NEUROSCIENCE FOUNDATIONS IN TEACHER PROFESSIONAL DEVELOPMENT DELIVERS UNEXPECTED ADAPTIVE EXPERTISE OUTCOMES

Timothy Kieran O'Mahony[1], Conn McQuinn[2], Jenny Williamson[3], Nathan Abe[4], Helen Buckland[3,] Susanna Cunningham[3]

[1]Institute for Connecting Neuroscience with Teaching and Learning, Seattle, WA
[2]Puget Sound ESD, Seattle, WA
[2]University of Washington School of Nursing, Seattle, WA
[2]University of Washington College of Education, Seattle, WA

Abstract

This paper reports findings from a National Institutes of Health longitudinal study that introduced fundamentals of neuroscience to middle school teachers. Results offer immediate implications for how teachers teach and how adolescent students learn. In this timely study we deliver tangible findings to a growing field that connects neuroscience with teaching and learning. Theories in action are described and studies for future research are suggested. The main question focused on measuring learning outcomes when teachers increased their knowledge of how brains work and how children learn. Can one gain insights into how to teach from the knowledge that neurons communicate with action potential firings along axons? Is an increase in knowledge about axons, dendrites and how neurons communicate beneficial for teachers' practice and how can we measure this? An interdisciplinary team implemented a learning sciences pedagogical model, which translated research in neuroscience into practice and strategies for incumbent middle school teachers (N=125) in a regional (Puget Sound) Educational Service District. Cumulative evidence is described in a mixed methods model that includes quantitative data and ethnographic descriptive data. Findings illuminate tangible outcomes for teachers who received (i) a prescribed neuroscience course, and (ii) a follow-on tech-enabled PLC (Professional Learning Community) experience. Three learning outcomes are reported here—findings, which appear to move the needle toward adaptive expertise for middle school teachers in adolescent classroom settings: (i) all teachers gained relevant information relating to human anatomy and brain for adolescent learning, (ii) all teachers used brain-centric pedagogic models that 'made visible' student attitudes in areas like 'stress' and 'mindset' in adolescent learning, and (iii) a knowledge of neuroscience principles impelled teachers to define an 'edge' to their teaching capacity with regard to classroom methodologies and theories--an edge that we describe as 'adaptive' expertise. Future studies are suggested that focus on ideas for attenuating these particular outcomes in more in-depth studies that seek to increase teacher capacity and neuroscience footprint in classrooms beyond middle school.

Keywords: neuroscience, adaptive expertise, pedagogy, learning models.

1 INTRODUCTION

Twenty-first century schools are different. It's not just technology—smart boards, laptops, iPads, cell phones, cloud services, collaborative practices, and more. The world is different, students are different in a connected, distracting information age, and teachers and parents recognize the need to be different as a direct consequence to this historical change.[1] Teachers are often reminded that they are tasked with preparing students for jobs that have not yet been created, technologies that have not yet been invented, and problems that we don't know will arise.[2] Qualities that are recognized as twenty-first century requirements in youth are not measured by standardized tests that tend to drive educational marketplace and parental choice. These include skills and qualities like persistence, curiosity, enthusiasm, courage, leadership, creativity, growth-mindset, civic-mindedness, resourcefulness, self-regulation, sense of wonder, big-picture thinking, compassion, reliability, motivation, humor, empathy, sense of beauty, humility, and resilience.[3] Until recently, many schools were modeled on systems that were grounded in conveyor-belt (factory) thinking.[4-6] Neuroscience, although recognized as an important component of mind, memory, and cognition [7, 8], remained peripheral to school content delivery systems and indeed was rarely an integral part of teacher courses in professional preparation.[9] Although this paper focuses on connecting neuroscience with teaching and learning, the findings described herein are evidential outcomes defined by insights from cognitive psychology. Strategically, the focus and intentionality engages questions about teacher's capacity to achieve learning outcomes when knowledge of neuroscience underscores practice in daily activities in classrooms. However, children were not inserted into fmri machines; no scanning of brain activity is reported and no evidence of changes in neural structures is either explained or mapped directly with imaging techniques.

