Designing beyond STEM: Public policy, public science and the Learning Sciences

The Annual John P. Keeves Lecture 2017 of the South Australian Institute for Educational Research (SAIER), given by

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2. Acknowledgements

Good evening.

I acknowledge that the land we meet on today is the traditional land for the Kaurna people. I come here with respect for their continuing spiritual relationship with and custodianship of their Country.

I also acknowledge the welcome I have had here in Adelaide from my colleagues at Flinders where I have been visiting from time to time over the last 6 months. The Flinders tradition, and indeed the South Australian tradition, to 'experiment boldly' is needed in education today and it has been a pleasure to become a small part of the work going on in that tradition.

Finally I need to acknowledge the Office of Teaching and Learning and Questacon, the National Science and Technology Centre for their support of different parts of the research work I will talk to tonight.

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3. Introduction

It is a delight to be giving the John Keeve lecture. Professor Keeves was a science and mathematics teacher so my topic tonight, ***Designing beyond STEM: Public policy, public science and the Learning Sciences*** seems quite appropriate. John, of course, is also well known for his work on educational measurement and educational research methods and I will have some things to say in that space too.

By way of brief orientation, tonight I want to take the opportunity to make two key arguments. In short, these arguments are:

I. STEM is more than the acronym suggests, but rather it is part of a larger movement to reclaim a central social space for science and mathematics,

II. To be successful, STEM requires a renewed or refocused research effort that supports changes in practice and not simply best current practice.

These arguments will be made from my research work at the intersection of public science, public policy and the learning sciences. I'll start with public science, by which I mean the world of science communication and the science museum sector, including those called 'centres'.

4. Public science

My first job as an undergraduate student was with the Wollongong Science Centre, so I have a long-standing relationship with the science museum sector. More recently I have had the opportunity to work in partnership with Questacon, Australia's National Science and Technology Centre and the Singapore Science Centre, and to visit with the world famous Exploratorium in San Francisco for their Teachers' Summer Institute.

My research work is heavily influenced by cultural historical activity theory and I think the social and historical background of the science museum sector also provides an instructive background to the research work I have been doing.

The earliest science museums date back to the European Renaissance, which is also when the enterprise we can begin to recognise as modern science began. These early museums were little more than 'cabinets of curiosities' and reflected the amazing diversity the European colonial powers were finding as they expanded into the wider world. They were typically dominated by zoological and mineral collections, although the tendency to also collect human remains has created serious ethical issues half a millennia later. These early science museums reflect the science of the time. Both were essentially driven by curiosity and a desire to understand a world that appeared increasingly complex.

5.

The great social change that was the Industrial Revolution also changed the role of science and of science museums. The Industrial Revolution was built on technologies such as the steam engine, which were in turn built on built on an increased scientific understanding. In this sense, science had shifted from being a way to exercise curiosity about the world, to being a way for humanity to *reshape* the world. In this era the communication of this science through exhibition came with a sense of triumphalism, with new museums and other exhibitions increasingly showcasing human achievement.

6.

A new type of science museum with an experiential focus first emerged in the1960s, the age of the space race, and their initial appeal needs to be understood in that social context. After the Second World War, scientific discovery and technological advancement became a matter of national prestige and significant 'weapons' in the cold war. In this context, the role of science communication and science education shifted from informing the public of the science underpinning the changes occurring in society, to one of recruiting and training the workforce that would lead that change. As America set itself the ambitious target of putting someone on the moon within a decade, the education systems of the developed world similarly set about developing the talent that could achieve such goals.

The museums of this type - such as the *Exploratorium* and *Questacon* (and Wollongong) - adopted an ‘interactive’ or ‘hands-on’ approach, inviting visitors not simply to look at curiosities, or to receive explanations about the artefacts collected, but to interact with the exhibits to gain new insight into a scientific phenomena.

7.

In the 21st Century, science museums have shifted again. I will flesh out what I see as the contextual reasons for this change shortly, but the change that has occurred is to increasingly support children to not simply experience phenomena, but to engage in what can be seen as ‘STEM’ learning experiences such as *tinkering* and *making*.

