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CONCLUSION

Cognitive Science and Educational Research: A Shotgun Courtship

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How useful would our favorite electronic devices be if computer hardware engineers and software developers worked in completely different worlds? Would personal computers, tablets, and mobile phones be as integrated? Would the applications we run to help us with many daily tasks be as advanced and widely available across as many platforms? According to the Bureau of Labor Statistics (2017), "…Computer hardware engineers ensure that computer hardware components work together with the latest software. Therefore, hardware engineers often work with software developers. For example, the hardware and software for a mobile phone frequently are developed jointly…"

As foolish as it would be to suggest that computer hardware and software engineers could prosper if they worked in completely separate worlds and knew little about each other's work, do we as teacher educators integrate findings from the science of learning into our daily work with students? Are we role models for our students as we teach so that they experience learning through engagement with the most effective pedagogical strategies? The purpose of the Deans for Impact (DFI) report was simple: "...to summarize the existing research from cognitive science related to how students learn, and connect this research to its practical implications for teaching and learning…" It is our hope that this special issue has prompted our readers to reflect on the integration of this knowledge base from the science of learning into the work of professional educators.

The purpose of this concluding essay is to review the six key questions raised by the DFI report, and to explore the following issues: 1.) the role of teachers, teacher educators, and educational researchers in ensuring that advances in cognitive science are effectively evaluated within real school contexts, 2.) partnerships with cognitive scientists to ensure that what we know and believe about quality teachers and schools, and the role of educators in a democratic society, is preserved within educationally appropriate application of advances in the science of learning, and 3.) the role teacher educators play in shaping the research agenda for the science of learning.

THE DEAN'S FOR IMPACT SIX QUESTIONS

How do students understand new ideas?

In their review of the research literature related to the first question, Boula, Morgan, Morrissey, & Shore (This Volume) address several pedagogical strategies that highly seasoned educators commonly incorporate into their routines. They discuss the empirical evidence for the value of helping students find points of entrée into new concepts, ideas, and skills by tying new learning to existing knowledge and experiences. Such strategies can easily and naturally flow out of time spent in review of prior learning at the beginning of each instructional unit.

Their review also highlighted the value of pure student discovery as a means to teach not just new content, but to teach the process of learning itself. When we as educators amplify natural curiosity and build upon student interests, we help engender lifelong learning skills and habits of intrinsically motivated learning in our students. Guided discovery is highlighted as a strategy for learning situations in which pure discovery can place overly high cognitive demands on the learner, particularly novice learners. Their review reminds us that while students often respond well to activities designed to help them construct and ascribe their own meaning to new content, carefully designed instructional activities that guide and support them through that process can be even more effective. Experienced educators know that students need to practice to solidify and perfect new cognitive skills. Explanatory feedback and worked examples were highlighted as strategies to support the process of practicing new learning.

Research was reviewed that connected the cognitive complexity and difficulty of the material to be learned to the type of guidance and support that works most optimally. High levels of guidance match well with complex content while more independent and student directed learning activities match well with more basic content. Similarly, research was reviewed that supported the use of more active participatory learning with relatively simpler content, while observation, demonstration, and modeling have their value in beginning the process of learning with more complex content. Research was also referenced that confirms the effectiveness of strategies designed to gradually withdraw support and encourage independence as the student masters content.

The authors included a very useful review of the role of working memory in the learning process. They point out the connection between the intrinsic cognitive load that is related to content complexity and the extrinsic cognitive load that is involved in the learning process. Procedural demands can place external load and demands on working memory and thereby limit what is available for constructing and extracting meaning from, and imagining meaningful application of new content. While teachers often place high value on interactive activities, their true value to the learning process and the facilitation of understanding may rest in part upon their ability to engage student interest without taking too much working memory away from a focus on the content to be learned.

How do students learn and retain new information?

In their review of the research literature related to this question, Spaulding, Thomas, Yearta, and Miller (This Volume) remind us of the value of contextualizing information provided to students so as to transform it into meaningful content. The research literature reviewed suggests that contextualized information is retrieved more successfully and that students can demonstrate their learning more successfully if they have been able to construct meaning and attach it to information. The value of rehearsing information and practicing the process of storing and retrieving it, was also reinforced by the research literature. Perhaps the most important contribution of this literature is the concept that all forms of practice are not equally effective. Teachers can benefit from understanding that quality practice is engaging and interesting to students through the use of higher order, open ended questions that encourage retrieval for the purpose of enhanced understanding and application, not just for recall as an end in itself.