How Do I Learn (HDIL) was a project under the auspices of the National Institutes of Health Blueprint for Neuroscience Research program that sought to increase knowledge of neuroscience in middle schools for teachers, students, and for parents. As part of a five-year grant, HDIL personnel created courses, curricula and institutes that delivered information to teachers, administrators, coaches and principals in educational service districts serving the locale within the geographic milieu of the university where the HDIL team worked. In addition, they provided workshops for parents so that they too had immediate access to the same information that 'made visible' the specific knowledge necessary to understand the developmental process of a typical teenager's brain. Finally, as active participants in face-to-face summer institutes that focused on the neuroscience of learning, teacher teams experienced pedagogical models and related materials and were required to create a dynamic keystone project that illustrated their understanding of how brains work and how humans learn. This paper will describe the HDIL program, including processes, practices, and data for the duration of the five years that the program was in operation. Findings will be presented and discussion relating to these findings will illuminate ideas that emerged as a result of the work accomplished and the dissemination of a meaningful corpus of information. Next steps will be suggested in the changing field of mind, brain, and education.

While it could be claimed that more information was discovered about the human brain in the past 25 years than in the previous 250 years, unfortunately, this information rarely percolates with any great depth into specific spaces that are highly dependent on knowledge about brain function for their daily thrust—teachers, learners, trainers, coaches, and parents. Consequently, ideas about plasticity, intelligence, mindset, and potential were uppermost in the minds of leaders and participants in the HDIL Summer Institutes, given that these topics engage so deeply with learning and the brain.[10] For instance, emerging research [11] concerning a deep understanding of the impact of white matter (myelin) and its involvement for normal cognitive function, learning and IQ was an underlying theme in HDIL summer institutes.[1] Emerging knowledge about brain can have profound implications for teachers and learning sciences researchers since it serves to "illuminate an under-appreciated role of myelin in information processing and learning." (p. 361) One of the key capacities of HDIL was intentional ability to locate and translate new research that has implications for the classroom by devising practices and processes that are tangible for teachers and parents, and can offer help to teenagers by growing their awareness of brain models.

The HDIL study coincided with a focus on learning and neuroscience associated with political insights into advanced tools for classroom improvements. In the closing years of the 20th century a real effort to engage in brain awareness permeated learning theory during the *'Decade of the Brain'* where research investment was expected to bring advancement to areas of cognition and learning.[12-14] This new knowledge was coupled with a visceral drive to understand both conceptually and practically how the emergent field of neuroscience (aided as it was by persistent developments in technological advances in imaging techniques) could deliver systems and methods to classroom teachers and, also, advance learning theory.[15] In spite of advances in biological and anatomical knowledge, and in spite of increased spending on research and inquiry, application of neuro-scientific principles ran into many roadblocks with regard efforts to engage in practices that might improve teaching and learning. Caution was the watchword of the day. Scientists in fields long associated with pedagogy and psychology urged guarded acceptance of new ideas that included neuroscience in the classroom. For instance, the educational psychologist John Bruer (1997) affirmed that neuroscience and educational practice was undoubtedly a bridge too far. He asserted that "…educational applications of brain science may come eventually, but as of now neuroscience has little to offer teachers in terms of informing classroom practice."[16] With the passage of time however, and the accumulation of a greater body of knowledge, both learning scientists and neuroscientists recognized that innovative

---

[1] Dr. Fields' seminal work on white matter, which pointed out that myelination continues for decades in the human brain. His work affirmed that myelination is modifiable by experience, and affects information processing by regulating the velocity and synchrony of impulse conduction between distant cortical regions.

designs could allow this promising material to study the effects of variables of interest (e.g., context) in education. For instance, Varma (2008) concluded that a powerful way to improve education was to design and implement new learning contexts and interactions and in particular using FMRI experiments “to measure differences in brain activity after students have experienced different contexts.”[17, 18]

