunks the sections of reading into manageable lengths and stops to explain difficult concepts to the class. The students were supported, through the use of a structured worksheet, to identify key terms, organise ideas from the text in sequence, and to identify themes and the main ideas in the text. The review found 16 studies of using scaffolds, guidance, and schema-based instruction. • The ages of children in the studied ranged from 8 to 16. • Studies covered a number of different subject areas including maths, reading, history, and science. • In seven of the studies pupils were taught by their regular teacher. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 28 Implementation Not all prompts or cues during learning tasks will reduce the burden on working memory. For example, the study identified with a negative impact included cues that were motivational rather than instructional. Cues should be targeted in such a way that they provide instructional support involving key elements of the problems that are being solved, for example, explanations of difficult vocabulary. Accounts of managing cognitive load from the theoretical evidence base indicate that reducing the level of support (or 'fading') is beneficial to learners. Pupils that already have strong foundational knowledge are less likely, for example, to benefit from the provision of key term definitions and providing support is likely to increase cognitive load. While the classroom evidence is too limited to confirm this account, the studies identified in the review did find that level of expertise determined the effectiveness of scaffolding approaches. Some studies indicated that when fading was used to gradually reduce scaffolding, it was more effective when adapted to the changing knowledge of pupils rather than fading at a fixed rate. One of the risks teachers identified around scaffolding was pupils becoming reliant on the scaffolds. Carefully monitoring pupil expertise and gradually reducing scaffolding might reduce the risk of reliance on scaffolds developing. Cognitive science approaches in the classroom: a review of the evidence 29 What is it? Collaborative problem-solving activities are those in which learners work together to complete a problem or complex task. Collaborative problem-solving is a general teaching strategy and concept. The evidence here focuses on a subset of this, specifically designed to optimise cognitive load. What does the evidence say? There is some evidence to corroborate the theory that collaborative learning can help manage cognitive load. The evidence, however, is not entirely positive and seems to indicate that collaborative work is not suited to every type of problem-solving activity. The evidence is also very strongly focused on learning in mathematics. No studies examined collaborative problem-solving in the humanities or social sciences. Strategy 3: Collaborative problem-solving An example approach (Adapted from Zambrano et al., 2019) When learning quadratic equations, pupils are given partial information, which means they must work together to solve the problem. Equation values are unpacked to distribute them among the pupils (for example, for -15x2 , each member would receive -5x2). Rather than holding all pieces of information in their head, group members depend on others' information to solve the problem. The review found nine studies that focused on the optimisation of cognitive load through collaboration when problem-solving. • Eight of the studies focused on learners aged 12 to 16. The other study took place with children aged eight and nine. • Six of the studies focused on mathematics, with two in biology and one in ICT. • Most of the interventions were overseen by the regular class teacher. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 30 Implementation The evidence suggests that collaborative learning is likely to reduce cognitive load as learners work together and share information. What is less clear is how this can be designed to optimise cognitive load for individuals within the group, ensuring that all are attending to relevant and challenging information relative to their prior level of understanding. If communication within a collaborative working strategy is ineffective, cognitive load may be increased by the effort of organising others and reduced in ways that are unhelpful as only some members of the group engage with key information. Providing support on effective collaborative working communication strategies, giving clear instructions on tasks, and allowing ways of working to develop in consistent groups of pupils may all reduce the cognitive load of collaborative activities. Teachers using collaborative problem-solving approaches outside of mathematics should be aware that there is limited evidence of its effectiveness in other disciplines and should carefully monitor whether the activities are reducing cognitive load and having a positive impact on learning. Cognitive science approaches in the classroom: a review of the evidence 31 5. WORKING WITH SCHEMAS Key things to consider • Teachers should consider pupils' prior knowledge and how this might influence their organisation of new knowledge and experience of misconceptions. • There is some evidence that concept mapping and comparison can improve pupil learning, although the variation in impacts suggests challenges with implementation. Indicative evidence suggests that it is how students engage with information—and the extent to which they self-generate and organise information—rather than any particular format, mapping, or organising information that matters. • When using concept mapping and comparison, it is important teachers know why they are employing these strategies and have a plan for assessing pupils' understanding to ensure key conclusions have been taken from tasks. What is the theory? Schemas (sometimes referred to as mental models, scripts, or frames) are structures that organise knowledge in the mind. When learning, the mind connects new information with pre-existing knowledge, skills, and concepts thereby developing existing schemas. Teachers often want to develop and refine learners' prior conceptions as opposed to teaching something entirely new. Approaches that compare, organise, and map concepts try to make schemas clear and visible and are thought to support learners to organise and extend their ideas. Working with schemas can prove challenging for teachers as schemas are formed in the minds of pupils as they relate new content to prior knowledge: schemas are therefore shaped by every individual's preconceptions, prior experience, and personal development of understanding. Also, schemas are never fixed in their contents or arrangements meaning that teachers are unlikely to know exactly how their pupils' minds organise new content. However, the flexible nature of schemas does mean that specific teaching and learning strategies may be able to foster a more desirable order to a learner's pre-existing and developing knowledge. There are several approaches to working with schemas, many of which focus on pupils organising, comparing, and elaborating on their ideas to develop more complex mental structures. Some approaches include: • problem-based learning whereby pupils learn through their struggle to apply existing knowledge to a challenging task; • using comparisons and analogies to add depth or address misconceptions; and • elaborating or questioning concepts and ideas to strengthen, develop, and transfer learning. Cognitive science approaches in the classroom: a review of the evidence 32 How do teachers work with schemas in the classroom? Many teaching and learning approaches that are informed by cognitive science are in some way influenced by schema development. For example, by presenting information in thematic groupings to manage pupils' cognitive load, teachers may also assist efficient schematic organisation. The review identified three specific approaches to working with schemas. These are: 1. concept/

knowledge mapping and organisation; 2. schema/concept comparison and cognitive conflict; and 3. elaboration and self-explanation. There was, however, insufficient evidence to review the possible impact of elaboration and self-explanation. Cognitive science approaches in the classroom: a review of the evidence 33 Strategy 1: Concept/knowledge mapping and organisation What is it? Organising key concepts or knowledge on maps or organisers. It is thought this approach may help pupils receive, organise, and extend schematic knowledge of a topic in a more efficient way, encouraging connections between related items of learning. What does the evidence say? There is some evidence to suggest that concept/ knowledge mapping can have a positive impact on pupil learning. The evidence, however, is not entirely positive and seems to indicate that if tasks are pitched beyond pupils' level of prior knowledge mapping approaches can have negative impacts. The evidence is also varied in the types of approaches concept/knowledge mapping is used for, suggesting it is not clear which tasks are best suited to this form of organisation. Many tasks took the form of teachers or learners creating a mind map to summarise and organise the key ideas in a text. An example approach After studying a text with her class, Ms Howarth uses her knowledge of the text and experience teaching the same text with other classes to create knowledge organisers that collate the most crucial foundational concepts and knowledge onto a single A4 page. These resources help pupils make links between ideas and concepts, often grouping information by big overarching themes from the text, key quotes with annotations on language devices, and relevant information on the social and historical context in which the text was written. Ms Howarth often provides pupils with the organisers ahead of end-of-unit assessments to help them self-assess existing knowledge and inform the writing of practise essays. The review found 15 studies on concept/ knowledge mapping and organisation that refer to contemporary cognitive science. • The ages of the students in the studies ranged from 8 to 17. Most studies focused on the 8 to 14 range. • Studies looked at a range of subjects including science, maths, geography, and text comprehension in either literacy or general studies. • Only six of the 15 studies were mostly delivered by regular teachers. Others were designed and delivered by researchers, involved independent study via computer software, or were delivered by teachers but heavily scripted with instructional materials. