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SIG 22 Neuroscience and Education Symposium

From neuroscience to the classroom: Emotions are not left in the lunch-break

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Symposium Abstract

The primary aim of the symposium is to present research from different fields of Neuroscience and Education to demonstrate how an integrative approach can provide new insights into our understanding of learning and instruction. To do this, research on a single theme will be presented from neuroscience, cognitive, and educational perspectives. One research theme considered critically important for learning is cognition-emotion interactions. For example, cognitive abilities and anxiety have been shown to interact to affect math problem solving abilities. fMRI and ERN evidence suggests that students with math anxiety have impaired attentional control during math and numerical tasks. Cognitive research has demonstrated mutual influences between cognitive abilities and math anxiety, which can lead to declines in cognition and increases in anxiety, which can affect students' math problem solving. Educational research has shown that children with math learning disabilities are likely to experience math anxiety. Taken together, an interdisciplinary approach to math anxiety research builds a more comprehensive understanding of the relationships between cognition and anxiety in math learning and implications for educational practices.

This second symposium of the Neuroscience and Education SIG will build from the inaugural 2014 symposium. During the 90-minute symposium junior researchers from three different fields will present research on math anxiety, followed by a critical discussion of how neuroscience research can inform education and vice versa, and the challenges and advantages of conducting interdisciplinary research in neuroscience education.

Chair of the symposium: Kelly Trezise [1,2] (kelly.trezise@gmail.com)

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Individual Presentations

1. **Title:** The role of inhibitory control in adolescent mathematical and scientific reasoning

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2. **Title:** Longitudinal relationships between math anxiety and basic arithmetic skills among primary school children

Authors: Riikka Sorvo[1], Tuire Koponen[1,2], Helena Viholainen[1], Tuija Aro[2,3], Eija Räikkönen[4], Pilvi Peura[1] & Mikko Aro[2]

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3. **Title:** Characterising math anxiety experienced solving algebra problem

Authors: Kelly Trezise[1,2] and Robert A. Reeve[1]

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4. **Title:** Educational Neuroscience and its contribution to learning and instruction: A critical review

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Presentation Abstracts and Summaries

The role of inhibitory control in adolescent mathematical and scientific reasoning

Annie Brookman

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Abstract

According to the traditional view of learning in maths and science, naïve theories are *replaced* in the face of new evidence. However, recent neuroimaging research with adults suggests that old theories *remain* even when new ones are learnt. Inhibitory control, the ability to stop a prepotent response, is thought to enable the suppression of incorrect theories. While this seems to be the case for adults, the relationship between inhibitory control and reasoning about counterintuitive maths and science concepts in adolescence is largely unknown. Adolescence is a particularly important time for maths and science reasoning as pupils work towards their compulsory exams in these subjects. In the first of the current studies, ninety 11- to 15-year-olds observed counterintuitive maths and science statements and judged whether they were correct or not. Across ages, performance on the counterintuitive reasoning task was associated with performance on a semantic inhibition (Stroop) task and a response inhibition (Go/No-Go) task. This suggests that inhibitory control does play a role in adolescents' maths and science reasoning in the form of suppression of an intuitive but incorrect answer. In order to test this hypothesis more directly, two further studies were designed. A functional magnetic resonance imaging study of similar measures investigated the overlap between brain areas used in these tasks. A classroom study was designed to examine the role of inhibitory control in *learning* new counterintuitive concepts. This set of studies has helped to uncover more about the relationship between inhibition and counterintuitive concept reasoning.

Extended summary

Maths and science learning requires the integration of new evidence about the world into one's existing theories. According to the traditional view of learning, naïve theories are replaced in the face of new evidence. However, recent neuroimaging research with adults suggests that in fact old theories remain even when new ones are learnt. When correctly solving counterintuitive science problems, expert scientists recruit the lateral prefrontal cortex and anterior cingulate cortex. These areas of the brain are associated with conflict monitoring, error detection and inhibitory control, the ability to stop prepotent response. Inhibitory control therefore seems to enable the suppression of naïve beliefs and misleading perceptual cues in the processing of counterintuitive material. While this seems to be the case for adults, the relationship between inhibitory control and reasoning about counterintuitive concepts in adolescence is largely unknown. Adolescence is a particularly important time for maths and science reasoning as pupils work towards their compulsory exams in these subjects. The studies described here aimed to uncover the role of inhibitory control in adolescent maths and science reasoning through a range of methods: behavioural research to discover relationships between cognitive abilities, neuroimaging research to examine shared neural correlates of abilities, and classroom research to see how learning occurs in a typical classroom setting. The studies are ultimately geared towards the design of future training studies to enhance maths and science performance in adolescence.