2 THEORETICAL FRAMEWORK

In this research project, we drew on the philosophic literature that describes adaptive expertise (AE) and the critical understandings that underpin this mode of thinking with particular reference to teaching and learning. HDIL theorized that teachers’ willingness and capacity to become ‘adaptive experts’ was essential for the success of implementing neuroscience pedagogies in the classroom.[19] In the expertise literature, Hatano & Inagaki[20] have identified two courses in expertise—routine versus adaptive—that define mindset and application. According to the AE school of thought, expertise is expressed in one of two dimensions decidedly orthogonal to one another; (i) processes that accelerate efficiency through well practiced routines, and (ii) processes that lead to growth and change through innovation and mindset.[21] Adaptive expertise has been further codified in educational settings[19, 22] as existential qualities of personal development that are as much emotion, resilience, and innovation as grit[23], and mindset.[24] Teachers, who are adaptive in their expertise, employ unique representations and methods to solve problems,[25] seek out opportunities for new learning in their practice,[26] successfully monitor their understanding of situations in a metacognitive manner,[27] and conceive of knowledge as dynamic rather than static.[28] We operationalized the measurement of adaptive expertise by defining categories and scoring output of EAs’ keystone deliverables that accounted for a deep understanding of how the brain works and how children learn. For instance, an EA who described a process for introducing and measuring the effectiveness of growth mindset in classroom activities (learners would develop positive self-esteem, and techniques for self-regulation) was scored on a scale of 1 – 10. Meanwhile an EA who focused his/her work on Skinnerian rewards or punishments (reducing a child’s recess time so that he/she could finish a Math homework) was scored on a similar scale only negative; -1 to -10. Methodology

HDIL team used a mixed method to make sense of the findings of this research program. Learning environments are invariably unbounded, non-linear, and messy. In classroom environments that are engaging and fun, outcomes are rarely attributable to causation principles in a simplistic manner, and it is often a stretch to assume that research data collected in these settings will converge on an indisputable ‘truth’ or panacea. Nevertheless, outcomes can be attributable to stimuli, interventions, and/or changes in methodologies/practices when evidence is demonstrable from situational angles, which point to causative impetus. A mixed method approach offers intriguing windows into what is really going on in ‘active’ learning settings. This method is used increasingly in social sciences because its nuances are more keenly aligned with the divergent issues that crop up in disorderly and often chaotic systems. Philosophically, mixed research methodologies make use of the pragmatic approach and system of thinking. Its logic of inquiry includes the use of induction (discovery of patterns), deduction (testing of theories and hypotheses), and abduction (uncovering and relying on the best of a set of explanations for understanding one's results.[29] To this end, triangulation events from a mixed method approach, provides breadth of perspective that illuminate issues we are interested in (for instance, could we assign functional adaptive expertise attributes to teachers who were intentional about metacognitive processes and growth mindset techniques). We were confident that variation in data collection associated with mixed method exposition would lead to measurable validity.[30] Finally, a mixed methods approach ensures that pre-existing assumptions articulated by the research team would be less likely, since this method allowed us to integrate data from several sources in order to clarify and/or better understand the problem space under investigation.

A team at the University of Washington’s School of Nursing collaborated with learning scientists at the university of Washington College of Education, LIFE Center (Learning in Informal and Formal Environments to deliver the HDIL program over a five-year period. The team was augmented by members of the University of Washington Professional and Continuing Education department and in close cooperation with the Puget Sound Educational Service District. Finally, expertise was culled from various other departments from within the colleges of psychology, health and sciences and neurosciences at the University of Washington and other third level institutions (e.g., expertise on sleep from a neuroscientist at Williams College, Massachusetts and expertise on stress from the Laboratory of Neuro-Endocrinology at Rockefeller University, New York). A central tenet of the program was to engage middle school teachers and their students (and to a lesser extent parents and the community), in a scientific program of neuroscience education. The objective was to increase middle school teachers' understanding about 'how students learn' as well as dispel common myths about brain and learning. Teachers were invited to attend a summer institute that presented current knowledge from neuroscience research relevant to brain and how children learn. HDIL intervention consisted of a two-part immersive and interactive program that engaged participant teachers in a one-week summer institute and follow-on professional learning community (PLC) program.

3.1 Subjects and Recruitment

Subjects were predominately middle school teachers serving the Puget Sound Educational Service District, Washington. Content expertise included middle school science, mathematics, English Language Arts, Library as well as Physical Education, counselors and several administrators. Participants were recruited through the University outreach emails and through partner organizations in the grant (e.g., Puget Sound Educational Service District, and University of Washington College of Education). A sample recruitment letter is attached in Appendix 3. Applications were restricted to teams (usually 3 to 6 individuals) that contained at least one middle school science teacher. In addition, preference was given to teams who represented Title 1 schools (high percentages of children from low-income families). An honorarium ($500) was awarded to successful candidates who fulfilled the academic requirements and attended/contributed to Summer Institute activities and deliverables. Academic credit and clock-hours were supplied to participant teachers who wished to advance their careers in this arena. Each participant was issued a schedule upon arrival at the orientation on day one (see appendix 1: Sample Schedule for EA Summer Institute) that outlined content, events and speakers during the week of the Summer Institute. All participants provided written informed consent, which was part of the recruitment and application process. No data was collected from any students for this study.