The review also stresses the value of formative assessment as a foundational instructional strategy. Much of the research reviewed confirms what assessment experts have long theorized (Heritage, 2013). When high quality formative assessment is incorporated into the natural routine and rhythm of the classroom, teachers are breaking content into manageable units and are aware of the progression of learning, development, and skill acquisition they are striving to support. Assessment is more focused on providing feedback to students to support their growth rather than validation of academic achievements. Authentic formative assessment strategies both contextualize assessment within naturally occurring classroom activities and reduce the cognitive load on students to more manageable levels that limit demands on working memory. Formative assessment also enhances a teacher's ability to understand and reflect about where each student is in the process of learning and development, and thereby helps the teacher to differentiate and individualize instruction more effectively. When formative assessment strategies are applied appropriately they also facilitate meaningful feedback to students and provide teachers with a source of feedback about the success of their instructional strategies.

How do students solve problems?

In their review of the research literature related to this question, Kennedy, Carney, and Moree (This Volume) remind us that much of learning occurs in phases that build on each other. When an instructional objective presupposes the presence of foundational skills or knowledge, students do much better if the foundational skills and knowledge have been encoded into long term memory. This frees working memory, attention, and capacity for cognitive load to focus on higher order skills acquisition and functioning, such as problem solving. They further provide an engaging review of the components of effective problem solving (Mayer, 1998), reminding us that in order to be effective problem solvers, students need the requisite baseline knowledge and skills, a working understanding of applicable problem solving strategies, and the motivation to tackle problems.

Their review portrayed the motivational factors required for successful problem solving as student attributes that transcend the merely mechanical processes of learning. Much of cognitive science rightfully focuses on learning process outcomes. It was refreshing to review the research evidence supporting more salient educational outcomes as precursors to learning process outcomes, such as self-regulation, self-efficacy, resilience, task persistence, and intrinsic motivation for learning. Their review also delineated the aspects of feedback to students that enhance learning, encourage confidence, and help build a positive social climate in the classroom, all of which in turn develop and enhance these motivational factors.

How does learning transfer to new situations in or outside of the classroom?

Wells and Le (This Volume), in their review of the literature related to this question point out the value of contextualized information in order to enhance its generalizability to new situations. They reviewed literature that suggested the value of critical thinking skills as helpful to the knowledge generalization process. Several other questions emerged for me as I reflected on the research literature reviewed. How do critical thinking skills function as learning process tools? How can we as educators most effectively help students move from the specific to the general? When we help students conceptualize abstract and universal principles, does that help them transcend specific applications of knowledge and generalize learning to new situations? Is a focus on abstract or universal concepts appropriate for all learners and all types of content? Is it better to focus student attention first on practical applications of knowledge and then move to general principles, or does a solid foundation in general principles facilitate a deeper understanding of practical applications?

I am reminded of the T.S. Elliot poem (1934) that asks the question (paraphrased here for this discussion): How can students extract knowledge from information? How can students distill wisdom from knowledge? Wells and Le (This Volume) suggest the use of case studies as a powerful pedagogical tool that adds approachable context, engaging narrative, and a type of face validity that allows students to relate to characters as an entry point to learning. They point out the unique value of case studies as a type of interactive simulation of the application of knowledge, as storylines within which students can speculate and make predictions about how the plot will unfold. I know in my own teaching, case studies have functioned as powerful parables, as vehicles that can help students ask deeper questions about what might have happened if the characters involved made different decisions, had different resources or barriers to success, or lived in different contexts. At times the resulting class discussions transport students in a sense to new situations and facilitate the transfer of learning as students share diverse personal and professional experiences.

What motivates students to learn?

Perrell, Erdie, and Kasay (This Volume) in their review of this question, address much research literature related to the value of intrinsic and extrinsic motivation. They present a balanced and nuanced picture of student motivation issues that is not limited to purely cognitive or neuroscientific issues, and includes issues that have long been concerns for educators and educational researchers. For example, they include a review of the literature on meta-cognition and self-regulated learning, and thereby address the recommended strategies for helping students think and learn about the way the think and learn. Similarly, it was refreshing to see attention given to a critical educational contextual factor, a respective and inclusive learning environment. The value in each student having at least one positive adult role model who believes in them, communicates to them that their efforts matter, and expects then to succeed can never be underestimated.

What are common misconceptions about how students think and learn?

Leahy, Shore, and Lambert (This Volume) in their review of this issue, prompted me to reflect about the narrowness and silo-specific nature of existing educational theories of teaching and learning. We do not have widely accepted and rich unifying theories that address all of the factors related to learning including developmental, cognitive, student and family, teacher, school, and policy climate issues that are part of the educational ecosystem. In the absence of rich enough theories, teachers often solve the cognitive dissonance that is created when encountering the complexity of real classroom challenges by placing their faith in magic bullets, bandwagons, fads, and yes, easy to digest myths about teaching and learning. There simply will never be easy answers to questions stemming from a search for the optimal teaching and learning strategies, and educational contexts regularly defy one-size-fits-all claims.

