The World Needs A Truly Open Science of Learning

A/E/T

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Introduction

The need for a revolution in learning is clear. Many of our greatest current opportunities and pressing social challenges were unheard of a few decades ago — but our education systems have changed little. Thankfully, the same scientific and technical advances that have driven this rapid change also enable better collaboration to explore new ways of learning, and thus face these challenges and opportunities. In this document, we outline ways in which open science methods can include learners, instructors, and researchers in an effort to "learn how learn" in ways suitable to this information age. This will require not just technological innovation, but also institutional a cultural change within the learning sciences.

This paper results from a workshop on future directions for an Open Science of Learning (OSoL), held at the Center for Research and Interdisciplinarity (CRI) in Paris, in June 2017. The workshop was convened by the CRI to identify its future research priorities in this area. However, this document is a wider invitation for researchers everywhere to join this collaborative effort on finding these new ways of learning how to learn.

Below, we start by laying out a sketch of what OSoL is, why it is necessary, and the broad conditions that will have to be met for a truly open science of learning (OSoL) to become a reality. We then nominate specific challenges that should be taken up now, so that OSoL can be a way for all people to shape the learning future they want. Some of these challenges are starting points, ways in which Open Science of Learning can be applied and prove its worth; others represent issues that will need to be dealt with, for the OSoL approach to reach its full potential.

What do we mean by “open science of learning”?

Open science of learning (OSoL) can be defined in many ways. A short definition might be: a distributed scientific inquiry into learning that gives outputs to and receives inputs from all people as much as their interests and abilities allow. More comprehensive definitions might enumerate appropriate strategies such as free dissemination of research products and data, toppling disciplinary boundaries, involvement of non-professional scientists in the scientific process (i.e., citizen science) and the open use, modification, and recombination of learning resources. Yet, cognitive science shows that it is seldom possible to draw precise borders around the things that fall under a term or category (Goldstone & Kersten, 2003; Kavanagh & Suhler, 2016), and OSoL is probably not an exception. Like most terms denoting a whole discipline, the usage of the term will change and develop as relevant scientific conversations mature. This document is meant to spark precisely such a conversation.

Why OSoL, Why Now?

While science and technology put the world’s information at our fingertips, this is where information tends to stay: it does not easily get into the mind to become knowledge. A learning community capable of delivering on the promise of the information age would skillfully assess the importance of skills and develop the necessary learning methods at a pace not far behind that of innovation. This community would become aware of important subjects and methods of learning as they emerge, and collectively accelerate promising developments in learning practice. OSoL could be the centerpiece of this collective effort to learn, systematically identifying valuable knowledge and using science to spread and perfect methods for learning this knowledge. A science of learning that is truly "open" would drive learning innovation not just through free communication between researchers, but by devising ways to document and spread innovation outside academia. It would also allow technologies developed by the research community to be shaped by on-the-ground experience and input from the field.

At present there is little systematic coordination of the elements necessary for an inquiry into learning: Educators and learners across the globe devote years to developing and perfecting learning and teaching methods, but have a difficult time proving their innovations' effectiveness. Researchers sometimes spread good learning methods through convincing experiments, but at a pace that often lags far behind innovation, leaving most learning practices to be spread by charismatic advocacy and word of mouth. Technology spreads slowly, and its fundamental design is not shaped by those with the greatest intuition for classroom needs. The emerging understanding of the mind has identified some powerful general principles of learning, but its application to creation of particular learning methods is uneven.

Recent efforts to advance learning methods through cutting-edge technology highlight the need of contextual knowledge to inform the application of such technology. Automated learning analytics put massive amounts of data in researchers' hands, but cannot be interpreted without context: small differences in environments and individuals often result in large differences in learning. Despite mountains of information, there is a gap in our understanding of learning, that will persist until the minds that understand contexts (e.g., teachers, learners) are effectively involved in research. These minds are largely working "in the field." Similarly, pursuit of better virtual learning environments will progress fastest if is guided by information stored in the thoughts and intuitions of learners and educators (see below.)

The creation of an OSoL thus presents a great obstacle but also a unique to opportunity to advance the learning sciences, while at the same time addressing problems of collective investigation that are especially challenging in applied fields. A unique group of talents both need and want to come together on a large scale to identify and address the special challenges of learning. In their role as educators and disseminators of their own discoveries, scientists in all fields are devoted to learning and are often responsible for aiding learning in the classroom. All of us are involved in learning and disseminating knowledge, making learning science especially in need of openness to other fields of expertise.