3.1.1 Instruments

Several instruments were drawn up to collect data. A thorough grounding in the biology and functional details of neuroscience was a requisite step to deep understanding of adolescent learning. To that end instruments were designed to ascertain the level of knowledge and changes that occurred as a result of the HDIL immersion.

- A Pre and Post instrument was produced in order to ascertain the level of neuroscience knowledge that on-the-job teachers were acknowledging as a result of immersion in the summer institute (see appendix 2: HDIL Summer Institute Pre-Survey 2015). The post survey is identical to the pre survey. In the survey, participants were asked to state their level of knowledge with regard to topics and content information that derived from neuroscience pertaining to teaching and learning.

- In addition, a similar Pre and Post Survey instrument was introduced in order to ascertain the impact of establishing an ongoing professional learning community (PLC) as a follow-on learning tool to advance the work of the project. The PLC that continued the work begun in the Summer Institute and focused on delivering similar experiences and materials for the remainder of the school year.

The goals of the PLCs were to increase knowledge of neuroscience research with a focus on applications for classroom teaching. The PLCs featured presentations from experts, a book study (Wilson & Conyers: *Five Big Ideas for Effective Teaching*), presentations from teams, and on-going discussion.

3.1.2 Pedagogical Model

Facilitators used a brain-centric pedagogical model called the Challenge Cycle during the PLCs to deepen participant awareness of learning models and engagement. To this end, a pedagogical model, (see: Fig. 1 The Challenge Cycle) was the central descriptive process for implementing both the neuroscientific content materials and the method for engaging the participants in their keystone project, which was a deliverable at the end of the summer institute and continued throughout the school year in the PLC interaction.

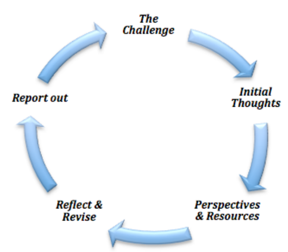

Fig. 1. The Challenge Cycle

A pivotal aspect of this methodology centered on making visible a metacognitive moment that highlighted a participant's shift in thinking (learning in action) and was associated with neural substrates that involved neural plasticity, cognitive rehearsal, and mental models that demonstrated synaptic connections, myelination, and learning with deep understanding. As part of the philosophic underpinnings of Adaptive Expertise, teachers were encouraged to become metacognitive about their own work and to reflexively witness a shift in their own thinking within the cohort.

3.1.3 Data

Data were collected via video, audio, observations, survey instruments and interviews. The data, being both quantitative and qualitative was treated differently as needed. Quantitative data derived from survey instruments were tallied and analyzed. Videos were transcribed and vetted for accuracy and clarity against the original tapes. Transcription protocols[31] were used to account for tone, humor, pace, and rhythm in turn-taking and other interactions of participants. Discourse analysis was used to unpack discussion topics and routine interactions in order to make meaning in relation to discovery and exposition. Categories and codes were deduced from the corpus of data that was produced. An on-demand real-time collaborative software package (Dedoose, 2016) was used to facilitate excerpting, coding, and analysis of the qualitative data and these data integration with demographic and other quantitative data to unearth hidden patterns and relationships.

3 RESULTS

Findings for HDIL summer institutes and follow-up professional learning community (PLC) data are described here. This one-year snapshot (end of a five-year cycle) summarizes implementation challenges and successes, expected and unforeseen impacts, and implicit and explicit teacher impact. Data, which were captured in pre and post survey instruments, were analyzed using data analysis tools that align with the data (quantitative or qualitative). Results describe impact of attending HDIL summer institutes and applying new information in school settings afterwards. We focused on participant gains in neuroscience knowledge, and the impact of the HDIL program on teaching practices.

3.1 Neuroscience Knowledge

Pre and post scores confirm that all participants gained with regard to naming, identifying, and understanding the function of regions of the Brain that relates to learning. In the following graphic, (*Fig. 2. HDIL SI 2015 Gains in Neuroscience Knowledge*) participants demonstrated a gain in knowledge about, and an understanding of, parts of the brain, and their functions. The Y-axis is calibrated to show knowledge levels from 0 to 100 (e.g., I know nothing about the hippocampus = 0, to the hippocampus is in both hemispheres and is associated with creating memory, processing and storing information = 100).