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 34 Implementation There is some evidence to suggest that concept mapping and organisation may be more effective when maps are generated by teachers rather than pupils, or when pupils already have good prior knowledge in an area. It is thought that when generating maps themselves, pupils may experience cognitive overload as they try to concurrently organise and engage with material. Indicative evidence suggests that it is how students engage with information—and the extent to which they selfgenerate and organise information—rather than any particular format, mapping, or organisation of information that matters. Teachers should consider why they are using mapping tasks and ensure pupils' attention is focused on the most useful components of the activity. Teachers may choose from a range of strategies for pupils to engage with content, including: summarising, (re)organising it themselves, drawing, imagining, self-testing, selfexplaining, filling in gaps, elaborating, enacting in some way, or teaching other pupils. Cognitive science approaches in the classroom: a review of the evidence 35 What is it? Studies in this area examined activities that compared contrasting, complementary, or conflicting concepts or examples as means of supporting pupils to differentiate between items of learning. What does the evidence say? Overall, the evidence on the possible impacts of approaches in this area are mixed, with some negative and neutral results amidst a majority of studies showing positive impacts on pupil learning. The variation in the findings suggests pupils may find it difficult to learn from comparisons or conflicts. Care should be taken to ensure pupils process differences in depth and derive the correct conclusions (rather than misconceptions) from the materials presented. Strategy 2: Schema or concept comparison and cognitive conflict An example approach: Teaching about the particle model of gases Adapted from Burrows et al., (2017 p. 47) One of the key things that pupils need to know about gases is that there is empty space (a vacuum) between the particles. These ideas can, however, conflict with pupils' preconceptions. Even if pupils know that the particles in a gas have gaps between them, they often think that the space between them is full of other things such as bacteria, pollutants, or oxygen. The review found ten studies on schema or concept comparison. • The ages of the students in the studies ranged from 10 to 18. Most students were of secondary age, the majority between 11 and 14 years old. • Studies looked at a narrow range of subjects, including only maths or science. • Only three of the ten studies were delivered by teachers who received training to implement interventions. The other studies predominantly used workbooks or computer programmes for delivery. What is the evidence based on? Solid Liquid Gas Cognitive science approaches in the classroom: a review of the evidence 36 Implementation The wider evidence in this area and practice-facing interpretation and guidance suggests that care is needed in selecting comparisons to support learning. How to ensure comparisons and analogies clarify rather than confuse concepts appears to be a key consideration. Pupils may benefit from the support of a scaffold to help them explain the differences between concepts, supporting them to make detailed comparisons with correct conclusions. For example, a teacher might provide reflection questions to help pupils specify the cognitive and metacognitiveprocesses they have used when comparing concepts. Regarding the former, the teacher might ask, 'What features of the diagrams did you compare to highlight the differences between them?' Or with regard to metacognitive processes: 'What did you find difficult about comparing the two diagrams and how did you overcome that difficulty to highlight the differences between them?' It is also important to use assessment to gather information on what pupils have concluded by making comparisons as this may uncover misconceptions that need addressing before moving on or revisiting during a later lesson. Cognitive science approaches in the classroom: a review of the evidence 37 6. COGNITIVE THEORY OF MULTIMEDIA LEARNING Key things to consider • The evidence around the use of multimedia is mixed: while many studies are positive, others show low or null effects. • Promising approaches use multimedia to support the learning of complex information, often with older pupils. • Multimedia approaches can be challenging to implement successfully. How are we to ensure that the multimedia does not increase cognitive load? What is the theory? Dual coding theory is based on the theory that working memory has two distinct components, one that deals with visual and spatial information and another that deals with auditory information. By presenting content in multiple formats, it is possible that teachers can appeal to both subsystems of the working memory, which subsequently strengthens learning. It is thought that given the specialised nature of the two subsystems of working memory, a larger amount of content can be understood with more richness when conveyed through multiple formats without overloading working memory. While this information is useful to teachers as it suggests learning may be more effective when information is presented in this way, the many different formats in which information can be presented—such as text, images, diagrams, equations, or combinations of any of these—means that teachers must make difficult decisions about which format to use without necessarily knowing how this will affect pupils' cognitive load and learning. Given the large variety of practice reviewed in this area, we decided to frame the area using a slightly broader theory: the cognitive theory of multimedia learning (CTML). This theory builds on ideas of dual coding, cognitive load, and generative learning (where students actively integrate new ideas with existing ideas). CTML describes organising, selecting, and integrating multimedia information into coherent representations and combining them with prior knowledge1 . It has three core assumptions: • there are two separate channels for information (that is, dual coding theory); • each channel has a finite capacity; and • learning is an active process of working with this information. How do teachers manage cognitive theory of multimedia learning in the classroom? While approaches that explicitly describe themselves as 'dual coding' have become very popular recently, teachers have always illustrated concepts or ideas through images or illustrations. We examine the evidence for three distinct uses of multimedia: • visual representations or illustrations; • diagrams; and • spatial, visualisation, and simulation approaches. 1 Mayer, R. E. (2005). Cognitive theory of multimedia learning. The Cambridge handbook of multimedia learning, 41, 31-48 Cognitive science approaches in the classroom: a review of the evidence 38 Strategy 1: Visual representations and illustrations What is it? Using visual representations and illustrations involves learners being presented with, or creating, an additional image, picture, or icon that symbolises, illustrates, or represents aspects of the content being learnt. Studies in this group involved the presentation of additional visual information to a task or concept that could potentially be learnt without the visual. In some cases, the visual representation was provided, in other cases produced by the learner. What does the evidence say? While many of the impacts of the studies identified are positive, results were mixed. Studies frequently reported no effect or harmful effects. The strategies included in this group were varied. It is likely that a regrouping that organised the studies by theoretically important aspects (such as whether the images were created by, or provided to, students, or the information content of the images) might have revealed a clearer picture about the conditions in which visual representations can support learning. There are also significant limitations to the evidence base. While all of the studies took place in school rather than lab conditions, few of them accurately reflect usual school provision. Most were delivered by researchers, used researcher tests, and were often delivered in one short session that was scripted for consistency. While these studies might give useful insight into the principles of how visual representations might have an impact in the classroom, they tell us less about whether impacts will be transferable to regular teacher practice. An example approach (Adapted from Moreno et al., 2011) When learning about circuits in science, pupils are provided with images at different levels of abstraction. Sometimes these include pictures of actual lights, while at other times they use the formal symbols for them. The review found 34 studies relating to visual representation and illustration. • There were no studies of Key Stage 1 or early years, but a good representation of pupils aged 7 to 18. • Most of the studies took place in science and maths, although other subjects were represented, including geography, history, and vocabulary learning. • Most studies were not delivered in typical school conditions: they were often small interventions, delivered by researchers rather than teachers, and often delivered in one short session. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 39 Implementation The limitations in the evidence mean that teachers should think carefully about how they use visual representations to support learning. While the evidence is too weak to tell us what works, there are some lessons from the theoretical evidence, which might support stronger effects in the classroom. Ensuring that images are informational rather than decorative means that they are more likely to support learning rather than placing an unnecessary strain on cognitive load. Teachers highlighted that while it may be straightforward to include illustrations while teaching, implementing approaches in a successful way so that they are more than 'drawing pictures for the sake of it' is more challenging. Surveyed teachers voiced concerns around whether dual coding in particular had become misunderstood and reduced to 'pretty icons' and complex graphic organisers. Cognitive science approaches in the classroom: a review of the evidence 40 What is it? Using diagrams is a subset of the evidence base on visual representations that represents or organises learning content or process information schematically. In most cases, the diagrammatic representation was an object of learning in its own right. The diagram goes beyond illustration and decoration to represent relevant concepts or phenomena and, additionally, how they are organised or structured. In the evidence, diagrams are often contrasted to textual representations of information and sometimes combined with other practices— for example, spaced restudy. In some studies, children are shown diagrams to explain concepts while in others children are encouraged to draw diagrams to summarise learning. What does the evidence say? As with the wider evidence on visual aids, the evidence on diagrams shows that while most studies have positive effects, many have null or negative effects. Similar to the evidence on visual aids, a key limitation is that studies often were not delivered by teachers in usual classroom conditions. Most of the studies were delivered by workbooks or computer programmes. Implementation Diagrams are a subset of other visual representations and illustrations and many of the same lessons apply. One of the distinct factors in a diagram, as opposed to an illustration, is considering how concepts are structured or organised. It is important that the visualisation does this accurately. It is possible, for example, for inaccurate diagrams to reinforce misconceptions. Strategy 2: Diagrams An example approach (Adapted from Coleman, McTigue and Dantzler, 2018) When learning about the water cycle, pupils are presented with diagrams with labels and process information that illustrate the different steps of the cycle. Evaporation is shown through an illustration of water rising from the sea to clouds, while a ray from the sun shines onto the sea. An arrow illustrates the direction of travel and a note explains that the evaporation is caused by heat from the sun's energy and occurs in water in lakes, rivers, oceans, and on land. The review found 14 studies related to the use of diagrams in the classroom. • Twelve of the studies involved pupils between 12 and 16. None of the studies focused on early years. • Studies were concentrated in maths and the sciences, with one study of technical illustrations in geography. • Most of the studies were delivered by workbooks or computers. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 41 What is it? Spatial, visualisation, and simulation approaches support children to imagine learning content, or representations of it, often in order to simulate, manipulate, or organise concepts and schemas across time or space. In some cases, visualisation is inherent to the learning objective (as, for example, in geometry); in others, it is used as a form of retrieval and rehearsal (for example, imagining a story); in other cases it is used as a scaffold for problem-solving (that is, visualising as a way of analysing or anchoring a learning object in memory). What does the evidence say? While the studies identified have small to moderate positive effects, the limitations of the evidence base make it difficult to assess the effectiveness of the strategies. The number of studies is small and there is real variation between the approaches that go beyond practical differences in delivery. The focus on mathematics across all but one study means that there is limited information on the promise of the approach for other subjects. Implementation The limitations in the evidence base for spatial, visualisation, and simulation approaches mean that there are limited insights on how teachers might apply these approaches successfully in the classroom. There is significant variation in how these approaches have been applied. Teachers should carefully consider how the visualisation strategy is being used, for example, is it inherent to the subject, or is it a method of retrieval or scaffolding? Strategy 3: Spatial, visualisation, and simulation approaches An example approach (Adapted from Barner et al., 2016, 2018) When doing calculation tasks in maths, pupils are taught to use the mental image of an abacus to visualise the way the calculation takes place. As they complete sums, they imagine their mental abacus and use it to support their calculations. There were only seven studies that focused on spatial, visualisation, and simulation approaches. • All of the studies focused on primary aged pupils. • All but one of the studies focused on mathematics. The final study focused on reading comprehension. • Two of the studies were delivered by regular teachers. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 42 Key things to consider • There are lots of reasons other than academic outcomes to consider physical factors at school such as nutrition, physical activity, and sleep hygiene. • The evidence around embodied learning is currently limited and the studies in this area of the review were loosely grouped. Nonetheless, the evidence we reviewed suggested considerable promise for approaches involving the body and physical activity to support learning. • The studies we reviewed explored a range of embodied and physical strategies including the use of gesture, actions, playground physics and maths, and tracing (for example, using the index finger to trace over a geometry worked example or water cycle diagram). What is the theory? Embodied learning and physical factors refer to strategies that engage and make use of movement and the body to support effective learning. More generally, embodied learning often also encompasses the role of emotions in learning—but this is something we have not included in the scope of this review. Most studies reviewed in this area emanated from searches for visual representation and the coding of information. In contrast to many of the other strategies explored in this report that primarily focus on improving the mind's ability to acquire, organise, and apply new knowledge and skills, approaches that use the body and physical movement to support teaching and learning work under the assumption that the mind is closely related to the body and its sensory experience. It is thought that by designing tasks and activities that appeal to pupils in a multisensory way, teachers may be able to make new information more easily comprehensible and memorable. Some actions and approaches for using embodied learning and physical activity in the classroom include play, enacting, gesturing, movement, and tracing. Another area of cognitive science includes evidence around exercise, nutrition, and sleep. While these factors have important links to cognitive science, we have not summarised the evidence in detail as they were outside the scope of the review. How do teachers use embodied learning and physical factors in the classroom? Schools frequently support physical factors that might interact with learning. Some examples include: • physical exercise as part of regular school timetabling; • incorporating physical activity into non-PE lessons; • breakfast clubs to increase nutrition; and • sleep hygiene education. Embodied learning approaches have most often been used in primary schools and use movement around the classroom while teaching other subjects, for example, throwing beanbags to each other during counting tasks. Other examples are tracing, the use of gestures when teaching, and play-based learning approaches. 7. EMBODIED LEARNING AND PHYSICAL FACTORS Cognitive science approaches in the classroom: a review of the evidence 43 What has been researched? The research summarises approaches that enact or represent concepts through movement of the whole body or part of the body (such as gestures or tracing) including learning or enhancing learning through the use of the body's sensory or motor capabilities. Included studies relate to physically doing, experiencing, or acting out or playing with the learning object, including both concrete and representational approaches, and in particular gestures and actions. What does the evidence say? The evidence in this area is consistently positive. Studies comparing embodied cognition approaches were found to have larger impacts on learning than normal curriculum delivery. There are, however, a number of limitations to the evidence base. A key challenge in interpreting this evidence is that there may be missing studies as no direct search of 'embodied learning' or similar terms took place. Almost all of the studies took place in primary schools, so caution should be applied when trying the approaches with older pupils. Similar to other approaches, there is limited evidence from studies that are comparable to usual in-school practice. Studies have typically involved delivery from researchers and have often only looked at short-term outcomes for pupils. Implementation Some of the wider evidence discusses the links between the gestures of teachers with cognition— particularly when teaching younger pupils. While the evidence in this area is too limited to pull out any direct implications for practice, the theoretical evidence does point to links between things like gestures and other cognitive science approaches like dual coding and managing cognitive load. Like with dual coding, teachers might consider how to ensure that gestures provide additional support rather than creating distractions that put a strain on cognitive load. An example approach (Adapted from Cook, Duffy and Fenn, 2013) When teaching equations, the teacher uses hand gestures when referring to different sides of the equation. When saying the word 'one side', the teacher sweeps her hand back forth beneath the left half of the equation. When the teacher says 'the other side', she sweeps her right hand back and forth below the right half of the equation. Unlike other strategies, the studies on embodied cognition and physical approaches were found through general searches of cognitive science rather than specific searches of the approaches. This means that this evidence may not be a comprehensive summary of the approach. Fourteen studies were found in total. • The studies mostly focused on primary school children with ages ranging from 5 to 14. • There were studies of maths, science, and language (including reading comprehension and vocabulary). • Ten of the studies were designed and delivered by researchers. Other studies were either delivered by teachers in collaboration with researchers or by using digital technology. What is the evidence based on? Cognitive science approaches in the classroom: a review of the evidence 44 Key things to consider • Mixed strategy programmes were amongst the strongest examples of applied research, often testing the strategies in realistic conditions and at scale. Such programmes are of interest to teacher educators and school leaders as potential vehicles for aligning teaching and learning with multiple principles from cognitive science across many teachers and schools. • The evidence on mixed strategy programmes was hard to interpret as it was difficult to ascertain which specific strategies were influencing pupil outcomes. • The seven programmes reviewed provided a mixture of positive and null outcomes. Many of the applied, mixed strategy programmes also suffered with implementation challenges. • It was unclear whether these challenges related to the organisational aspects of the programmes, school improvement efforts more generally, or from the nature of the cognitive science strategies in question. What is the theory? While not exclusively, these programmes often embed strategies throughout curricula or learning topics, meaning they are most frequently implemented at a school or departmental level. Some mixed strategy programmes also include professional development as school leaders seek to develop teachers' fluency in knowledge and use of cognitive science principles. It is thought that by increasing knowledge and use of cognitive science strategies, teachers can harness the evidence base of how people think and learn to support pupils more effectively. How do teachers implement mixed strategy programmes in the classroom? Most of the mixed strategy approaches are programmes that are implemented at the level of the school, either through professional development or curriculum development. MIXED STRATEGY PROGRAMMES An example approach When co-designing a new Year 8 curriculum, the head of English and Key Stage 3 lead think hard about the sequencing of schemes of work and how key concepts and items of learning can be revisited over several weeks (spaced learning) and can be built upon to support pupils in developing complex mental models with a secure grasp of foundational knowledge (as seen in Working with Schemas). For example, when considering how best to develop pupils' ability to organise the structure of literary texts, they introduce some learning around Freytag's pyramid during the study of Macbeth at the start of the year before building on this through a later scheme of work on the sequencing of sections in short story narratives. To ensure that teachers are aware of the rationale for these curriculum design choices, the head of English and KS3 lead provide time to develop and explain the curriculum during a departmental meeting. Furthermore, to support teachers responsible for delivering the new curriculum, the English department also make time to discuss the possible misconceptions pupils might experience while learning about narrative structures and develop worked examples and scaffolds that will assist learners with differing needs. Cognitive science approaches in the classroom: a review of the evidence 45 What has been researched? Approaches in which two or more cognitive science informed strategies are used together to test the combined effect. What does the evidence say? Some studies show mixed strategy programmes can have a positive impact on pupil outcomes, although several null or mixed results suggest challenges with implementation. Mixed strategy programmes are likely to link to school improvement processes and may also involve curriculum design and professional development. The effectiveness of these other school practices could therefore influence the success of any largescale approach within this area. Implementation When implementing one or a combination of cognitive science informed strategies, it is important teachers consider the applicability of research evidence to their context and intended use of approaches. The findings of studies that involve predominantly independent study by pupils or technology-based interventions give some insight into the impact of approaches, but this evidence often focuses solely on the strategies being tested and does not explain how best to integrate cognitive science principles into conventional classroom practice. Considering how to implement cognitive science strategies in a way that complements existing school and classroom practices is of high importance. Teachers' understanding of