I became particularly interested in these 2st Century efforts of this sector to promote STEM when I was conducting a professional learning workshop for secondary science teachers with Questacon. Through post-workshop discussion it became clear that the teachers were intending to use the specific activities that had been used in the workshop, but that they saw no reason to change their overall program or approach.

This discussion reified the work on implementation research I had been reading from William Penuel and Barry Fishman (Fishman, Penuel, Hegedus, & Roschelle, 2011; Penuel, Fishman, Yamaguchi, & Gallagher, 2007) in the United States who have, or some years, been writing of the poor scalability and sustainability of just this type of professional learning.

Before I turn to matters of implementation though, I want to mount an argument about STEM education and its cultural-historical context.

8. STEM and public policy

Although derived from the acronym for science, technology, engineering and mathematics, I want to suggest that 'STEM *education'* is something more – or perhaps something *different* – than the sum of the parts.

Getting more particular still, I want to argue that STEM is fundamentally different to formal *science* and *mathematics* education as carried out in our schools and undergraduate programs and will put technology and engineering to the side for the time being. I do so firstly because what technology and engineering education looks like at the school level is far from clear. Technology is amazingly diverse in its applications and its pedagogies, while engineering is largely not present in schooling. Further, I suspect the traditions of technology and engineering education are more consistent with the policy discourse around STEM that I am about to outline. My argument that STEM is something fundamentally different to formal science/maths education, therefore, may not apply to the T and E disciplines.

9.

While I am playing around with acronyms, or ideas signified by an acronym, I will also mention STEAM, which is STEM with an 'arts' component. I have seen many a science educator roll their eyes at this, and I am sure I have done so myself. But I think STEAM points to something particular in the discourse here and that is the perceived importance of *creativity* within the 'technical' disciplines incorporated within STEM. Personally I remain unconvinced and even sceptical that the arts, or 'tinkering', or even open-ended problem solving will achieve this creativity, but I think we need to acknowledge this desire within the discourse.

10. STEM v formal science/maths education

Returning to my argument.

Formal science/maths education has been shaped as an ontological endeavour. It is about the nature of being or the nature of existence. This is not in a religious sense – although comparisons can be made – but in the sense that, say, Ohm's law exists independently of we humans knowing it. Simply put, there are physical properties and mathematical relationships that are part of the nature of our universe, and formal science/maths education has been fundamentally about exploring those properties and relationships.

STEM, on the other hand, has emerged in the discourse as an essentially epistemological endeavour. That is to say it is about *how* we know – and STEM, I would contend, represents a *campaign* for an important shift in how we 'know' science and mathematics.

The case I am sketching out here goes beyond debates of 'content' versus 'skills' that are often had within discussions of science curriculum. Scientific and mathematical thinking are now well established as a legitimate part of the curriculum. One could point out that the default position of the vast majority of our science and maths teaching community is to make ontological investigation central to their design and to 'bolt on' the skills and 'human endeavour' outcomes. But this is not my central point.

11.

Rather my argument is that STEM is a campaign for the development of a different *habitus* to knowing science/mathematics education and its applications through technology and engineering. I use *habitus* here following Bourdieu. In his field theory, the sociologist Bourdieu talks of habitus as 'feel for the game'. Of course the feel for a game is meaningless without reference to the game being played, and I think STEM is actually about changing the 'game'. It is about a wider strategy to claim, or perhaps to reclaim a central place for the activity of science and mathematics in our society.

12.

To dwell briefly on this idea, consider two statements from the Australian Office of the Chief Scientist. The first comes from a policy text that became the bedrock for Prime Minister Turnbull's signature policy on innovation. In it we see STEM as part of Australia becoming a:

> science nation… in which science is woven, not only into our classrooms, but also into our boardrooms, our workplaces and our living rooms, as one of the building blocks of our prosperity (Commonwealth of Australia, 2014).

This discourse has led to our leading scientific thinkers taking an increasingly active role in areas that might once have been the jurisdiction of economists:

13.