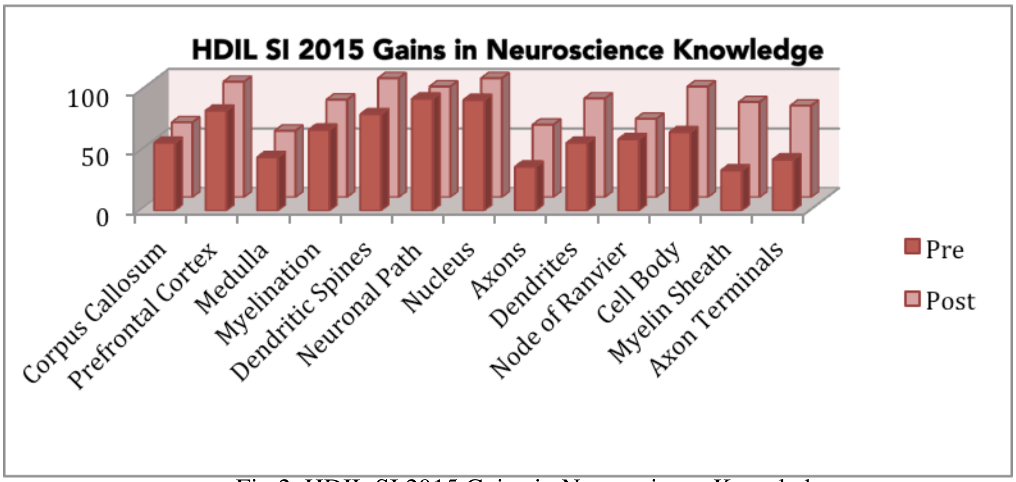

Fig 2. HDIL SI 2015 Gains in Neuroscience Knowledge

Survey responses from participants show clear evidence that teachers gained knowledge about how neuroscience implicates learning and teaching. Areas of focus included the following: Plasticity, Intelligence, Learning, Stress, and Beliefs. *Figure 3. HDIL SI 2015 Gains in Application Neuroscience Knowledge* demonstrates the change from pre to post for participants of the Summer Institute in 2015.

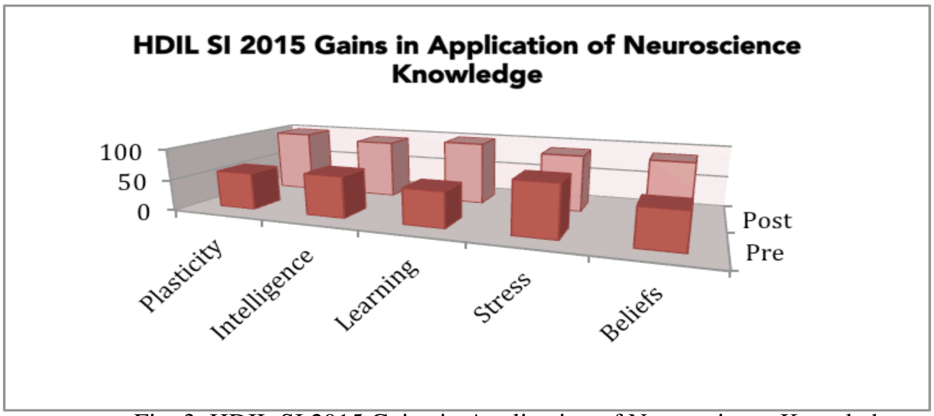

Fig. 3. HDIL SI 2015 Gains in Application of Neuroscience Knowledge

Fig. 4. HDIL SI 2015 Gains in three areas related to Application of Neuroscience Principles in the Classroom, demonstrates the change from pre to post for HDIL participants. The three areas are, (i) stress reduction, (ii) How Neurons Communicate, and (iii) how to understand neuroscience papers and articles in places like Internet, TV, newspapers, journals and libraries.