The applied nature of learning also sets it apart from basic research fields in which open science is already thriving, and make OSoL a potential testing ground for broader collective intelligence strategies. We are not likely to create theories of learning that allow us to deduce the optimal means of learning for every particular kind of knowledge. Like engineering, architecture and programming, the learning of each new subject is unique challenge (Laurillard, 2012.) OSoL must then manage new challenges and technologies, and arrive at pragmatic answers on an ongoing basis. Given our imperfect knowledge of an always evolving situation, the same features are common across the biggest open-ended challenges of our time — such as addressing global warming, inequality and unexpected consequences from technologies like artificial intelligence.

Learning Challenges

Creating an OSoL is a great challenge, which will require concerted, long-term efforts. Having discussed OSoL at a relatively abstract level thus far, in the remainder of this document we will move towards a number of learning challenges which presented themselves at the OSoL workshop. Areas have been forwarded as challenges either because they are starting points, or serious obstacles that must be crossed on the way to mature OSoL.

Attention to All Appropriate Measures

In order for a science of learning to be influential, it must balance knowledge gain against the costs and convenience of the learning methods (i.e., the time and effort of learners and teachers). One simple point, here, is that innovations that make teachers' job easier are more likely to get adopted, and create time for them to do other things, and thus might have higher impact than research on learning outcomes. Research efforts aimed at validating time-saving strategies will also attract participation from educators. Administrators focused on the big picture will also be more responsive to research that deals with all aspects of a learning strategy. For example, large University lectures have long been a target for critics, but are popular in many places because they address the common situation wherein one person knows a lot about a subject that many people would like to hear about (Bligh, 1971.) Though personal tutoring gives higher outcomes the cost effectiveness of lectures (and, more recently, MOOCs) has made them a favored methods to transfer knowledge from one to many (ibid.) In this area, as well as others, new learning methods will have to address time and cost factors in order to be adopted (Dillenbourg, Järvelä & Fischer, 2009). Part of the openness that OSoL requires is the ability to talk about these factors openly, rather than emphasizing only learning.

Changes in Values and Culture

Achieving a truly open science of learning will require real changes in culture on many levels of the scientific enterprise. The teachers and learners who contribute will place priority on innovation, and be willing to experiment and sometimes to fail in the process of finding new strategies. To allow this, institutions must support such a focus on exploration as opposed to short term performance as the ultimate value. Crucially, this means taking difficult steps that will lower the stakes for making errors in teaching and learning.

The involvement of trained scientists will be necessary so that the exploration of learning can be scientifically rigorous, but these scientists must be willing to work on research questions and methodologies from all players in the science of learning. Research culture will also need to transition from thinking of learners and teachers as data providers or "human sensors", to thinking of them as researchers. The strengths of teachers, learners, and scientists have to be mutually appreciated for collaboration to be mutually beneficial. For example, scientific methods of forming precise hypotheses and testing them through controlled experimentation is a skill learned at great effort, but the intuition for interventions that work in real learning situations is also necessary.

Incentivising Participation

Creating a system for the sharing of learning resources and testing the results seems like a reasonable way to advance education, but participation in such systems may have to be incentivized. For example many shared instructional resources exist and are lightly used (Perrault, 2016) — they often take too much specialized knowledge, too much effort, and extant networks for teachers to find them useful. These barriers to participation may be minimized through personalization, crowd-sourcing, and (massively) co-designed interfaces that enable teachers to share more easily and effectively. Still, these barriers will remain substantial and the process of addressing them will require participation as well. Strong incentives (or at least, enough "breathing space") are needed for deep participation, especially at the beginning of such a network. Any OSoL effort targeting teachers would need to find incentives that are meaningful to teachers. The relevant questions are: how might they save time? Could they get professional development credit for publishing curricula? Might school districts allow teachers to spend part of their day publishing and maintaining open resources if they no longer had to pay for technology or textbooks? How do we effectively measure participation, so that we can reward it?