cognitive science principles may be a crucial component of effective implementation of mixed strategy programmes and therefore professional development is likely to be key. Careful monitoring of teacher beliefs about cognitive science prior to implementing a programme may be a useful way of judging the readiness of the school or department for the intended change. Following this, consistent modelling of the new strategies, observing ongoing delivery, and providing ongoing feedback and support can help staff make lasting change to their practice. The review found eight studies reporting tests of mixed strategy programmes. • The ages of the students in the studies ranged from 11 to 14. • Studies looked at a narrow range of subjects, including only maths or science. • Five of the eight studies were delivered by regular class teachers who received professional development in addition to curriculum resources to implement strategies. What is the evidence based on? 46 Cognitive science principles of learning can have a significant impact on rates of learning in the classroom. There is value in teachers having working knowledge of cognitive science principles. Theories from basic cognitive science imply principles for effective teaching and learning. Principles include 'spacing' learning out over time, providing worked examples or 'scaffolds' to support problem-solving, and presenting information both verbally and visually. The applied evidence summarised does provide support for many of the principles of learning implied by basic cognitive science, albeit in specific contexts. For most of the strategies included in this review, cognitive science principles were significant factors affecting rates of learning and retention of information in the classroom. Most of the results could be explained using theories from basic cognitive science and practice-facing versions of these. The evidence for the application of cognitive science principles in everyday classroom conditions (applied cognitive science) is much more limited, with uncertainties about the applicability of specific principles across subjects and age ranges. Applied cognitive science is far more limited and provides a less positive, and more complex, picture than the basic science. For many of the strategies, the evidence was restricted to particular age groups, subject areas, or learning outcomes. Applications of cognitive science outside of these, while plausible given the basic science, are yet to be tested and found effective in the classroom. • Even approaches with indicative evidence of promise like retrieval practice, spaced practice, and the use of worked examples are, as yet, only supported by a few studies that examine their impact in everyday classroom conditions— delivered by teachers over long periods of time. • With some approaches—like interleaving—there are studies with promising results but they have almost exclusively been tested in one subject area (mathematics). More generally, there are serious gaps and limitations in the age ranges, subjects, and learning outcomes studied for most of the strategies we reviewed. These gaps make the extent to which strategies apply across all age ranges and subject areas unclear. • Some approaches—like combining verbal explanations with graphical representations, also known as 'dual coding'—are possible to implement poorly. While some studies show positive impacts on pupil outcomes, there are also multiple studies showing null or negative findings. It is important to note that a lack of evidence is not the same as evidence that an approach is not successful. We should be cautious about concluding that because a principle is found to be ineffective in the lab or in one classroom context that it cannot be deployed effectively elsewhere. Applying the principles of cognitive science is harder than knowing the principles and one does not necessarily follow from the other. Principles do not determine specific teaching and learning strategies or approaches to implementation. Considering how cognitive science principles are implemented in the classroom is critical. Some accounts of cognitive science principles prescribe practice based on the strength of the underlying theory and claim that the behavioural or neuroscientific evidence justifies application OVERARCHING FINDINGS 47 across subjects and ages (see previous). These are inevitably interpretations of how principles apply in the classroom. The fact that many strategies have not been consistently tested in everyday classroom settings means that it is particularly important to think carefully about if, and in what circumstances, they are applicable and how we could implement them in a way that has a positive impact on pupil outcomes: • Teachers looking to apply cognitive science principles in the classroom will need to consider how, and in what conditions, approaches informed by cognitive science might improve learning. The effectiveness of strategies is likely to depend on factors including the age of learners, learner prior knowledge, the nature of the subject and learning outcomes, and whether the approach is practically feasible—and make sure that they are successfully enacted. • Special care should be taken to make sure that principles are successfully implemented, avoiding 'lethal mutations' when a practice becomes disconnected from the theory. For example, teachers have reported that dual coding sometimes means that irrelevant illustrations are added to presentations, which may be a distraction rather than a way of developing schemas and optimising cognitive load. Schools should consider how—and in which contexts—to give teachers high quality CPD around cognitive science approaches, and enough time to test and incorporate approaches appropriately into their practice and for their subject and learners. Many teachers report that their main form of engagement with cognitive science is independent study. Principles of cognitive science interact and should not be considered in isolation from each other, or without taking into account wider practical and pedagogical considerations. There are clear links between the different approaches summarised within this review. In particular there are relationships between: • approaches that consider how to optimise retrieval of information from the long-term memory: spaced learning, interleaving, and retrieval practice; • approaches that consider how to present information effectively and support students to work through information without overloading working memory: dual coding and multimedia theory of learning, strategies to optimise cognitive load such as scaffolding and use of worked examples, and embodied learning approaches; and • approaches that consider the balance between didactic instruction and the pupil's role in learning: strategies for working with schemas, learnerled strategies within managing cognitive load, cognitive theory of multimedia learning, and embodied learning. Little research has effectively explored how distinct and similar strategies interact but it is clear that careful consideration is required to optimise mergers between approaches, for example, combining retrieval approaches with appropriate spacing. 48 Future work Many of the classroom approaches inspired by cognitive science are promising and knowledge of cognitive science is an important part of understanding how pupils learn. There is, however, much more work to be done to understand in which contexts findings from the basic science are applicable and effective in everyday classroom conditions, and how these can be implemented. The EEF will continue to evaluate approaches that provide scalable programmes or training for the effective deployment of cognitive science principles. We will also continue to fund teacher choices trials, which seek to rigorously assess the nonprogrammatic teacher techniques for deploying cognitive science in the classroom. The current evidence base on cognitive science applied to the classroom is largely focused on how individual learners process and remember information. Social, emotional and physical aspects to cognition and learning receive less attention in the applied evidence found in this review. The survey of teachers, review of the underpinning science, and the applied evidence in areas such as embodied learning however suggest that social, emotional and physical aspects to cognition are also important considerations for research and practice. 49 Basic science. The study of phenomena and scientific laws, often referred to as ‘fundamental’ or ‘pure’ science. Applied science. Using approaches informed by conclusions from basic scientific knowledge in practical, real world contexts. Working memory. Where information that is being actively processed is held—it is where ‘thinking’ happens. Long-term memory. A ‘store of knowledge’ that is constantly updating and evolving. Cognitive load. The amount of information our working memory can hold at any one time. Schema. A pattern of thought that organises categories of information, and the links between them. Schemas are stored in long-term memory. Spaced practice. Distributing learning and retrieval opportunities over a longer period of time rather than concentrating them in ‘massed’ practice. Interleaving. Sequencing learning tasks so that similar items are interspersed with slightly (but not completely) different types of items rather than being presented consecutively. Retrieval practice. Using a variety of strategies to recall information from memory, for example flash cards, practice tests or quizzing, or mind-mapping. Dual coding. Using both verbal and non-verbal information (such as words and pictures) to teach concepts. GLOSSARY 50 www.educationendowmentfoundation.org.uk @EducEndowFoundn Facebook.com/ EducEndowFoundn Education Endowment Foundation 5th Floor, Millbank Tower 21–24 Millbank§ London SW1P 4QP Production and artwork by Percipio https://percipio.london

 IFTE 2016 : 2nd International Forum on Teacher Education Embodied Simulation in the Art of Teaching Piano Damilya S. Nadyrovaa * * Corresponding author: Damilya S. Nadyrova, dumila@yandex.ru a Kazan (Volga region) Federal University, 18 Kremlyovskaya street, Kazan, Russia Abstract Recent studies show a close interrelation of emotions and movements in the music performance art, while the understanding of music is related to the modeling processes (embodied simulation), or the bodily transmission of music. It is clear that this approach is particularly promising for music pedagogy, and first of all for pedagogy of music performance. This view will help the beginning performer to find the most efficient way for a better understanding of musical emotion within the content of the musical piece, and, moreover, will contribute to the development of expressive technical skills. In this article we will study the embodied perspective in piano teaching, as well as the system of teaching methods, based on the motor modeling of musical rhythm. Keywords: Piano teaching, emotions, expressivity, embodied simulation, music performance, musical rhythm. 