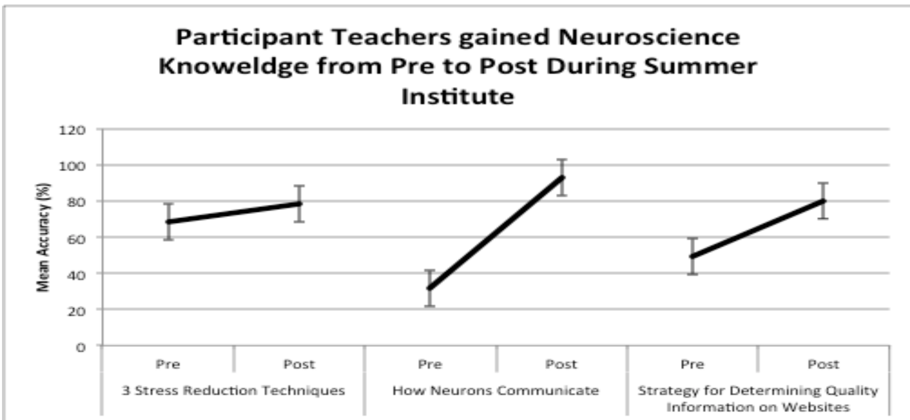

Fig. 4. HDIL SI 2015 Gains in three areas related to Application of Neuroscience Principles in the Classroom: (i) Stress Reduction; (ii) How Neurons Communicate; (iii) Reading Research

Fig. 5. HDIL SI Codes Report highlights how teachers expressed ideas and espoused practices that connect with constructs in Adaptive Expertise. While teachers (see arrows) were heavily drawn to constructs like Neuroscience Structures (score = ~60), and the importance of Exercise for brain-centric learning (score = ~45), the largest (by a considerable margin) impact for teachers emerged as change to their processes and practices – a shift to Adaptive Experts (score = ~130).

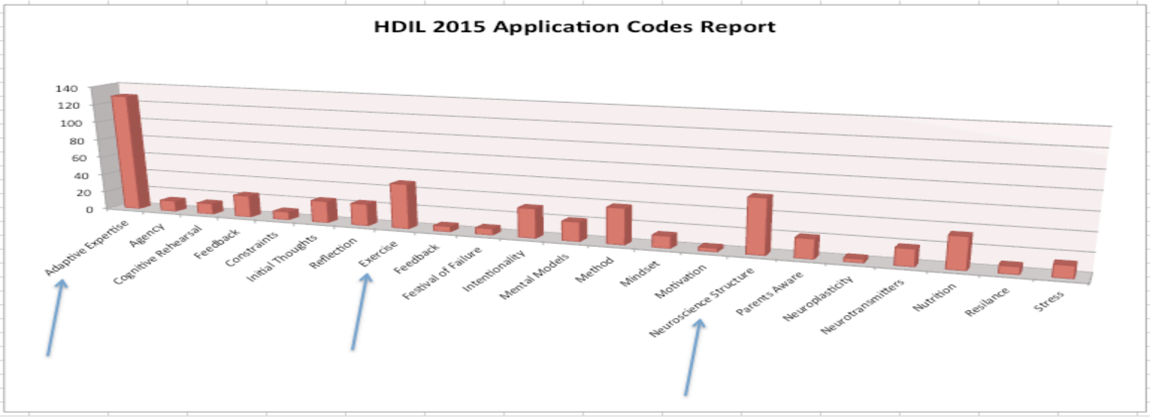

Figure 4. HDIL 2015 Application Codes Report

Evidence from recorded meetings, back-chat exchanges, and report-out presentations of participant keystone projects verified that teachers who took part in the Summer institutes and followed through with PLC activities manifested an edge to their expertise that was in alignment with protocols that are evidence for constructs of Adaptive Expertise.[19]

3.1.1 Adaptive Expertise

Ostensibly, prescriptive teaching in a traditional methodology is exemplified in Fig. 6 on the lower left hand sector of the learning cube. It is characterized as Routine, Fixed and Behaviourist. Teachers who participated in the HDIL program were able to visualize their being in this space and knew lots of other teachers (and parents) in this space. On the other hand, teachers who completed the HDIL program were able to witness their own progression to a more Adaptive, Growth and Cognitivist space (upper right reaches of the learning cube), where they associated knowledge of neuroscience with their everyday classroom teaching and learning activities.