The first of the current studies investigated the relationship between inhibitory control and a novel maths and science counterintuitive reasoning task in adolescence. Ninety 11- to 15-year-olds observed counterintuitive maths and science statements, pictures, and equations, and judged whether they were correct or not. A set of control questions that were not counterintuitive were also presented. A Stroop task measured semantic inhibition, where *meaning* must be suppressed, and a Go/No-Go task measured response inhibition, where an *action* must be suppressed. Regression analyses found that across ages, when controlling for general cognitive ability and performance in the control questions, individual differences in performance on the counterintuitive reasoning task were associated with individual differences in performance on both inhibition tasks. This was the first behavioural evidence that inhibition seems to be important for adolescents in suppressing incorrect theories or misleading perceptual cues: the inhibition of an intuitive but incorrect response.

The results of this study led to the design of a functional magnetic resonance imaging study. Here the expectation was that there would be overlap in neural activation for the inhibitory control tasks and the counterintuitive maths and science reasoning task. While the previous research with adults found activation in areas associated with inhibitory control during science reasoning, these studies included no measure of inhibitory control in the scanner. This study with adolescents included semantic and response measures of inhibitory control to be performed inside the scanner. The counterintuitive maths and science task used a similar format to the behavioural study described above: counterintuitive and control statements that are judged as true or false. The study design also included a number of measures outside of the scanner. Verbal and non-verbal measures of general cognitive ability were included, as well as working memory measures. Maths and science anxiety questionnaires were included, since anxiety is known to impact both school performance and inhibitory control. Finally, socioeconomic status was included as a variable through the comparison of low and high socioeconomic groups. Again, previous research has shown that both school performance and inhibitory control are affected by this measure.

A final study was designed to investigate the role of inhibitory control in learning new counterintuitive concepts in the classroom with the prediction that inhibitory control ability would predict learning and retention of the concepts. Both the adult literature and this work with adolescents suggests that inhibitory control training within the context of maths and science curricula could help to improve pupil performance in these subjects. Executive function training programmes tend to show improvement in the skill being trained, with little transfer to non-trained questions or topics. Future work should therefore aim to train inhibitory control within the context domain, to enhance the likelihood of meaningful, school-related improvement. This research highlights the importance of ensuring stimuli used in behavioural and neuroscientific studies are relevant for education. Within the studies discussed here, the concepts tested were all relevant for the UK school context and aimed to provide findings applicable to the classroom. A suite of behavioural, neuroimaging, and classroom-based studies such as this has the potential to move the field forward scientifically, while providing educationally-relevant findings.

Longitudinal relationships between math anxiety and basic arithmetic skills among primary school children

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Abstract

Already first-graders have been shown to report math anxiety, but still little is known about its development during primary school. Causal relations between math anxiety and performance remain unclear, especially among children. The aim of this study was to examine the development of math anxiety in primary school children and the relationships between basic math skills and the two math anxiety dimensions. Participants (n=1326) were primary school children from grades 2 to 5, and they were assessed three times in a time period of one year. Math anxiety was measured with altogether six items and basic arithmetic skills were assessed with three tests focusing on addition and subtraction tasks. The longitudinal relationships between the math anxiety dimensions and basic arithmetic skills were examined using cross-lagged modeling. The development of math anxiety was examined with latent growth modeling. The findings indicate that, among primary school children, individual differences in math anxiety are less stable over time than those in basic arithmetic skills. Previous level of anxiety about failure in mathematics predicted later anxiety about failure, and anxiety about math-related situations predicted later anxiety about math-related situtions. However, the two math anxiety factors did not predict each other nor later basic arithmetic skills. Low early basic arithmetic skills predicted later anxiety about failure, but the effect size was small. On average, anxiety about failure in mathematics did not change during the follow-up in any grade level, but anxiety about math-related situtations decreased during 2nd and 3rd grades.

Extended summary

Aims

In his meta-analysis, Hembree (1990) concluded that among adolescents and adults math anxiety weakens math performance, but that there is no evidence suggesting that poor performance would increase anxiety. However, already second and third grade children with math learning disabilities have been found to differ from their low and typically achieving peers with respect to the level of math anxiety (Wu et al. 2013). Thus, the causal relations between math anxiety and performance among young children remain unclear. In addition, little is known about the developmental sequelae of math anxiety.