1. Introduction Pedagogy of art has a number of specific properties, the main property is the special role of emotion, and artistic experience in all types of learning activity. Compared to other areas of education, a much greater role in art pedagogy is played by intuition, emotional, and creative processes. It allows for the definition of "Pedagogy of art as art." Music content specificity can create a problem in the understanding and perception of its emotional sense. At the same time it is a necessary requirement for any kind of musical activity. Full understanding and perception of music is important in all areas of musical activity, including artistic performance and pedagogy. The purpose of this report is to look for, and prove new approaches to solving the problem of musical knowledge, which will contribute to the effective comprehensive professional training of a prospective music teacher, both in terms of performance and methodology. http://dx.doi.org/10.15405/epsbs.2016.07.26 http://dx.doi.org/10.15405/epsbs.2016.07.26 eISSN: 2357-1330 / Corresponding Author: Damilya S. Nadyrova Selection and peer-review under responsibility of the Organizing Committee of the conference 157 2. Methodology New opportunities to search for effective ways in this sphere are revealed with the latest scientific findings in neurophysiology and psychology of emotions, in the philosophical theory of knowledge. These milestone events in the human science have included the discovery of the mirror neuron system of the brain by Rizzolatti (2004); the emergence of new concepts in cognitive science, among which the interdisciplinary concept of the "embodied cognition" has become the leading one, as well as the studies on its future implementation in education (John B. Black, 2010; Doug Holton, 2010) et al. These ideas were continued by the concept of enactivism formulated by F. Varela, E. Rosch and E. Thompson in the book "The Embodied Mind" (1991), and in Music Cognition - Matyja J. R. & Schiavio A. (2013). According to the theory of the embodied cognition, cognitive abilities depend on the reconstruction of sensory and motor representations. The implementation of this concept in education is based on the unified approach to the brain and body, on the understanding that the learning processes and body movements are inseparably linked to each other. Theoretical and experimental research indicates that, the movement of the whole body or its parts may have a positive impact on the effectiveness of education, especially if these movements are integrated into the learning task. The methodological basis for our research is the "embodied simulation theory" developed by Vittorio Gallese (2012), Marco Iacoboni (2004), which considers simulation (reproduction of the elements of a perceived phenomenon in movements, e.g. the expression of another person), as an important mechanism for the emergence of empathy. Music psychology and neuroscience research has shown that these processes also appear in the perception of music. They can be traced quite clearly and are related to the recognition of the emotional sense of music, that is, with the musical emotional responsiveness or musical empathy. The theory of the embodied cognition in terms of pedagogy has been actively developed in such areas as; learning languages, mathematics, and computer education technologies. This concept was considered in relation to music, mainly in the aspect of musical perception of listeners, but it hasn't been applied yet in the theory and practice of piano teaching. However, this theory so accurately explicates the essence of emotional and cognitive music processes, and therefore, so accurately complies with learning objectives and requirements of talented music teachers as the result of their creative musical and pedagogical intuition (Nadyrova, 2012). The convergent approach which includes the analysis and integration of theoretical and experimental research in the related fields of human science, has been used in order to find the solution to the task at hand. It has resulted in the development of the system of methods for motor simulation in piano pedagogy, which is hierarchically built in accordance with the learning objectives and tasks. It is possible to speak about two main forms of simulation: a) when the melodic movement expression is reflected in gestures, and b) when the musical rhythm is reproduced in movements. We will consider the second form, which is the use of motor simulation in the course of work on the rhythm of performance. It is also known that the problem of rhythm is very important for learning to play the piano. eISSN: 2357-1330 Selection and peer-review under responsibility of the Organizing Committee 158 3. Movement and rhythm in music performance Researchers observe the two most typical attributes of music rhythm. The first attribute is its ability to very actively affect the emotional state of listeners. The second attribute is its ability to arouse active motor reaction response, a sort of the "motor accompaniment for perception." The experimental results show that these two attributes are interrelated, and they determine each other's degree of intensity. It is also known that the rhythmic sense always requires support in external movement, in a distinct muscular sensation (Sechenov, 1961; Teplov, 1985). In this regard, the reasons for failures in the pianoforte work can be explained by the following circumstances: On the one hand, it is the traditional conservatism of the piano pedagogy, in which the problem of movements didn't usually go beyond basic pianistic movements, and pianoforte technical skills. All other movements not directly involved in sound production were perceived as unnecessary, harmful, or even as a manifestation of bad taste. On the other hand, it is the complexity of the performance process which consists of a huge variety of pianistic movements, large and small, very precise and differentiated by the strength and nature of touch. So, the introduction of additional emotionally determined movements, which could become the support for the rhythm sensation (e.g. rhythmical sway, head nods etc.) into this structure, really can disorganize this complex process. It is true that the system of performing pianistic movements is so complicated, multi-layered and technically vulnerable that it is easy to lose "efface", or suppress natural motor rhythm sensation related to reproduction and imitation of rhythmic accents in large muscles. Therefore, to restore the natural sense of rhythm (rhythm emotions), it is advisable to temporarily separate it from the performance process of piano playing motor skills, and perceive and experience it as it is. In other words, it is necessary to separate in time two different motor processes – the performing process responsible for accurate sound reproduction, and the process of the motor physical embodiment of rhythm responsible for its emotional comprehension - in order to subsequently join these two processes in a new way. This physical embodiment can include various motor skills like; movements of arms, legs, and even the vocal apparatus (e.g. counting out loud or "rhythmic words or lines"). To put it another way, we use the method of imitation, motor simulation of musical rhythm in other "nonperformance" spheres of human motor skills. The next important step is to convert these living, emotionally catching rhythm sensations (beats) into clear intra-aural presentations (but with preservation of motor sensations), and then to introduce them into an actual performing process without disturbing its naturalness and accuracy. The method of music "physical embodiment" is often used in music pedagogy, but only as the way shown by a teacher, rather than a student. We often see a teacher gesticulating, stomping, clapping, and sometimes even dancing, trying to convey necessary mood or pace to the student playing the piano, to captivate him with emotion. It really helps, but it brings only a temporary effect, and as soon as the student loses this energy "recharge", his playing returns to the previous level. It is true that even watching someone else's expression gives good results because of the mirror neuron system (visual and auditory neurons), but it is not comparable to the student's own physical embodiment when he absorbs and perceives music with his body. http://dx.doi.org/10.15405/epsbs.2016.07.26 eISSN: 2357-1330 / Corresponding Author: Damilya S. Nadyrova Selection and peer-review under responsibility of the Organizing Committee of the conference Fig. 1. Structure of the movements of the performing musician Therefore, a teacher's responsibility is not only to show the character of the music in his movements, but to involve the student in this work and create an appropriate atmosphere during the class. 4. Motor simulation of rhythm The following forms of rhythm motor simulation can be used in music education: 4.1 Traditional form of musical conducting Firstly, it is a traditional form of musical conducting, which is used not for the control over other people, but for better perception of the music character by a performer. In the process of work on a piece of music H. Neuhaus advised "to act exactly the same way as the conductor when he works on a music score: put a music sheet on the music stand and conduct this music piece from the beginning to the end to master its rhythmic structure, i.e. its time process organization..." (Neuhaus, 2007). It is suitable for older students when learning large music pieces such as sonatas by Beethoven. Fig. 2. Traditional form of musical conducting 4.2 Elementary conducting Elementary conducting is free simulation of metric structure in simple hand movements, e.g. smoothness and softness in circular gestures eISSN: 2357-1330 Selection and peer-review under responsibility of the Organizing Committee 160 Fig. 3. Elementary conducting 4.3 Simulation of rhythm with clapping, tapping Simulation of rhythm with clapping, tapping small elements of a rhythmic pattern, dotted and syncopated figures. These techniques help to better feel the brightness, clarity and clearness of a rhythmic pattern which are often lost in the process of playing due to difficult technique. Fig. 4. Simulation of rhythm with clapping, tapping 4.4 Movements of the whole body Movements of the whole body in the form of free improvisation (e.g. imagining movements of floating in water or a flying body) or using any dancing style (minuet, waltz, polka, boogie, tango), which enables the sense of rhythm especially in the work with young pianists. Fig.5. Movements of the whole body in the form of free improvisation 4.5 Movements of the legs This is the movements of the legs in the form of careful, low voice "time beating". Remoteness and independence of these movements on the pianoforte motor skills shows, good muscle "perceptibility", http://dx.doi.org/10.15405/epsbs.2016.07.26 eISSN: 2357-1330 / Corresponding Author: Damilya S. Nadyrova Selection and peer-review under responsibility of the Organizing Committee of the conference 161 visibility, and inertial resistance. The ability to partially use it during the playing are important advantages of this technique. Fig. 6. Movements of the legs A very important attribute of the music physical embodiment method is that, it develops rhythmic independence in students, releasing their own rhythmic feelings, which were bound to the keyboard. Rhythmic independence is possible, only when rhythm is naturally perceived through the whole body, without emotional restraints, the presence of genuine stability and reliability of metro-rhythm in the performance. 5. Conclusion Motor simulation method is based on the selection and embodiment of the most emotionally significant elements of rhythm. In this way it is easier and more natural to vary and absorb their sensory individuality. It is similar to animated films or cartoons where the most expressive elements are exaggerated, and insignificant ones are obscured. In such a way, our perception focuses directly on the most important elements and doesn’t waste time to select them in the stream of "excessive" information. As you can see, the concept of physical cognition amazingly conforms to music cognitive activity, which again confirms its reliability and versatility. It is clearly visible in music which is regarded by neuro-physiologists as the mirror of all psychical processes. Acknowledgments I would like to thank my student Lyaisan Mukhametzyanova for participation in preparation of photos and videos for this article. References Black, J. B. (2010). An Embodied/Grounded Cognition Perspective on Educational Technology. In M.S. Khine and I. Saleh (Eds.). New science of learning: Cognition, Computers and Collaboration in Education. Gallese, V. (2012). Embodied simulation theory and intersubjectivity. - vittorio.gallese@unipr.it. Dept. of Neuroscience – Section of Physiology, University of Parma, Italy. 