EVALUATING ADVANCES IN COGNITIVE SCIENCE IN REAL SCHOOL SETTINGS

Much of the literature reviewed emerged from laboratory research. Cognitive science is appropriately and necessarily concerned with limiting confounds by creating artificially simplified environments. Naturally it is therefore often basic research, and basic researchers should not feel compelled to be either immediately relevant or applicable to the classroom, or to have their research agendas driven by the needs of educators working in real schools. Consequently, it is often unclear how the results of such studies can be generalized or applied across diverse content areas, student age groups, and school settings. In stark contrast, educational research is often very contextually bound, applied field research. The settings are so real that it can be extremely difficult to make causal inferences. The presence of such a wide range of potential confounds makes even the most carefully planned and strictly executed field-based randomized trial a quasi-experimental study waiting to happen. The process of evaluating applications of the science of learning in the classroom will not be exempt from this classic tension between internal and external validity that is often part of educational research.

Empirical validation of effectiveness of pedagogical strategies and learning process techniques that emerge from cognitive science research is one of the key guiding principles for DFI. Educational researchers may need to conceptualize new ways to partner with cognitive scientists. New research strategies that blend basic and applied research approaches may be needed to develop and refine effective applications of the advances in the science of teaching and learning. Educational innovations are often developed in hot house settings that are uniquely resourced and situated close to the developers. Promising yet context-specific evidence of effectiveness is often parlayed in large scale, expensive, multi-site randomized trials that fail to replicate the effects across new contexts.

The culture of the education profession encourages us to abandon such strategies because they didn't achieve "what works" status and move onto the next trend. In contrast, the culture of engineering encourages developers to fail, to progress toward perfection within a cycle of development, testing, and redesign, refinement, and retesting. Again, according to the Bureau of Labor Statistics, "…Hardware engineers also may perform some computer programming in a hardware description language (HDL), which describes the digital circuits in hardware. Using this language, computer hardware engineers can simulate how the hardware design would work, test for errors, and then fix the design…” Can cognitive scientists, educational researchers, and teachers form partnerships that can carry new learning strategies through a cycle of basic research, development of applications, evaluation of strategies, redesign and refinement, and further testing?

Such a cycle will require rich understanding of context and thus the role of teachers, teacher educators, and educational researchers will be critical to forming and maintaining successful partnerships. Almost all educational research takes place in the social context of classrooms and schools. Schools of course operate within communities, districts, policy driven political climates, and serve real neighborhoods and families. Furthermore, most educational processes can neither be understood in isolation nor separated from their social and political context. Consequently, findings from educational research studies often understandably do not generalize to new contexts. And yet meaningful questions beyond specific applications remain to be investigated by such partnerships. How much does social context matter to the success of specific teaching strategies and learning techniques? Are there universal principles of teaching and learning that transcend context? How can we test for the ideal match between evidence-based principles of teaching and learning and the complex interactions between the nature of the content to be learned, the complexity and difficulty level of the content, and the age, developmental stage, and special needs of the learner that shape the real situations teachers face every day?

EDUCATIONALLY APPROPRIATE APPLICATIONS OF ADVANCES IN THE SCIENCE OF LEARNING

A focus on learning process outcomes in isolation from broader educational outcomes is simply incomplete. Galinsky (2010), in her seminal work on what she calls 21st century learning skills, raises important questions about the types of outcomes that will become increasingly more central to student success in the digital age. Task persistence, curiosity, and creative problem solving are a few of the skills she highlights. Furthermore, will learning process outcomes that have traditionally been the focus of schooling and cognitive science continue to matter as much in the digital world within which students now grow up? Are digital literacy skills more important than cognitive information retrieval skills? Which students will be more successful citizens, those who can locate information virtually when it is needed by searching cyberspace and can use critical thinking skills to apply that information to creative problem solving tasks, or students who have developed advanced cognitive information storage and retrieval skills (Lambert, 2015)?

Educators are interested in educational outcomes that help shape and develop the whole student as a unique individual. Therefore, the process of being and becoming a successful teacher involves complex balancing acts that recur daily, are challenging and stressful, and persist across one’s entire career. For example, high quality teachers find the appropriate balance between the very real need for direct instruction of basic content, cognitive complexity, high expectations, and rigorous demands on students, and the very real need for stories, anecdotes, analogies, parables, narrative, and meta-organizers that make learning relevant and engaging for students. They strike the balance between the need for students to make their own meaningful connections to their own interests, experiences, and prior knowledge, and the need for instructors to help guide students through a journey of discovery. They balance the need to create inclusive, accepting learning environments where all students feel like they belong, with the need to reward and recognize hard work and accomplishment. They find a working balance between the development of self-efficacy and self-esteem in their students, and the need for strategies that reward resilience and task persistence. They balance a real passion for content with a deep and rich knowledge of effective pedagogical strategies. They instill passion for content in their students by pointing to the practical applications of learning, and engender a healthy focus on abstract, creative, and critical thinking. They balance the intrinsic value and rewards of learning for the sake of learning and becoming an educated lifelong learner, with a healthy respect for the very real extrinsic benefits of educational achievement.