> Entrepreneurship is an economic activity requiring attention to the framework conditions for business creation and growth. But more importantly it is a human endeavour, requiring attention to the way that our attitudes are shaped, our skills developed, our networks formed. And so it is inseparable from education – not independent of it (Chubb, 2015)

The discourse analysts might be quick to note Chubb's use of 'human endeavour' here as the same term that is used to describe the 'nature of science' part of the Australian science curriculum, that is 'science as a human endeavour'. I cannot know if this discursive link between science and entrepreneurship was conscious or intentional, but I do not think it was accidental.

Shifting the social position of science and mathematics

My argument is that STEM is much more than an acronym joining a set of related disciplines, and is part of a wider campaign to reclaim a more central social position for science and mathematics, and particularly to ensure science and mathematics are seen as central to matters economic. The reasons for such a campaign are numerous and complex, but I will highlight just two.

One.

Following the industrial revolution, science the centrality of science and it applied disciplines became almost unchallengeable. The rise in living standards and the expansion of the human imagination that the scientific revolution brought about was evident to all who looked and, in many ways, science replaced religion as a central social reference point for understanding the nature of being – our ontological work shifted from church to university.

In the last few decades, however, the broad social 'faith' in science has broken down. Headlined by debates around issues such as climate change and vaccination, this trend follows a deeper social decline in respect for expertise and institutions; and a shift in how we as a society assess claims of truth. STEM is a response to this – it is a campaign to reclaim a central place in social truth making that was thought won in the enlightenment.

14. Two.

STEM is also a response to the apparent decline in interest in study science and mathematics. I say 'apparent' because while the issue has caused much angst and can be seen in raw data, there is some highly informative and nuanced research that challenges the idea of declining interest per se, and suggests an alternative of declining interest in the focus of traditional curriculum.

15.

The research I am referring to is the *Relevance of Science Education* (ROSE) project (Sjøberg & Schreiner, 2010). Based on findings of very large differences in interest in particular STEM topics between different countries, these researchers have argued that students in rich countries can 'afford' to see school as an obligation and be more selective in their educational choices. Noting then the very large differences in interest between particular STEM topics within the rich countries, on the other hand, they conclude that the decline in interest is in topics such as how plants grow, chemicals and their properties, soaps and how they work, famous scientists and basic mathematics skills; but they find continued and sustained interest in topics such as environmental protection and the possibility of life beyond the Earth.

16, 17 & 18 [unpack]

The essential message of the ROSE project is that the decline in interest may not be in science per se, but in the way science is taught in schools – including in topics that are intended to be relevant to the every day lives of students, but which the students themselves see as irrelevant.

19. Knowledge transmission versus knowledge creation

The epistemological change represented by STEM reflects a broader shift in educational thought, which is in turn reflective of our 'information' age. This shift is one that increasingly sees education as a knowledge-creation rather than knowledge-transmission process. This is something more than constructivism, I think, and comes at a time when computing is changing the nature of intellectual work in ways that we have not yet fathomed. Yet – and this is notable for public policy advocates of STEM - it stands in tension with the governance systems of our neo-liberal age.

Knowledge-transmission learning processes are familiar to us all in traditional formal education. In them, the desired knowledge exists prior to the learning, and the attainment of this knowledge can be readily measured and rewarded. This process is valorised by the standardise-and-measure model of neoliberal governance under the banner of 'quality'.

20.

STEM, on the other hand, advocates for *informal* learning in the sense suggested by Ambjörn Naeve (Naeve, Yli-Luoma, Kravcik, & Lytras, 2008). In this type of learning process the desired knowledge is only determined through the execution of the learning process, and the learning process may even create the knowledge! These processes will *also* feel very familiar to us in the academy, as they are the learning process of the research world where the *explorative learning* behaviour of figuring out fruitful questions, and then providing answers to them, is greatly rewarded.

The different reward systems in play must be heeded in understanding the nature of the STEM 'campaign'. The *informality* of STEM is quite simply not a good fit for formal education as it is currently formed. It does not conform to a system where quality-assured assessment can be linked to status enhancements such as grades and certificates.