The aim of this study was to examine the development of math anxiety in primary school children and the relationships between basic math skills and math anxiety. We examined two different math anxiety factors: *anxiety about math-related situations* and *anxiety about failure in mathematics*, of which the former has been found to be cross-sectionally more strongly related with math performance than the latter (Sorvo et al., submitted).

Method

Participants of the study (n=1326) were primary school children, from Grades 2 to 5 (637 girls and 689 boys) from 20 schools in Central and Eastern Finland. Parental written consent was received for all participating children.

Basic arithmetic skills of the participants were assessed with three time-limited group tests. Addition Fluency Test and Subtraction Fluency Test (Koponen & Mononen, 2010a, b) consist of simple addition/subtraction tasks and the three-minute Basic Arithmetic test (Aunola & Räsänen, 2007) consists of addition, subtraction, division and multiplication tasks. *Anxiety about failure in mathematics* was assessed with questions adopted from Math Anxiety Questionnaire (Thomas & Dowker, 2000): "*How anxious or relaxed would you be if you were unable to…?"* targeting mathematics in general, mental calculations and math homework. *Anxiety about math-related situations* was assessed with three statements tapping anxiety or tension arousal in situations involving mathematics. Both basic arithmetic skills and math anxiety were assessed three times during one year.

Mplus was used for all main analyses. First, the longitudinal relationships between the math anxiety dimensions and basic arithmetic skills were examined using cross-lagged modeling. Then, the development of math anxiety was examined with latent growth modeling.

Findings

The factor loadings and intercepts of the observed variables, as well as cross-sectional relationships between the factors, were invariant across time and across all grade levels. The results of the cross-lagged model showed that individual differences in basic arithmetics were highly stable across time (from Time 1 to Time 2 β =.95, $p < .001$; from Time 2 to Time 3 $\beta = .97$, $p < .001$). Previous level of anxiety about failure in mathematics predicted later anxiety about failure (from Time 1 to Time 2 $\beta = .54$, $p < .001$; from Time 2 to Time 3 $\beta = .51$, $p < .001$) and anxiety about math-related situations predicted later anxiety about math-related situations (from Time 1 to Time 2 $\beta = .44$, p <.05; from Time 2 to Time 3 $\beta = .51$, $p < .001$). Anxiety about failure and anxiety about math-related situations did not predict each other nor later basic arithmetic skills, but low basic arithmetic skills predicted later anxiety about failure (from Time 1 to Time 2 $\beta = -.08$, $p < .05$; from Time 2 to Time 3 $\beta = -.14$, $p < .001$).

The levels of the two math anxiety factors were positively, significantly related (r = .78, p < .001), as well as the changes over time (r = .52, p < .01).

The latent growth model revealed that the change in anxiety about failure was not statistically significant for any grade levels. Anxiety about math-related situations decreased in 2nd ($M = -1.31$, $SE=1.64$ $p < .05$) and 3rd graders ($M = -1.44$, $SE=1.64$, $p < .05$), but there was no significant change in 4th and 5th graders.

Theoretical and educational significance

These preliminary results show that individual differences in math anxiety are less stable over time than those in basic arithmetic skills among primary school children. It seems that the causal relationship between math anxiety and perfomance is different in the beginning of the schooling than later: in primary school, math performance predicts math anxiety, whereas among adolescents and adults evidence of such causality has not been found (Hembree, 1990). On average, anxiety about failure in mathematics did not change during the one-year follow-up in any grade level, but anxiety about math-related situations decreased during 2nd and 3rd grade. The individual differences in the development of math anxiety should be investigated in the future for understanding both risks and protective factors.

Characterising math anxiety experienced solving algebra problem

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Abstract

It is well recognized math anxiety (MA) affects math problem solving performance. However, it is currently unknown how MA changes as a function of problem solving difficulty. Nearly all MA assessment is based on questionnaire responses, which tacitly assume that MA is a trait construct. However, fMRI and physiological evidence suggest that MA co-varies with math problem difficulty. Understanding how problem context and/or difficulty affect MA may help clarify its effects on math achievement. If a student's MA is higher for difficult problems, it may impair their ability to learn new math material or result in math avoidance. If a student's MA is higher under time pressure it may affect test outcomes. To address these issues, we examine whether MA changes as a function of problem solving difficulty and time pressure.