Crowdsourcing of Pedagogy

Open Science of learning can make it possible for teachers and learners to take full advantage of innovations in instructional materials and pedagogical strategies, and adapt these to their own purposes. This requires improvement of teachers and researchers' ability to create, test, analyze, and disseminate pedagogical innovations. Open science tools can enable interactive crowdsourcing of the design of materials. Innovations reported to be effective by one instructor could be investigated, replicated, and adapted by other instructors. Together, a distributed community of teachers and learners could collectively explore a high-dimensional space of instructional possibilities that would be impossible for any instructor to explore on their own. As teachers and researchers are increasingly empowered with these tools, learning outcomes will become publicly available for numerous points in a learning space which has many dimensions (e.g., content, learner age, learner experience, other individual differences, educational context, learner activity, kinds of feedback, …). This will further allow the contours of the space to be seen, and teachers and learners will be able to make increasingly good predictions about the kinds of learning strategy that will be most effective for their particular needs. Where measures of the effectiveness of methods differ, concentrated scientific study will be necessary.

Training Artificial Learners

The teachers who serve as mentors and leaders in classrooms are typically trained in schools of education, where they do not have the opportunities to practice their teaching in low-stakes but authentic environments. While many other advanced professions (from physicians to pilots) rely on simulations for their initial and continuous training (Lateef, 2010; Salas, Rosen, & Held 2010), such simulations are not currently available to teachers. One reason for this is that, while the human body and airplanes are complex systems, systems of learning are perhaps even more complex, and require larger amounts of data to model (See, e.g., Davis & Simmt, 2003.) An Open Science of Learning could, however, build useful models using data science and machine learning methods. Pursuing this approach would require teachers and researchers to work together as a community to design, create and instantiate systems that would allow teachers (and potentially their students) to play a role in defining the instructional difficulties that they face. Researchers would help develop new models of the way that students learn, in order to better explore and capture successful methods of teaching. New teachers, in turn, would be provided with opportunities for both learning and practicing their teaching that reflect our understanding of the way people learn.

Perfecting Peer to Peer Education

Peer to peer teaching and collaborative learning can enable and equalise learning across the globe. Other resources, like Massive Open Online Courses (MOOCs) are making education more accessible and open, with few prior academic requirements. Adding improved methods for learning by interaction with peers can increase accessibility across economic and geographic constraints by another order of magnitude. The questions to be addressed are how students can contribute to others' learning even while finishing their own studies, and how peer teaching/learning can validate learning and earn academic credit.

Yet, in contrast with classroom learning where "regression to the mean" can help us understand what strategies are "good on average", a one-on-one tutoring situation varies more widely depending on both tutor's and tutored's skills, prior knowledge and context — and so will vary the successful strategies. Concerted scientific efforts are needed to determine the most effective practices for peer to peer learning, as compared to more traditional models, and how these change across different cultures and settings (e.g., in person, online, through virtual reality, and across different subjects). The scalability and sustainability of these efforts would greatly benefit from an open model, that maximises the opportunity for participants to add their data, and from projects focused on the design of peer to peer teaching systems, with the best ideas determined in a scientific manner (through debate and experiment). This would nurture an ecosystem that leads to citizen learning science and scientific citizenship.

A Working Consensus on Assessments

Standardised measurements are the way that science compares outcomes across situations, but in learning science, measurements of learning (assessments) often take place in a political context that is challenging to navigate. OSoL needs common assessments of learning and performance for comparing learning strategies or construct and take advantage of large databases of common assessments. Assessment is a subject, however, that raises endless controversies (e.g. Popham, 1999; Wang, Beckett, and Brown, 2006.) Different approaches to education often come with different notions of the most appropriate goals and assessments (Levin, 2012.)

Debates rage over the importance given to standardised assessment, and whether or how assessment impacts learning positively. Critics of standardised assessment can point out that the Finnish system, among the top in the world does not rely on national standardized exams (Simola, 2005). Of course it can be replied that standardised international assessments are what is used to show that the Finnish system compares well to others (ibid.)

Efforts to create and administer common assessments that can drive scientific inquiry may easily become enmeshed with these debates. To create workable research strategies involving common assessments of learning, especially those collected in a classroom setting, OSoL needs to understand the aforementioned debates and find a way to balance its needs with the concerns that historically have arisen for educators.