The STEM campaign

If nothing else, the tensions created by STEM provide a fascinating case study for the processes of change in educational policy and practice. STEM has a significant foothold in the educational landscape, but it has not come in through the traditional forums for curriculum. Rather, it has taken an all-together more 'public' route through mechanisms such as the already cited Office of the Chief Scientist – not a regular agent in the world of education policy; it has been promoted through the informal settings such as the science museums; and its development has been heavily funded through grants outside the normal formal curriculum bodies.

I have been involved in three of these grant driven projects with a collective value of over $11 million – money almost unheard of in educational research. Two of them have focussed on influencing pre-service teachers, while the third, the Early Learning STEM Australia project, is supporting teachers in early learning and pre-school centres to provide learning in STEM. So if my assessment that STEM is more than a combination of allied disciplines and actually a campaign to reclaim a central social position for science and mathematics, it is a well-funded campaign.

21. STEM and the need for *implementation* research

So far I have been setting out the argument that STEM is something more than the combination of disciplines that the acronym suggests and that it can be understood as part of a campaign to reclaim a more central position for science and mathematics within social decision-making and public imagination. This is a campaign that I essentially support, and the focus of my research in recent years has been on improving the effectiveness with which we do this.

The second argument I want to make tonight is that if STEM and the wider campaign it represents is to be successful, then those advocating STEM or knowledge-creating learning processes have been overly focussed on uncritical participation. I contend that what is needed is a *a renewed research effort that informs 'next' practice, and not simply 'best' practice.* This effort must give us new ways to understand complex informal learning environments, and must provide new models of teacher professional learning.

Now I appreciate that this almost sounds like aphorism - of course research should inform innovation! That is one of the primary reasons we do research in any field. But innovation in education is very difficult. It is far more difficult than just doing good research on 'what works'. The widespread implementation of innovation in education requires the coordination of the learning science that underpins under-pins the innovation; of good design to translate that science into something that can actually be done; and of teacher professional learning even at the level of conceptual change. Beyond this it needs to overcome the assumptions we have about how schooling works, the 'grammar' of schooling if you will (Tyack & Tobin, 1994). These are issues of policy and management, and complex ones as education is a highly political activity, and it has been structured in a way n which teachers still exercise significant autonomy.

So what I am suggesting, what I refer to as *implementation* research, is a complex thing. And I guess if it were easy, we would never hear talk about the alleged ‘gap’ between ‘theory and practice’.

Before I give some examples of implementation research from my own work, I want to be clear that I am talking about something different to ‘school improvement’ here. As I see it implemented in schools, reforms under that banner are closely aligned with doing knowledge transmission better, but they probably make knowledge-creation processes more difficult. The implementation research I am suggesting should actively seek to support the use of knowledge-creation learning processes within formal learning settings.

To explain this a little further, I will give two examples from my own work.

22. *New forms of measurement and evaluation*

In the first example, my thinking has been driven by the difference in the ‘reward’ systems of formal and informal learning.

I am quite taken by John Hattie’s argument that assessment should be understood as a way to test educational interventions rather than children. I am less taken with his insistence on a pre-test/post-test methodology, which requires knowledge-transmission learning processes and so, not surprisingly, finds that almost all forms of informal learning is relatively ineffective. It is my belief that new technologies might provide us with viable and meaningful alternatives to understand what is occurring in learning environments, including informal learning environments. I have outlined this argument in some length in a recent paper in the *Australasian Journal of Educational Technology* (Leonard, Fitzgerald, & Bacon, 2016), while my work on applying this argument is ongoing.

23.

The example I am sharing here (Leonard & Mulligan, 2016), is an analysis of student learning journals made using the textual analysis software *Leximancer.*

Leximancer is a software application that automatically analyses text to identify the high level concepts with the text, and how those concepts are used in relation to each other. It is essentially a *corpus linguistic* approach looking at the statistical relationship between concepts in a given body of text.