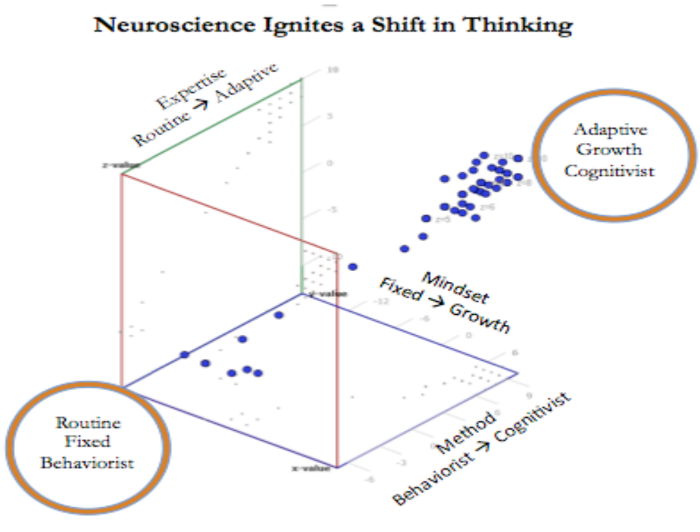

Fig. 6. HDIL 2015 Apparent Shift in Thinking

4 CONCLUSION

This paper described a program in which teachers acquired theoretical and practical knowledge relating to neuroscience with respect to how the brain works and how children learn. Two questions were of interest: would this kind of experience and knowledge have meaningful implications in the classroom for students and would teachers adopt new methods and practices as a result? Findings verify that teachers gained insights into neuroscience and were able to convert this knowledge into practices in the classroom to bring about positive change. Teachers describe many instances where they attained ignition in their practice because methods that used to work intuitively connected with evidence from neuroscience, and methods, which they experienced as not working, were equally associated with evidence that explained why they could never work.

There were several items that color this research. First, assignment was not random and we do not have a true control group; participants in the advanced group (which is the closest thing we have to a comparison group) are self-selected rather than randomly assigned.

The most important take away from this research program focuses on the positive impact that neuroscience knowledge has for teaching and learning. There is an increasing body of knowledge about neuroscience and learning at universities even if it is spread out across several silo'd organizations/schools (e.g., nursing, medicine, psychology, education, biology and so on). We highlight in this research project that it can be successfully centralized through one program and passed on to teachers and parents through an immersive summer institute and a follow-on PLC. Lessons we learned included information about the design of such a project, Summer Institutes, online PLCs, organizing teachers in teams, using expert presenters effectively, integrating book study and discussions as interactive learning, and so on.

4.1 Next Steps

Clearly then, one of the next undertakings for educational researchers involved in this sphere of inquiry is to measure (with imaging devices), structural pathways and neural activations that result when teachers approach their work from a cognitive neuroscience perspective and framework.

Capacity building is clearly a next step in the execution of further gains in this emergent field—connecting neuroscience with teaching and learning. The need for brain-centric thinking in the classroom has been made more than visible by this study, and teachers who are imbued with knowledge, skills, and mindsets that translate into meaningful practices are testament to the transformative change that such a program can deliver.

ACKNOWLEDGEMENTS

This work was funded by NIH Blueprint for Neuroscience Research and administered by the National Institute on Drug Abuse (NIDA), part of the National Institutes of Health through grant number 1R25DA033002-04.

REFERENCES

1. Fullan, M., *Change Forces with a Vengeance*. 2003, London: Routledge Falmer.
2. Schleicher, A. *Use data to build better schools*. TED Talks 2012 [cited 2016 10/10/2016]; Education surveyor and the PISA test for schools]. Available from: https://www.ted.com/talks/andreas_schleicher_use_data_to_build_better_schools?language=en.
3. Vye, N.J., et al., *SMART environments that support monitoring, reflection, and revision*, in *Metacognition in educational theory and practice*, D. Hacker, J. Dunlosky, and Graesser, Editors. 1999, Erlbaum: Mahwah, NJ.
4. Cubberley, E.P., *Pubic school administration: a statement of the fundamental principles underlying the organization and administration of public education*. 1916, New York: Houghton Mifflin.
5. Callahan, R.E., *Education and the cult of efficiency*. 1962, Chicago: University of Chicago Press.
6. Rogoff, B., et al., *First hand learning through intent participation.* Annual Review of Psychology, 2003. **54**: p. 175-203.