We report findings from two studies in which adolescents rated their worry as they solved algebra equations and time available to solve them (short or longer time). Algebra equations reflected those used in Australian high schools, and ranged from simple arithmetic-style equations, through to complex linear algebra. Latent variable analysis identified four patterns of problem solving accuracy, and five worry profiles that varied as a function of equation-type and presentation time. Worry profiles were associated with problem solving accuracy patterns. Findings suggest that a students' MA changes as they engage in math problem solving. One implication of this finding is that different aspects of math classroom situations (e.g. problem difficulty or time pressure) elicit anxiety in different students.

Extended Summary

Math anxiety (MA) is associated with poor achievement and avoidance of math in high school and beyond. Most MA studies use questionnaires to probe the anxiety experienced solving general math problems; and, questions tend to focus on arithmetic difficulties, even though arithmetic is well-practiced by early high school. Arguably, a better understanding of MA and its sequelae would be gained by investigating anxiety associated with high school math (e.g., algebra). Moreover, questionnaire derived measures seem to tacitly assume MA is a trait, rather than a state than may vary as a function of context. However, fMRI and physiological evidence suggest that MA changes with math problem difficulty (Lyons & Beilock, 2012; Suárez-Pellicioni et al., 2013), which implies that MA is a state rather than a trait. We argue a more complete model of MA requires a fine-grained understanding of these issues.

Previous research has examined different patterns of MA-cognition relationships, and how MA and cognition interact to impact individuals' MA and/or cognition relationship within short time periods (Trezise & Reeve, 2014a, 2014b, 2016). Different patterns of MA were be identified (as well as different patterns of cognition—specifically, working memory) and these interact and change over time in predictable ways. While this research provides insight into the complexity of changing MA-cognition relationships, it does not address the issue of how problem solving context and/or difficultly affect MA-cognition relationships. To address these lacunae, we conducted two studies that examined whether MA changes as a function of problem solving difficulty and time pressure.

In Study 1, 129 14- year-olds' rated the worry (the cognitive component of anxiety) they experienced as they solved algebraic equations. Five levels of algebra equations were presented, akin to very easy through to very hard problems. Equations were developed from an integration of school curriculum, and known mathematical conceptual development. Students completed two versions of the task on different days: a slow and a fast version. Latent variable analysis (LVA) was used to analyse worry as a function of equation difficulty and task version, and accuracy patterns as a function of equation difficulty and task version. A step-three analysis procedure was employed to examine the relationship between worry profiles and algebraic accuracy clusters. The findings show that worry profile membership predicted problem solving accuracy cluster membership. Students in the No Worry and Low Worry profiles were more likely to belong to an accurate problem solving cluster; students with High Worry or worry that increased with problem difficulty were more likely to belong to an inaccurate problem solving cluster.

While Study 1 showed patterns of MA were associated with algebraic problem solving accuracy, it was unable to examine the relationship between MA and math/algebra learning. Previous research has shown that MA change with age and is likely to peak around 14 years of age, and poor math achievement predicts increases in MA (Ma & Xu, 2004). In a second study, the relationship between MA and algebraic problem solving in three grades was examined to (1) examine whether MA changes with development/age, (2) characterise patterns of algebraic problem solving development, and (3) examine whether patterns of MA are related to algebra development.

Specifically, Study 2 sought to examine whether the algebraic worry and accuracy patterns identified in Study 1, changed with age. One-thirty-eight 14- to 16-year-olds, from grades 8, 9, and 10 completed a modified algebraic problem solving task and rated their worry as they completed each problem. LVA was used to identify worry profiles and accuracy profiles. Analyses examined the degree to which algebraic worry and/or algebraic problem solving accuracy change across age. Findings revealed grade predicted accuracy cluster membership, but not worry profile membership. Finally, relationships between worry profile membership and accuracy cluster membership similar Study 1 were found, indicating that relationships between MA and algebraic ability do not vary with age/development.

Findings imply that different aspects of math problem solving contexts, such as difficulty or time pressure, elicit different anxiety in different students. The research provides insight into students' MA while engaging in problem solving, and some likely stumbling blocks that affect algebraic problem solving. For many students, MA is higher for harder math problems, and given MA reduces cognitive capacity, findings suggest these students' cognitive abilities may be most impaired for difficult math problems. The findings demonstrate that latent variable modeling can be used to characterise the relationships between emotions and cognition in learning contexts. Moreover, understanding triggers of increases in MA may help institute educational practices to minimize anxiety experienced in the classroom.