4, 2. Holton, D. (2010). Constructivism + Embodied Cognition = Enactivism: Theoretical and Practical Implications for Conceptual Change, AERA 2010 Conference. Iacoboni, M. (2003). 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 J5JRM R58410.1177/0022429410385945StambaughJournal of Research in Music Education M38594 1 Georgia Southern University, Statesboro, USA Corresponding Author: Laura A. Stambaugh, Department of Music, Georgia Southern University, PO Box 8052, Statesboro, GA 30458 Email: laurastambaugh@gmail.com When Repetition Isn’t the Best Practice Strategy: Effects of Blocked and Random Practice Schedules Laura A. Stambaugh1 Abstract The purpose of this study was to investigate the effects of blocked and random practice schedules on the performance accuracy, speed, temporal evenness, and attitude of beginning band students in a group instructional setting. The research assumptions were based on the contextual interference hypothesis,which predicts that a blocked practice order (low contextual interference) leads to superior performance immediately following practice but that a random practice order (high contextual interference) supports superior performance at delayed retention testing. Beginning clarinet students (N ! 41) completed three practice sessions and one retention testing session, performing three seven-pitch exercises. At the end of practice, no significant differences were found between blocked and random practice groupsfor accuracy,speed,ortemporal evenness. At retention, the random group performed significantly faster than the blocked group, F(1, 38) ! 24.953, p " .001, !2 ! .92, and the blocked group performed significantly slower than it did at the end of practice (p " .001). No significant differences were found between groups for transfer tasks or for attitude toward practice. Keywords practice, beginning band, contextual interference, blocked and random, clarinet “When you can play it correctly three times in a row, you know you’ve got it!” This statement is likely to be heard in a student’s private lesson or in a group band class as Journal of Research in Music Education 58(4) 368–383 © 2011 MENC: The National Association for Music Education Reprints and permission: sagepub.com/journalsPermissions.nav DOI: 10.1177/0022429410385945 http://jrme.sagepub.com   the teacher prompts her students to “try it again.” However, how many students have sat in a lesson or rehearsal on the following day only to find they were unable to retain the previous day’s performance? Method booksrecommend multiple repetitions of technical passages (e.g., Singer, 1956), practice software includes “looping” capabilities (Rodet, Roebel, Peeters, Bogaards, & Corfu, 2008), and expert musicians make extensive use of repetition in their practice (Maynard, 2006). Repetition permeates practice rooms and rehearsal spaces, yet rarely does a teacher consider that this time-honored strategy may not be the most effective means of learning for all students and in all situations (Duerksen, 1972; Green, 2006). While this strategy is often successful for adults with fully developed cognitive systems and a wealth of prior experience, it is important to examine its effectiveness with children whose cognitive systems are still developing and who have minimal playing experience. Musicians are not alone in their endeavors to maximize the results of practice. Researchers in motor learning have invested considerable effort comparing blocked practice orders, when all practice trials of one task are completed before starting to practice the next task (111 222 333), to random practice orders, when the learner constantly switches among tasks (123 231 312). In laboratory settings, practice in a blocked schedule supported immediate performance, but practice in a random schedule was more effective for long-term learning (Brady, 2004; Lee & Magill, 1983; C. H. Shea, Kohl, & Indermill, 1990; J. B. Shea & Morgan, 1979). The construct explaining the blocked/random paradox is termed contextual interference, the amount of cognitive disruption present when practicing multiple tasks. It is most often operationalized as blocked and random practice orders. Blocked practice orders cause a low level of cognitive interference because the learner is focusing on only one task for a period of time. Random practice orders cause a high level of cognitive interference because the learner must constantly redirect his or her attention to the next task. Performance analysis in contextual interference studies occurs at acquisition (the final practice trials), retention (at least 10 minute latency), and on transfer tasks (tasks similar to the practiced tasks but containing purposefully designed parameter changes). The differing levels of cognitive engagement led to the contextual interference hypothesis, which predicts that practice in blocked orders is more beneficial at acquisition but that practice in random orders supports superior learning at retention (J. B. Shea & Morgan, 1979). One theory explaining this paradox is reconstruction (Lee & Magill, 1983, 1985), whereby the constant switching of tasks requires cognitive movement plans to be reconstructed at each trial, thus strengthening the representation of each task. Alternatively, elaboration (Battig, 1966; J. B. Shea & Morgan, 1979; J. B. Shea & Zimny, 1983) would be demonstrated if random practice schedules support superior learning because the simultaneous presence of multiple tasks in working memory allows comparisons and elaborations to be made among the various tasks. The elaboration hypothesis recently has been supported by neurological findings (Lin, 2007). Based on results of a recent meta-analysis, Brady (2004) determined that the contextual interference effect is generally reliable in laboratory settings but is less reliable   in applied studies and when participants are children. Children have been found to learn effectively in both low (blocked practice) and moderate contextual interference conditions (Pigott & Shapiro, 1984; Rey, Whitehurst, & Wood, 1983). In addition, groups may perform similarly at acquisition, but at retention or transfer the random group will exhibit superior learning (Pollock & Lee, 1997; Ste-Marie, Clark, Findlay, & Latimer, 2004). Despite inconsistent results in applied settings, strong motivation remains for contextual interference research because of its potential application to teaching situations (Lee, Chamberlin, & Hodges, 2001). Considering practice from the viewpoint of blocked and random orders is highly relevant to musicians. For example, in the common assignment of practicing three scales, should the student do all repetitions of Scale 1, then all repetitions of Scale 2, and then Scale 3 (blocked practice)? Or should the student cycle through Scales 1, 2, and 3 and then repeat that pattern several times (a form of random practice)? Questions such as these only recently have been addressed in musical contexts (Rose, 2006; Stambaugh & Demorest, 2010). Rose compared a control condition, a blocked order, and a varied (random) order for learning right-hand-lead snare drum sticking tasks by university music majors who were not percussionists. Consistent with the contextual interference hypothesis, the random group performed the most errors at the end of one practice session. However, there were no significant differences among groups at retention or transfer for rhythmic accuracy or sticking accuracy. Stambaugh and Demorest investigated the effects of blocked (changing melodies every 6 minutes), serial (changing melodies every minute), and hybrid (changing melodies every 2 minutes) practice schedules on an eight-measure melodic task. Seventh-grade clarinet and saxophone students completed one practice session and a 24-hour retention test. No significant main effects were found among groups for rhythm and pitch accuracy, musicality, or attitude toward practice condition. A significant interaction was found for musicality, with musicality scores improving from Day 1 to Day 2 for blocked and serial participants, but decreasing for hybrid condition participants. The results of these two studies and previous motor studies raise further questions about the effects of blocked and random schedules in musical contexts. How do the length and nature of musical tasks, or participants' prior experience, interact with cognitive load? Can a framework of practice trials be used, instead of practice time, to eliminate the mini-block effects present in 1-minute practice chunks? Can the level of contextual interference be made even lower than in previous research by employing a multiple-day design? The purpose of the current study was to address these questions by examining the effects of blocked and random practice schedules during three practice sessions on performance accuracy, speed, and temporal evenness by beginning clarinetstudents. Based on the contextual interference hypothesis, the following assumptions were examined: 1. Students in the blocked condition will perform more accurately, faster, and more steadily than students in the random condition at the end of practice (acquisition).   2. Students in the random condition will perform more accurately, faster, and more steadily than students in the blocked condition at 24-hour retention and transfer testing. In addition, an attitude measure was included at retention to examine differences between groups for attitude toward practice. Method Participants (N ! 41) were beginning clarinet players recruited from 16 elementary schools in five school districts from the northwest United States. Students were enrolled in the first year of theirschool band programs, which started in either fifth orsixth grade, depending on the district. Students with private lesson experience on non-wind instruments were included in the study, but students with private lesson experience on the clarinet were excluded. University and school district institutional review board approvals were obtained, parents gave informed consent, and students gave assent. I composed the stimuli to meet several constraints. Because the beginning clarinet students had been playing only for a few months, their range was limited to about one octave. The screening tasks (see Figure 1) were designed to ensure that students could play concert A, B-flat, C, D, E-flat, and F. The first practice example was composed and then transposed into two additional keys to control for potential confounds from aural aspects of the stimuli. Anovel pitch, concert E, F-sharp, or C-sharp, was included in each practice example to prevent possible ceiling effects that could arise from using only familiar pitches. Four students from another beginning band program in one of the participating districts successfully completed a 4-day pilot test. Pilot students' performances did exhibit increasing accuracy and speed throughout the pilot study. Therefore, the stimuli were determined to be challenging enough and the study procedures appropriate. Performance measures were speed, pitch accuracy, and temporal evenness. Speed was measured in hundredths of seconds from the onset of the first pitch to the onset of the last pitch, using the internal timer in Cubase software. I measured pitch accuracy through repeated listening, employing a point deduction scoring system (range: 0–7) used in a previous study (Stambaugh & Demorest, 2010): 1 point deducted for each incorrect, skipped, repeated, or added pitch, and 2 points deducted for each instance of stopping or starting over, with only the second attempt scored. A second expert judge scored 15% (534) of the trials for accuracy, and interjudge reliability was satisfactory (r ! .85). The use of speed and pitch accuracy enabled analysis of the speed–accuracy trade-off, a phenomenon describing the inverse relationship between speed and accuracy in motor tasks. Generally, as a person moves more quickly, his or her accuracy toward a target will decrease (Schmidt & Lee, 2005). Parameters such as intonation, tone, and articulation were not evaluated due to the wide range of abilities among clarinet students in their first 6 months of study, as well as a desire to maintain high scoring standards by evaluating only the most salient features of beginner performance.   