Unlocking the Potential of Improved Understanding of the Mind for Learning

Although all learning depends on the human mind, educational design or testing does not fully benefit from our increasing scientific understanding of cognition. A challenge for an OSoL is to make appropriate use of such growing understanding of cognitive processes, so that educational designs can be improved by rigorous understanding of such underlying principles. Cognitive Science and Neuroscience are increasingly describing specific learning methods in terms their underlying processes (e.g., Brooks, Pogue, & Barner, 2011; Raynor, 1998; Yu, Landy and Goldston, 2018) and understand how humans interact with their environment to learn (e.g., Clark, 2008; Pea, 2004; Vygotsky, 1967.) Potentially, a mature cognitive science could be to learning science what physics is to architecture or engineering. On the other hand it must be recognized that, like architects, educators have been able to create successful pedagogies prior to the emergence of a rigorous basic science describing their underlying principles, so received wisdom in the learning community must be respected. At the same time, insights from the learning community that work well, but are not adequately explained by our understanding of mind are an exciting challenge to cognitive science and deserve rigorous scientific investigation.

Sustainability Education and OSoL Need Each Other

Developing the methods of OSoL requires sustained collaboration on focused issues. Thus OSoL needs priority areas that can draw intense and diverse engagement in the near future. Sustainability and climate change education, which is integral to keeping the earth comfortably habitable in the future, is a logical choice for such an area.

There are existing efforts to build on. For instance, Finland has recognized that traditional university courses are not sufficient to drive widespread, comprehensive understanding of climate issues. This realization lead to climatenow.fi, a nationwide learning module that has drawn enthusiastic collaboration from experts, educators and artists to create content that can inspire a new generation of sustainability experts, and allow the general public to understand how climate change affects their lives.

An international information infrastructure that would allow distributed development, testing, and adaptation of materials for climate education is a great challenge, involving all of the aspects that will be challenging for OSoL in other areas. Climate scientists understand the material best, but others, such as teachers and even activists, have more experience communicating to a wide audience. The challenges of communicating science will be culture-specific, and cognitive scientists specializing in dissonance will be useful in helping to identify and understand barriers to understanding. Finally, technologists will be required to deal with the technical aspects of such an infrastructure. This are all great challenges, but few areas of learning could possibly attract a larger, more diverse, and more devoted set of collaborators.

Learning for the Work of the Future

While technological change creates many possibilities, it also means that learners of all ages live in a vulnerable, uncertain, complex, and ambiguous world where skills can become obsolete quickly. Our educational system, however, is inherited from ages of stability. A priority for a truly open science of education is to identify the skills needed for the future, and quickly perfect means for learning these new skills. Anticipating the need for skills is hard — organisations such as 21st century skills (Johnson, 2009) and the World Economic Forum (WEF, 2015) have contributed lists of such needs, but continuous innovation means that the future is uncertain for us all. Science has made advances in prediction practices (Tetlock & Gardner, 2016), but given the depth of our uncertainty, OSoL will want to accept unpredictability and create ongoing measurements of changes in skills as comprehensively as possible. This can be done by gathering as much data as possible on emerging trends in learning, and studying the learning decisions of those who have greatest information about the future. This awareness of important knowledge can then be complemented with agile methods for quickly creating learning environments for new skills. Openness here might mean, for example, allowing employers and citizens to nominate certain learning areas for open prize competitions that can encourage the stimulation of new learning strategies.

Fueling Technical Innovation with Human Intuition

Expert intuition is often unable to be justified in words, but can be applied to concrete situations (Berry, 1987), so allowing experts to have an experiential sense of the strategies they are suggesting is important. Finding ways to query human intuition, letting it guide us to the best learning methods is a challenge for all of OSoL. Consider immersive artificial learning environments, in which learners are taught in a lifelike manner. Even here, human intuition will not be obsolete anytime soon. Serious games allowing humans to guess at quantum computing (Magnussen, Hansen, Planke, & Sherson, 2015) or protein folding problems (Eiben, et al., 2012) have shown that human intuition finds better solutions than machine learning can, and similar results should be expected in the design of learning environments. The right interfaces are necessary to unlock this potential, however. Those designing artificial learning environments can create flexible designs with the ability to be shaped by intuition, particularly that of expert teachers. This can be done by having several parameters which can easily be set by teachers (for example, the delay of feedback, the increase in problem difficulty, or specific verbal instructions.) Suggested solutions can then be tried both on simulated learners (see above) and real learners, to see where intuition out performs modelled learners. Both instructional methods and model learners will be improved in the process.