Educational Neuroscience and its contribution to learning and instruction: A critical review

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Abstract

"Neuroscience and Education" is a relatively new field of scientific inquiry based on three core disciplines: neuroscience, psychology and education. The purpose of the field is to develop a more complete characterisation of the factors involved in learning, and use this understanding to inform practices to improve instruction and reduce the impact of learning difficulties. However, a number of challenges have been levelled at the education neuroscience field, centred on the pragmatics of interdisciplinary research. The aim of this presentation is two-fold: first, to provide a background to contextualise the methodological differences of the other three interdisciplinary talks in the symposium, and second, to present a critical review of current educational neuroscience research. We identify issues that arise from adopting a modular approach to research, focusing on neuroscience, psychology, or education. Rather, an integrative approach that links the knowledge of all three disciplines has the ability to contribute to our theoretical understanding of learning processes, and inform educational practice. We outline methodological challenges that need to be considered in order to create fruitful interdisciplinary research. Overcoming these challenges and developing an integrative interdisciplinary approach, educational neuroscience has the potential to develop novel research approaches that enhance our understanding of the functioning brain, the thinking child and the learner.

Extended Summary

The field of "Neuroscience and Education" represents an inherently interdisciplinary approach to addressing the challenges posed by education in a dynamic world. The relatively new scientific field encompasses multiple research methodologies (neuroscience, psychology, education) and pedagogical orientations. The objective of the field, in combining these difference disciplines, is to better characterise learning processes, in order to inform instructional practice, and develop remediation practices that reduce the impact of learning difficulties. In essence, Neuroscience and Education is the science of learning and instruction. However, like any new field there are obstacles to overcome in the establishment of the science and relevance of Educational Neuroscience. Indeed there is some scepticism regarding the integration of these disciplines given their different scopes and methods (Bowers, 2016). Without overcoming these issues, the development of the field could be undermined. Accordingly the aim of this paper is to provide a critical review of the current state of educational neuroscience research, and discuss implications for measurement and characterisation of learning and instruction.

We examine the current research in two ways. First, we examine the integration of neuroscience, psychology, and education research, addressing some of the current criticisms levelled at the interdisciplinary nature of the field. Second, we examine the contributions of each domain that comprises “educational neuroscience” research by analysing measures and methodology employed to assess learning.

Examination of educational neuroscience literature shows that some studies are adopting an integrative approach with the aim of linking the knowledge of all three domains. Conversely, many studies continue to use a modular approach, focusing on neuroscience, psychology, or education.

Inconsistencies between education, psychology, and neuroscience raise questions as to the structural and integrative nature of the disciplines that make up educational neuroscience. For example, attention and emotional behaviours in a classroom learning environment tend to implicitly refer to disruptive behaviour, whereas attention and emotion in psychology and/or neuroscience can refer to a broad range of phenomena represented by a wide range of tasks. These inconsistencies in terminology restrict the ability to communicate, and consequently integrate, across disciplines. However, research that has been able to successfully integrate between the three disciplines contributes to understanding learning processes and informing instructional practices (e.g., . Lee, Fincham, Betts & Anderson, 2014).

Tasks used in neuroscience and psychology research, by necessity, are often substantially different from classroom-based tasks. To examine spelling ability, for example, most fMRI and/or EEG experiments use some form verification tasks as an indices of spelling ability (e.g., Harris, Perfetti & Rickles, 2014). However, few examine the relationship between spelling production (as used in classrooms) compared to spelling verification. It is therefore possible that the ability to detect spelling errors (i.e., notice) does not represent a child's ability correctly spell the same word. Without establishing validity between classroom learning and the tasks used by neuroscience and psychology, the teachers may question the potential contribution of neuroscience and psychology for classroom practice.

Many neuroscience and psychology studies use differences between individuals on a general ability task as a proxy measure of classroom learning. Fewer studies examine changes in task performance to characterize or examine learning. Without reference to how individuals change over time, the ability to evaluate educational effectiveness, and/or characterize learning processes is limited.

On the basis of the critical review, we argue that considerable work is still required to develop the field of Educational Neuroscience, but that progressing towards this goal is expected to produce exciting benefits for learning and instruction. Individual differences in learning processes could be more broadly conceptualized, in order to provide targeted instruction for learning disabilities. In development of a more complete characterisation of learning capacities, integrative educational neuroscience research has the ability to inform, and learn from, curriculum and pedagogy. Inability successfully create interdisciplinary research with contributions from all three disciplines could weaken the relevance of neuroscience research to education theory and practice. Successful educational neuroscience should enhance our understanding of the functioning brain, the thinking child and the learner.