7. Vygotsky, L.S., *Thinking and Speech*. The Collected Works of Vygotsky: Problems of General Psychology, ed. R.W. Rieber and A.S. Carton. Vol. 1 (pp. 37-285). 1987, New York and London: Plenum Press.

8. Hoadley, C. and J.P. Van Haneghan, *The learning sciences: Where they came from and what it means for instructional designers*, in *Trends and issues in instructional design and technology*, R.A. Reiser and J.V. Dempsey, Editors. 2010, Pearson: New York.

9. Sparks, S.D., *Experts call for teaching educators brain science: 'Neuro-myths' seen permeating the field*, in *Education Week*. 2012, Focus On: Brain Science: New York, NY. p. 16-17.

10. Willis, J., *Research-based strategies to ignite student learning: Insights from a neurologist and classroom teacher*. 2006, Alexandria, VA: Association for Supervision and Curriculum Development.

11. Fields, R.W., *White matter in learning, cognition and psychiatric disorders.* Trends in Neurosciences, 2008. **31**(7): p. 361-370.

12. NRC, *How people learn: Brain, mind, experience, and school*, N.R. Council, Editor. 2000, National Academy Press.

13. Nuthall, G., *The cultural myths and realities of classroom teaching and learning: A personal journey.* The Teachers College Record, 2005. **107**(5): p. 895-934.

14. O'Mahony, T.K., et al., *A comparison of lecture-based and challenge-based learning in a workplace setting: Course designs, patterns of interactivity, and learning outcomes.* Journal of the Learning Sciences, Routledge, 2012. **21**: p. 182-206.

15. Obama, B., *Obama calls for more engineering graduates*, in *The Seattle Times*. 2011, Seattle Times: Seattle WA. p. A3.

16. Bruer, J.T., *Education and the brain: A bridge too far.* Educational Researcher, 1997. **26**(8): p. 4-16.

17. Varma, S., B.D. McCandliss, and D.L. Schwartz, *Scientific and pragmatic challenges for bridging education and neuroscience.* Educational Researcher, 2008. **37**(3): p. 140-152.

18. Dubinsky, J.M., G. Roehrin, and S. Varma, *Infusing neuroscience into teaching professional development.* Educational Researcher, 2013. **42**(6): p. 317-329.

19. Wilson, D. and M. Conyers, *Five big ideas for effective teaching: Connecting Mind, Brain, and Education Research to Classroom Practice*. 2013: Teachers College Press, New York, NY.

20. Hatano, G. and K. Inagaki, *Two Courses of Expertise*, in *Child development and Education in Japan*, H. Stevenson, H. Azuma, and K. Hakuta, Editors. 1986, Freeman: New York. p. 262-272.

21. Schwartz, D.L., J.D. Bransford, and D. Sears, *Efficiency and innovation in transfer*, in *Transfer of learning: Research and perspectives*, J. Mestre, Editor. 2005, Information Age Publishing: Greenwich, CT. p. 1-51.

22. Bransford, J.D., *Preparing people for rapidly changing environments.* Journal of Engineering Education, 2007.

23. Seligman, M.E.P., *Flourish*. 2012: Simon & Schuster.

24. Dweck, C.S., *Mindset: The new psychology of success*. 2006, New York, NY: Random House.

25. Biswas, G., et al., *Learning by teaching: A new agent paradigm for educational software.* Applied Artificial Intelligence, 2005. **19**: p. 363-392.

26. Darling-Hammmond, L., et al., *Powerful learning: What we know about teaching for understanding*. 2008: John Wiley & Sons Inc.

27. Lin, X., D.L. Schwartz, and G. Hatano, *Toward Teachers' Adaptive Metacognition.* Educational Psychologist, 2005. **40**(4): p. 245-255.

28. Hatano, G. and J.G. Greeno, *Commentary: Alternative perspectives on transfer and transfer studies.* International Journal of Educational Research, 1999. **31**(7): p. 645-654.

29. Johnson, R.B. and A.J. Onwuegbuzie, *Mixed methods research: A research paradigm whose time has come.* Educational researcher, 2004. **33**(7): p. 14-26.

30. Cohen, L., L. Manion, and K. Morrison, *Research Methods in Education*. 7th ed. 2016, New York: Routledge.

31. Goodwin, C., *Action and embodiment within situated human interaction.* Journal of Pragmatics, 2000. **32**: p. 1489-1522.