The pitches in the examples were written with the same duration (see Figure 1), permitting temporal evenness to be defined as variability of the interonset intervals (IOIs) between notes within each trial. To measure temporal evenness, the individual trials were exported from Cubase into Audacity software. The IOIs of each interval Figure 1. Performance tasks, as presented to participants Screening tasks determined covariate score; Examples 1, 2, and 3 were played during practice Trials 1–18 (including acquisition) and at 24-hour retention;transfer tasks were played at the 24-hour retention session.   were determined to the hundredth of a second using the internal timer in Audacity. The following equations were then applied: | IOIx – IOIm | ! IOIΔ, Σ IOIΔ / Σ IOI1 , which determined the average IOI per trial, relative to trial duration. Evenness was measured only for acquisition, retention, and transfer trials due to the time-intensive nature of such analysis. A fourth dependent variable was attitude toward practice, which was measured by a six-statement questionnaire. Hewitt (2001) noted the importance of measuring attitude because children may choose not to use a practice strategy if they do not enjoy it or think it is ineffective. The questionnaire addressed three topics: (a) Did the student think his or her practice schedule was effective? (b) Would the student use that practice schedule in future practice? (c) Did the student find the practice satisfying? Each topic was stated in two items: one positive and one negative. The scores of the negative statements were reversed for generating the total attitude score. A 4-point Likert-type rating scale was selected because verbal descriptors could be generated at a fifth-grade level and 4-point scales have been used in previous practice research (Hewitt, 2001). Design. The design was modeled after J. B. Shea and Morgan's (1979) study, which was the first investigation of contextual interference with motor tasks. Students within schools were assigned randomly to either the blocked (n ! 22) or random (n ! 19) practice condition. Participants began by completing a screening task; this score was used as a covariate. During one week, students completed three practice sessions and one retention testing session. In the blocked condition, participants played 18 trials of one example on each day, creating the lowest possible level of contextual interference. In the random condition, participants played six trials of each of the three examples in a random order (e.g., Example 2, Example 3, Example 1, Example 3, etc.) on each day. In both practice conditions, the final three practice trials of each example were designated as the "acquisition" score (performance ability at the end of practice). Twentyfour hours after acquisition Trials 16, 17, and 18, participants performed retention Trials 19, 20, and 21, and then three transfer trials of each transfer task. Complete experimental designs evaluating the effect of blocked and random practice schedules also include examining potential interactions between acquisition order and retention orders. Participants in each practice group are divided and assigned to retention testing in either blocked or random orders. Given the inconsistency of previous results (Hall, Domingues, & Cavazos, 1994; Landin & Hebert, 1997; Moreno et al., 2003; C. H. Shea et al., 1990; J. B. Shea & Morgan, 1979; Ste-Marie et al., 2004), it was deemed appropriate to include this variable in the present study. Retention testing occurred 24 hours after the third practice session, with participants within each practice group randomly assigned to perform three retention trials of each example in either a blocked or random order (BB ! blocked practice/blocked retention, BR ! blocked practice/random retention, RR ! random practice/ random retention, RB ! random practice/blocked retention). Assignment to the blocked or random retention order was distributed across schools and gender. The transfer trials, performed after the retention trials, were performed in a blocked order by all participants. Students completed   the practice questionnaire immediately after the transfer trials. The design was fully counterbalanced. Procedure. Students began by playing the screening tasks individually. All other sessions were conducted in groups of 1 to 7 students, depending on the number of participants per school. The students sat in a semicircle, while I was in center front, in a manner consistent with public school lesson instruction. I recorded all performance trials digitally at 16-bit 44.1 kHz sampling rate with Nady CM-60 miniature condenser lavalier microphones attached to the clarinet bell. These were connected to a PreSonus FireStudio interface into a MacBook Pro laptop running Cubase LE4 software. The use of individual microphones and multitrack recording software allowed each clarinetist's performance to be recorded as a separate track within an ecologically valid group practice setting. I led all study sessions. At the first practice session, I introduced the novel sharp note of the first music task by the playing it on a clarinet and then displaying the fingering on a large fingering chart. I presented the fingering chart throughout all the practice and retention testing sessions. Next, students played the first example very slowly, while I observed any errors. I informed students of errors, and these were remedied before moving on to the practice phase of the session. Students practiced 18 trials on each practice day in either blocked or random order, receiving knowledge of results about accuracy in the form of verbal statements, which I gave every third trial. A 2-minute rest break occurred after 9 practice trials. Study materials did not go home with the students, and students were instructed not to practice the examples between class sessions. Results Accuracy and speed scores were determined for every trial performed (3,554 trials). Temporal evenness was scored for acquisition, retention, and transfer trials (1,286 trials). Scores from every 3 trials were averaged into a block (see Table 1). Tests indicated negative skew by both groups on most practice blocks for accuracy scores, and most blocks met the assumption of homogeneity of variance. Due to a linear relationship between means and standard deviations in many blocks of speed and evenness scores, these times were transformed logarithmically. Preliminary analyses. Before testing the null hypotheses, it was necessary to determine if testing order at retention interacted with practice group. If no significant interactions were found within practice groups (BB and BR; RB and RR), these groups could be collapsed to simply blocked and random. Separate univariate ANCOVAs were completed for accuracy, speed, and evenness at retention. The a priori alpha level for each ANCOVA was set at .016 using a Bonferroni adjustment to control for Type I error (this procedure was followed for all sets of ANCOVAs listed below). The omnibus tests indicated no reliable differences in accuracy or temporal evenness, but the omnibus test for speed was significant, F(3, 36) ! 9.501, p " .001, η2 ! .38. Pairwise comparisons indicated the significance was due to the between-practice group differences of BB and RB (p ! .007), BR and RB (p " .001), and BR and RR (p ! .002).   Therefore, the four testing groups were collapsed into two groups and labeled by their practice condition (blocked and random) for all subsequent analyses. Hypothesis testing. Null hypotheses were tested for each research assumption. The first assumption predicted that students in the blocked condition would perform more accurately, faster, and more evenly than students in the random condition during Blocks 1–6/Acquisition. Table 1 presents adjusted means and standard errors for both conditions in each block. Accuracy at acquisition was generally high for both groups (grand mean ! 5.4 out of 7). A repeated measures ANCOVA indicated no significant main effect of trial (p ! .59) and no Trial " Condition interaction (p ! .28) for accuracy. Likewise, an ANCOVA for temporal evenness at acquisition found that the blocked group did not differ significantly from the random group (p ! .35). However, a repeated measures ANCOVA on speed scores indicated a significant main effect of trial, F(5, 34) ! 5.052, p ! .001, η2 ! .11, with speed scores improving across trials, and a Trial " Condition interaction, F(5, 34) ! 4.346, p ! .004, η2 ! .06. Figure 2 shows that the blocked group averaged faster times than the random group during Blocks 1, 2, and 3. However, starting at Block 4, students in the random condition performed faster than students in the blocked condition. The second assumption predicted that students in the random practice condition would perform more accurately, faster, and more steadily than students in the blocked practice condition at 24-hour retention testing. Repeated measures ANCOVAs from acquisition to retention indicated no significant main effect of trial (p ! .25) Table 1. Adjusted Means and Standard Error for Accuracy, Speed, and Evenness Accuracy score (0–7) Speed in seconds Evenness in seconds Blocked Random Blocked Random Blocked Random M (SE) M (SE) M (SE) M (SE) M (SE) M (SE) Block 1 (Trials 1, 2, 3) 5.48 (0.18) 5.49 (0.19) 4.37 (0.30) 5.09 (0.32) n/s n/s Block 2 (Trials 4, 5, 6) 5.60 (0.20) 5.33 (0.21) 3.90 (0.29) 4.13 (0.31) n/s n/s Block 3 (Trials 7, 8, 9) 5.62 (0.16) 5.43 (0.18) 3.53 (0.25) 3.61 (0.27) n/s n/s Block 4 (Trials 10, 11, 12) 5.50 (0.18) 5.35 (0.20) 3.29 (0.21) 2.87 (0.23) n/s n/s Block 5 (Trials 13, 14, 15) 5.49 (0.22) 5.21 (0.23) 3.51 (0.38) 2.77 (0.41) n/s n/s Block 6/Acquisition (Trials 16, 17, 18) 5.47 (0.17) 5.67 (0.18) 2.92 (0.21) 2.41 (0.23) 0.16 (0.02) 0.14 (0.02) Block 7 (Retention) 5.51 (0.15) 5.89 (0.16) 3.96 (0.24)* 2.34 (0.26)** 0.20 (0.02) 0.13 (0.03) Block 8 (Transfer) 4.96 (0.25) 5.51 (0.27) 4.55 (0.30) 3.78 (0.33) 0.22 (0.02) 0.19 (0.02) n/s ! not scored; * ! significant within group, acquisition to retention trial, p " .001; ** ! significant between groups, blocked compared to random, p " .001.   Figure 2. Adjusted means and standard error for accuracy and speed Source: Data points represent the average of three trials.   or Trial " Condition interaction (p ! .44) for accuracy nor for temporal evenness (trial, p ! .47; Trial " Condition, p ! .06) or for speed (trial, p ! .22). Despite stability in accuracy and temporal evenness scores, however, a significant Trial " Condition interaction was found for speed, F(1, 38) ! 24.953, p " .001, η2 ! .92. Students in the random condition played significantly faster than students in the blocked condition at the retention stage, and the effect size was strong. Furthermore, pairwise comparisons indicated that students in the blocked condition played significantly slower at retention than they did at acquisition (p " .001). The second assumption also predicted that students in the random condition would exhibit superior performance on transfer examples. Repeated measures ANCOVAs for Block 6/Acquisition and Block 8/Transfer on accuracy, speed, and temporal evenness scores indicated no main effects of trial (accuracy, p ! .79; speed, p ! .24; evenness, p ! .90) and no Trial " Condition interactions (accuracy, p ! .36; speed, p ! .78; evenness, p ! .88). The results of the attitude questionnaire were examined at the descriptive level, due to the limited number of survey items. Participants in both groups responded positively to their practice conditions: blocked, M ! 3.03, SD ! .43; random, M ! 