The capacity of this software to produce reliable and valid analysis is now well established with Penn-Edwards (2010) noting it is 'able to deal with large amounts of data without [coding] bias, identify a broader span of syntactic properties, increase reliability, and facilitate reproducibility' (p. 253). The software represents the analysis in a number of ways including a concept-map visualisation.

It makes possible computer-assisted or semi-automated phenomenography, a methodology built on variation theory (Akerlind, 2005) and the methods of manual phenomenography (Dahlin, 2007; Marton, 1986). Phenomenography is a method developed within science education as a way of mapping different understandings of reality. It begins from the position that there are many 'correct' ways to understand a given concept but that some understandings show a greater level of 'discernment' than others.

In the example I am presenting here, *Leximancer* was used to analyse the reflective learning journals kept by student during a course designed to improve the science knowledge of undergraduate primary teacher education students. The initial analysis showed that student conceptual coherence was apparent from week three of the course.

24.

Through the iterative testing of the connections leading to this coherence, however, it was evident that the connections driving this coherence were based on students learning the 'rules of the game' for how to pass the assignment, over and above the targeted conceptual change relating to the processes of science being studied. This testing was achieved through the software's capacity to systematically suppress given concepts and so more fully understand which concepts are central and linking – an idea similar to the measure of 'between-ness' in social network analysis.

25.

The importance of this work, in terms of the arguments I am making tonight, is that the technology provided a way for us to see quite quickly that the learning design was not working well. The student reported positively on the course, but they were responding primarily to their ability to be able to navigate the trappings of formal education.

Also important is that the method is able to evaluate knowledge-generation. It does not require the pre-determination of knowledge to be achieved, but is able to map conceptual change during the execution of the learning activity. In this early example, the results are highly qualitative, but when we link the maps to the conceptual development models that have been created by Variation Theory researchers, the method can be used to compare and 'value' different learning environments.

Of particular note here is the speed that the software allowed for this insight into the learning environment to be developed. While some care was needed to ensure the data – student writing – was 'clean', the analysis itself took a matter of hours, and less time than marking. This is not to suggest that such an analysis can or should displace marking, but simply to point to the potential of emergent technology to provide deep evaluative insight into learning environments at a reasonable cost.

I don't have pretty pictures to show yet, but more recently I have been working with my colleague Geoff Woolcott at Southern Cross University to explore a similar method to map conceptual exchange during a collaborative learning activity based on the programing of simple robots. This process has been far more labour intensive at this stage, but as we get better at targeting our audio recording, and as we speech to text software improves, we can see a time when the sort of analysis we currently do with *Leximancer* will be possible for spoken interactions too.

26. Conjecture mapping

In my second example my thinking is driven by the need to support teacher conceptual change. The project is reported in a forthcoming paper in the journal *Quality in Higher Education,* and in a recent paper in a new journal called *EDER – Educational Design Research*, an open access journal edited by my colleague Sebastian Fielder at the University of Hamburg whose work in establishing a new scholarly journal is, I think, worthy of special mention.

Educational design research, known in the American literature as design-based research, is the response of the learning sciences to the challenges of translating the findings of the learning sciences to school practice. It seeks to simultaneously investigate questions of learning science and educational practice. In this example, the 'practice' problem we sought to engage was the one I described earlier following the professional learning sessions at Questacon – teachers adopting the activity, but not seeing – not perceiving – the deeper design principles, even when they were taught explicitly.

To do this we revised the professional learning design, making use of William Sandoval's approach of *conjecture mapping* (Sandoval, 2004, 2014). Conjecture mapping is an approach that assists in fully articulating the purpose of, and decision-making within, an educational design. This articulation of what was supposed to work, and how it was supposed to work, provides a fixed point for analysis within the complexity of an educational environment. Sandoval's approach starts with the assumption that educational designs and educational environments are inherently theoretical and intrinsically embody hypotheses about how learning happens.

To examine this with a well-known example in science education, let's suppose we design a student investigation into acid-base reactions. We might do this with the design conjecture that students will test a variety of substances for evidence of a reaction (observable interactions between student and design), and that the students will create records of those reactions (participant artefacts). Our design conjecture might be that the students will observe and discern the relevant evidence of a reaction such as the emission of a gas. To encourage students to discern the most pertinent evidence, many teachers will include in their design explicit information on what to look out for.