Some of the research findings reviewed in this volume showed that when mere information retrieval is considered a learning process outcome, students are more successful when they have been encouraged to attach meaning to that information. So we have some examples of the blending and balancing of learning process outcomes and educational outcomes in the extant literature. Advances in cognitive science will only lead to educationally appropriate applications if they are situated in this way within the broader complex reality of schools that are increasingly called upon to develop the whole child. Our society asks teachers and schools to play a wide range of roles, and to function like social service agencies. Successful teachers not only have to create a healthy balance between learning process outcomes and educational outcomes, but regularly face role strain as they try to be teacher and parent, mentor and childcare worker, to develop effective learners and successful citizens of a democratic society.

SHAPING THE FUTURE OF THE SCIENCE OF LEARNING

Inherent in much of the literature the authors reviewed in this volume is the contrast between research that focuses on the structural components of the capacity to learn, the physical attributes that enable learning, the process of learning itself, and research that focuses on the demonstrable outcomes of successful teaching and learning, such as the knowledge, skills, and performance capacities that are gained when learning has taken place. In a very real sense, this tension holds a valuable means versus ends argument that both cognitive scientists and educators can reflect upon. How does the development and enhancement of working memory, transfer of information from working memory to permanent storage, information retrieval speed, and processing efficiency transfer to learning? Do these capacities enhance, even create, the possibility of learning? Can too much value be placed on the content of learning, the educational objectives, to the exclusion of the means by which they are learned? How surprised would hardware and software engineers be if they realized we even need to ask these questions? It seems so self-evident that the most sophisticated computer hardware is of little value without software applications, and similarly the most creatively and imaginatively conceived software is of little value without hardware on which it can run.

Perhaps the first step in this process is the development of rich theories of teaching and learning that are complex enough to include contingencies for type and difficulty of content, learning context, type of teaching strategy, student characteristics and needs, and all of the complex interactions between these and other factors. Perhaps the next step is moving toward a more mature culture within the education profession that encourages and rewards educators for reflecting about both successes and failures. The current high stakes accountability policy climate in education ties teacher performance appraisal to, and rewards a narrow focus on, learning process outcomes and the production of short term knowledge gains. Teachers are therefore discouraged from focusing on longer term educational outcomes and find it challenging to be open and transparent about the effectiveness or lack of effectiveness of pedagogical strategies to produce short or long term advantages for students. The design, test, redesign cycle will require a policy climate that rewards openness, risk and reflection.

It is our hope that this volume has prompted reflection about the future of the science of teaching and learning. It has certainly identified many meaningful questions for further research to be addressed within partnerships between cognitive scientists, educators, and educational researchers. For example, how can we create life-long learners? How do we amplify, nurture, and support the inherent curiosity of the young children that come to our schools so full of innocence and life? How do we help young children learn to be optimistic and secure about their own ability to succeed in the social role of student? What would the high school dropout rate be if young children experienced the most effective teaching and learning strategies from their very first experiences in school, and therefore had successful learning experiences earlier? Have we failed to identify learning styles or preferences, not because they don't exist, but because of the challenges inherent in measuring these constructs, and how they may interact with varying content types? How can we as professional educators help students internalize self-regulated learning and task persistence to such an extent that it is an automatic part of the way they approach all learning? How can we help them generalize and extend these habits of effective learning to new tasks and challenges outside of their comfort level? How can we as professional educators learn to reduce cognitive load and demands on working memory so as to free students to focus on the new steps in their learning progressions, without artificially reducing the difficulty level of our content or the cognitive complexity of the engaging and interactive activities that make content come alive for students?

Hardware and software engineers have worked together to create much of the digital world we live in, not because their prototypes were discarded if they did not work the first time, but because they were encouraged to design, test, redesign, and retest. We rely on wonderfully innovative electronic devices and their useful software applications, not because hardware and software engineers work in artificially separate worlds, but because they work closely together. Hopefully this volume can help inspire educators, educational researchers, and cognitive scientists to learn from the way hardware and software engineers work together to form lasting partnerships that will advance the science of learning in ways that lead to meaningful applications in the classroom.

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