Avoiding Techno-Solutionism

Techno-solutionism is the tendency to believe that long-standing social difficulties have technical solutions. For example it was once fashionable to believe that spreading the internet would end political tyranny (Morozov, 2013.) We can appreciate the genuinely exciting possibilities of the technological ideas listed above while still realising that technology alone cannot solve every problem facing learning. For example, crowdsourced sustainability education cannot wipe away ideology— as Plato wrote long ago: “can you persuade us, if we refuse to listen to you?” Likewise, time and effort are required to make meaningful contributions to investigations of learning even with the slickest collaborative techniques. Such efforts will have to concretely incentivised somehow, because they require resources that could be spent making money or doing research. School bullying can be studied, but requires person-to-person intervention, and so on.

Purely information-driven approaches are nearly costless to scale, producing massive benefits for little investment — when they are applicable. We should not let the possibility of such easy fixes tempt us to focus solely on the technical aspects of learning. This challenge could be addressed best by work on principled identification of those kinds of challenges that will be susceptible to technical solution, and those that require social, cultural, or political involvement.

Studying All Learning

A truly open science will tend to study what society values. In the OSoL context this would mean that the forms of learning that people choose to pursue, would be studied. Thinking more broadly, this would mean all learning, regardless of subject or context, could be studied. Cooking with one’s grandmother, for example, could be a form of learning, as could be reflecting on life.

Certainly OSoL could study how to learn just about anything, but just as important might be simply documenting what type of learning matters most to people. “Learning celebrations” in which participants reflect on, share, and celebrate the learning that most affected their lives, could be a rich and rewarding activity in itself that would draw participation and also produce valuable data. By finding patterns in the characteristics of life's most valuable lessons (for example, the intimacy and continuation of a tradition in the case of cooking with Grandma), we may help people distribute their attention to the most important learning. At the same time, contributing to learning celebrations can help us appreciate what we already know — a major contribution.

Appreciating the Implicit

Several previous challenges touch on the importance of the subjective and intuitive in learning, but it is worth nominating appreciation of this dimension of life itself as a challenge for OSoL. The concept of implicit or "tacit" knowledge was coined by Physical Chemist turned philosopher Michael Polanyi as part of an effort to understand how science works (Polanyi, 1958, 1966.) Polanyi felt that science itself was a process that was learned by close contact over time, during which values and practices are subtly communicated. By definition, implicit learning is not usually noticed or named by human language and reason, or easily recorded. Thus implicit knowledge is hard to share, discuss or appreciate openly — though we all notice when an educator has a "certain something". We cannot say what it is, which makes it hard to even begin to study it. OSoL cannot be a complete science if it does not include this dimension of learning, but a skew towards artificial study environments could easily lead to marginalisation of the importance of the implicit. On the other hand, VR environments that are realistic may allow this dimension to be represented and recorded. Recognising the difficulties of capturing this knowledge is a first step towards redressing this potential "blindspot" for OSoL.

Getting the University to Study Itself

It sometimes seems that nothing interests the University less than how it educates students. This is unfortunate because the skill in conducting good controlled experiments is nowhere more prevalent than in the university, where many advanced skills are also taught. Although the vision shared in this document is that of an OSoL that encompasses all learners and educators, openness must start at the core of the scientific community. This currently means academia, which is designed and funded to foster scientific thinking. The most open scientific investigation will always require the involvement of trained scientific professionals, because the design and conduct of controlled experiments requires time and resources to master, like any other complex skill. OSoL should thus ask universities to become more active in promoting and incentivising experimentation with (and study of) new learning methods. Faculty are not, however, given anywhere as much resources or encouragement for creating innovative learning methods and demonstrating the effectiveness of these, as they are for research (Brownell & Tanner, 2012.) Changing this would be a massive boost to OSoL, and universities who take this step will be able to better attract talented students.

Conclusion

We have tremendous challenges ahead, if we are learn how to have a planet to live in comfortably, and create societies in which technological advance leaves a role for everybody. We will not meet those challenges by learning, teaching and researching as we have always done. A new "open science of learning" is necessary to explore learning and teaching and accumulate knowledge more effectively than we have ever done. The question is, where to start dealing with the challenges of creating an OSoL? As with all new initiatives, OSoL will take shape by a variety of local actions taken in the context of a global awareness.

Many local actions are straightforward. OSoL is an open idea — Institutions that, like CRI, have discretion to support pioneering efforts in this direction, should take the opportunity. Many of the challenges above, such as a global warming education, efforts to find the most valuable learning, or better measurements of learning trends, can be studied under existing funding mechanisms. Individual researchers in the learning sciences can aggregate their data or findings, and pursue collaboration with colleagues from other fields. And if you are a researcher in a field not related to education, explore the opportunities for collaborating with learning scientists, perhaps making your classroom into a laboratory.