3.18, SD ! .49. Discussion The purpose of this study was to examine the effects of blocked and random practice orders in the ecologically valid setting of group beginning band instruction. There were no performance differences between groups at the end of three practice sessions. However, 24 hours after completing practice, random group participants were able to play significantly faster than blocked group participants without sacrificing accuracy. Performance speed by the blocked group participants actually deteriorated to the level of early practice trials. Participants in both groups expressed a positive attitude toward their practice conditions. The contextual interference hypothesis predicted that the blocked group would perform better at acquisition but that the random group would perform better at retention. Results of this study provide partial support for the second half of this hypothesis, because the random group did perform faster at retention. These findings are consistent with other applied studies with adults practicing badminton (Goode & Magill, 1986), baseball (Hall et al., 1994), and basketball (Landin & Hebert, 1997), as well as children practicing handwriting (Ste-Marie et al., 2004) and beanbag tossing in laboratory (Edwards, Elliott, & Lee, 1986; Pollock & Lee, 1997) and real-world settings (Baker, 2002; Pigott & Shapiro, 1984). However, unlike the contextual interference hypothesis, the extra challenge of random practice schedules did not moderate the random groups' performance at acquisition. Ste-Marie et al. recognized this pedagogical significance, noting it "implies that a child can maintain the same level of performance even when exposed to what might seem to be a more difficult task" (p. 124). Several alternatives could explain the divergence between the classic contextual interference hypothesis and the present results. First, unlike laboratory studies, the motor task for this study was an applied task of a musical nature. Variables in applied studies cannot be controlled as carefully as in laboratory studies (Brady, 2004). Regarding the musicality of the task, the stimuli were designed specifically to begin and end on tonic pitch. Students cultivated an aural imprint of the task, and as automaticity progressed, it is possible that this aural component facilitated a pitch-to-finger mapping that is not possible in nonmelodic tasks. Another possible explanation for the similarity between group performances at acquisition is differences between single-day practice designs (e.g., Rose, 2006; J. B. Shea & Morgan, 1979) and 3-day practice designs. In single-day designs and in the blocked group in this study, Block 6/Acquisition occurred on the same day as all practice trials: there was no sleep-based consolidation interval (Davis, 2009; Duke, Davis, Allen, & Goins, 2006). However, the random groups in the current study and in Landin and Hebert's (1997) study distributed their practice on each task over 3 days, allowing some consolidation to occur during the first and second nights prior to Block 6/Acquisition. This early consolidation may have overcome the initial benefit of blocked practice. Duke and Davis (2006) investigated how sleep-based consolidation affected participants' learning of two motor tasks (silent piano, five-note sequences) during the same practice session, finding that performance of both tasks improved significantly following overnight sleep. While those participants practiced only two tasks, and the participants in the current study practiced three tasks, Duke and Davis's findings suggest that more than one task may benefit from sleep-based consolidation. After practicing in either the blocked or random order, students in these groups were tested in either a blocked or random order. J. B. Shea and Morgan (1979) found that university students who practiced in a blocked order performed significantly slower when tested in a random order than when tested in a blocked order. For those adults, the mismatch between encoding and retrieval significantly affected performance. However, like Ste-Marie et al. (2004), I found no significant differences for accuracy, speed, or temporal evenness within practice conditions by children who were tested in random or blocked orders at retention. This is of interest because a random order is often more similar to actual musical performance than a repetitive order is. The ability to balance speed and accuracy reflects how skillful one is in performance (Drake & Palmer, 2000). The clarinetists were given the directions, "Perform as accurately [verbal emphasis added] and quickly as possible," placing a priority on playing the correct pitches before attempting to play faster. Students did maintain high accuracy standards throughout the practice sessions while improving their speed. Although this finding is contrary to motor learning research, it is consistent with other music–motor studies involving piano tasks (Palmer & Meyer, 2000; Palmer & van de Sande, 1993; Simmons & Duke, 2006). A possible motor explanation for this discrepancy is found in the results of Langolf, Chaffin, and Foulke (1976), who suggested that smaller limbs, including fingers, were less susceptible to task difficulty than larger limbs like arms. Alternatively, a musical factor such as maintaining the melodic integrity of the pitch sequence also could be a key factor to musicians' preservation of accuracy. Investigations of beginning instrumentalists' practice and performance   demonstrate that this concern for pitch starts early, as McPherson and Renwick (2001) found that beginners attend to pitch before rhythm to a large degree. The results of this study indicate that there may be a modest or selective learning advantage for beginning clarinet students practicing in a random order, but Rose (2006) found no differences between groups of college students practicing snare drum sticking. There were many differences between these two studies, including ages of the participants, number of practice sessions, retention delay, and aural nature of the musical task. In addition, the clarinet task was essentially a fine motor skill with the primary degrees of freedom in the fingers. The snare drum task was more similar to a gross motor skill, with the primary degrees of freedom in the wrist and/or elbow joints. Because there is only one other applied study of blocked and random practice schedules with a fine motor skill (Ste-Marie et al., 2004), it is not yet known if that alone could account for different results between these musical tasks. The practice orders implemented in this study could be considered a form of structured practice. Structured practice, which involves using a planned sequence of practice activities, has been found to be beneficial for students of all ages (Barry, 1990, 1992; da Costa, 1999). Because this study did not include a control group, it is not known how these results would compare to the progress students might make during their own free practice sessions. Rose (2006) included a control group to compare to her blocked and random practice groups, finding that both the blocked and random groups performed similarly to the control group for sticking accuracy but that the control group performed less accurately on rhythm. Implications and Recommendations for Music Education Results of this study demonstrate that repetitive practice may not always be the most effective strategy for beginning musicians. Teachers could structure class instruction using random orders, rather than relying exclusively on repetitive drill, and teach students how to structure their home practice in this way. For example, having identified three short pitch sequences within a longer melody, teachers would direct individuals or groups of students to play the sequences in a random order. The teacher could call out which sequence to play, students could choose the random order, or if SmartBoard technology is available, it could generate an order. It is important to note that this recommendation is a very specific practice strategy that is being suggested for use with short pitch sequences that pose technical challenges. When a similar strategy was investigated previously (Stambaugh & Demorest, 2010) using eightmeasure songs, no significant differences were found among groups for pitch or rhythm accuracy. In order for beginning students to use a specific practice strategy, they must be able to self-regulate their practice. Many descriptive studies have shown that beginners make very limited use of self-regulated practice strategies (Austin & Berg, 2006; Hallam, 2001; McPherson & Renwick, 2001; Pitts, Davidson, & McPherson, 2000). Therefore, it would be critical for teachers to help students make this application   at home. This isolation of particular technical challenges may encourage the development of effective "analytical" practicers (Rohwer & Polk, 2006). Although the results of this study apply only to a specific instrument, student level, and nature of musical task, they invite researchers to examine random practice schedules in other musical contexts. Blocked and random practice schedules manipulate the cognitive load present during practice. Therefore, it would be interesting to examine this impact with other instruments, especially in the brass and violin families, that may place greater cognitive demands on performers. Because cognitive abilities change across a lifetime, age may have a significant influence on the effects of practice schedules. Likewise, experience also has been shown to be a critical factor in applied motor learning studies. It would be worthwhile to include musicians at the high school, college, professional, and amateur adult levels in future studies. Other group designs could include a blocked schedule of 1111 2222 3333 each day, controlling for consolidation effects because both groups would be practicing the same tasks an equivalent number of trials on each day. Finally, blocked and random schedules should be compared with a control group schedule to ascertain how the performance improvementsseen here would compare to improvements that students would have made in their usual practice. Researchers in this area need to select carefully the musical tasks participants will practice. The number of specific pitches in the tasks needs to be considered, because motor learning tasks should represent a task that can ultimately be thought of as a unit. In addition, a critical factor for designing control group procedures will be determining the duration of practice: How will the researcher match the practice trials in blocked or random practice orders to a time measure (or some other measure) in a control setting? In this study, I investigated an alternative to traditional, repetitive methods of practice. Instrumental practice has been investigated primarily from the assumption that what experts do is what learners at all ability levels should do. Since most beginners are significantly younger than experts, questioning this assumption is a valid concern. In addition, arming beginning band teachers with specific recommendations for their first-year students' practice may enable students to be more efficient and effective in their practice. Author's Note This article is based on the author's dissertation, "Effects of Blocked and Random Practice Schedules on Performance by Beginning Wind Players," completed at the University of Washington in 2009. Declaration of Conflicting Interests The author declared no potential conflicts of interests with respect to the authorship and/or publication of this article. Financial Disclosure/Funding The author received no financial support for the research and/or authorship of this article.   Note 1. For each trial, the average interonset interval (IOI) of the six intervals was determined (IOIm) and subtracted from the IOI of each individual interval (IOIx) in the trial. This produced six scores for the differences between individual IOIs and the mean within the trial. The sum of all difference scores (∑ IOIΔ) was divided by the sum of the IOIs for the trial (∑ IOI).

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