At least as important are higher-level actions that can affect broader institutional reality. As mentioned above, current incentives to participate in OSoL are not adequate. Although many people are starting to contribute in such collaborations, institutional support for involvement in OSoL by non-learning researchers, learners, and teachers will ultimately be necessary for OSoL to reach its full potential. Administrators and policy makers can advocate these changes, and individual researchers, teachers, should not expect this change to happen automatically. We are all learners, we are all teachers and we are all researchers, and all concerned groups will have to work together to make an open science of learning a reality.

References

Berry, D. C. (1987). The problem of implicit knowledge. Expert systems, 4(3), 144-151.

Bligh, D. A. (1998). What's the Use of Lectures?. Intellect books

Brooks, N., Pogue, A., & Barner, D. (2011). Piecing together numerical language: Children's use of default units in early counting and quantification. Developmental Science, 14(1), 44-57.

Brownell, S. E., & Tanner, K. D. (2012). Barriers to faculty pedagogical change: Lack of training, time, incentives, and… tensions with professional identity?. CBE—Life Sciences Education, 11(4), 339-346.

Clark, A. (2008). Supersizing the mind: Embodiment, action, and cognitive extension. OUP USA.

Davis, B., & Simmt, E. (2003). Understanding learning systems: Mathematics education and complexity science. Journal for research in mathematics education, 137-167.

Dillenbourg, P., Järvelä, S., & Fischer, F. (2009). The evolution of research on computer-supported collaborative learning. In Technology-enhanced learning (pp. 3-19). Springer, Dordrecht.
Eiben, C. B., Siegel, J. B., Bale, J. B., Cooper, S., Khatib, F., Shen, B. W., ... & Baker, D. (2012). Increased Diels-Alderase activity through backbone remodeling guided by Foldit players. Nature biotechnology, 30(2), 190.
Goldstone, R. L., & Kersten, A. (2003). Concepts and categorization. Handbook of psychology, 597-621.
Johnson, P. (2009). The 21st century skills movement. Educational Leadership, 67(1), 11.
Laurillard, D. (2012). Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology. Routledge.
Lateef, F. (2010). Simulation-based learning: Just like the real thing. Journal of Emergencies, Trauma and Shock, 3(4), 348.
Levin, H. M. (2012). More than just test scores. Prospects: Quarterly review of comparative education, 18, p. 5.
Magnussen, R., Hansen, S. D., Planke, T., & Sherson, J. F. (2015). Games as a platform for student participation in authentic scientific research. arXiv preprint arXiv:1511.01653.
Morozov, E. (2013). To save everything, click here: The folly of technological solutionism. Public Affairs.
Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. The journal of the learning sciences, 13(3), 423-451.
Polanyi, M.(1958). Personal Knowledge: Towards a Post-Critical Philosophy. University of Chicago Press.
Polanyi, M. (1966). The tacit dimension. London, Routledge.
Popham, W.J. (1999). "Why standardized tests don't measure educational quality". Educational Leadership. 56 (6): 8–15.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. Psychological bulletin, 124(3), 372.
Salas, E., Rosen, M. A., Held, J. D., & Weissmuller, J. J. (2009). Performance measurement in simulation-based training: A review and best practices. Simulation & Gaming, 40(3), 328-376.
Simola, H. (2005). The Finnish miracle of PISA: Historical and sociological remarks on teaching and teacher education. Comparative education, 41(4), 455-470.
Tetlock, P. E., & Gardner, D. (2016). Superforecasting: The art and science of prediction. Random House.
Vygotsky, L. S. (1967). Play and its role in the mental development of the child. Soviet psychology, 5(3), 6-18.
Yu, J., Landy, D., & Goldstone, R. L. (2018). Visual flexibility in arithmetic expressions. Proceedings of the 40th Annual Conference of the Cognitive Science Society. (pp. 2750-2755). Madison, Wisconsin: Cognitive Science Society.
Wang, L., Beckett, G. H., & Brown, L. (2006). Controversies of standardized assessment in school accountability reform: A critical synthesis of multidisciplinary research evidence. Applied Measurement in Education, 19(4), 305-328.
World Economic Forum. (2015). New vision for education: Unlocking the potential of technology. British Columbia Teachers' Federation.