Of course, what students will actually do is conjecture. Students may choose to mix all the reactants together all at once just to see what happens, or they may focus on the colour of some reactants because they find them pretty, or they may decide to investigate the effects of drinking an acid!

Even if the design creates entirely the desired activity, the translation of the process to learning also involves further conjecture. Embodied in the activities teachers design are the theoretical conjectures teachers have about how a concept is learned, or on the order in which concepts ought be learned, or perhaps on what motivates students to learn. In our acid-base example, we may have a working theory that students will construct a more complete understanding of the acid-base reaction through combining direct observation with theoretical knowledge and, further, that the observation of multiple examples of the reaction will allow them to draw a generalisation.

27.

In the example I show on the slides here, the teachers developed a conjecture map for a standard high school science activity on the rusting of iron nails. This is a deceptively simple activity, which as the many arrows show is actually very complex pedagogically.

What we found with the mapping activity was that it allowed a different type of conversation to those following the original PL design. In short, the conversations shifted from the ‘performance’ of teaching – a knowledge-transmission process – to a dialogue regarding how knowledge might be *created* through the activity. The teachers sounded like researchers.

What I want to highlight here is not so much what this research has achieved, but rather what there is yet to do. If we are to support teachers in doing things differently – to support change in how they understand their practice - then it is evident that we need to more than simply show them alternative learning process designs. To do this we need continued research into professional learning that is effective in these terms.

Significant within this conjecture mapping design – although as I indicated, needing further investigation – appears to be the use of visual thinking. The visual nature of the mapping exercise may have engaged visual thinking processes, which we can now show is neurologically different from language-based thinking (Amit, Hoeflin, Hamzah, & Fedorenko, 2017). It is reasonable to hypothesise that this allows for different associative links (Kahneman, 2011) to be made and so may be effective in facilitating different understandings of the problem to emerge. This appears a fruitful line of inquiry from here.

28.

Also worthy of further research is the capacity of this method to identify *design principles* that allow for transferring innovation from 'innovation labs' such as Questacon into the wider field of STEM education. Euler (2017) describes the value of design principals lying in the provision of knowledge that goes 'beyond the scope of a unique individual case' but remaining limited in their generalization range. This is similar to Bereiter's (2014) argument regarding 'principled practice knowledge (PPK)' which moves beyond the immediate needs of the practitioner, but not so far beyond as to be unrecognizable. The use of approaches form design science are inherently knowledge creating, but they have had limited use within education and there is much more to learn.

4. Conclusion

'There is much more to learn' sounds like an appropriately scholarly conclusion, so let me draw this lecture to an end here.

Tonight I have been making the case that STEM is much more than an acronym joining a number of disciplines, but is part of a wider social movement to reposition science and mathematics education within society. In outlining previous changes to the role science and mathematics education has held, I have shown such a repositioning to be a normal part of our social evolution, recognising that science is a human, and therefore social endeavour.

Drawing on examples from my own work, I have the gone on to call for a renewed research effort into the *implementation* of knowledge-creation learning processes, and indicated my belief that such work must engage in questions relating to the evaluation systems in use and to effective teacher professional learning.

I am looking forward to your thoughts and questions.

References

Akerlind, G. S. (2005). Academic growth and development: How do university academics experience it? *Higher Education, 50*(1), 1-32. doi: 10.1007/s10734-004-6345-1

Amit, E., Hoeflin, C., Hamzah, N., & Fedorenko, E. (2017). An asymmetrical relationship between verbal and visual thinking: Converging evidence from behavior and fMRI. *NeuroImage, 152*, 619-627. doi: http://dx.doi.org/10.1016/j.neuroimage.2017.03.029

Bereiter, C. (2014). Principled Practical Knowledge: Not a Bridge but a Ladder. *Journal of the Learning Sciences, 23*(1), 4-17. doi: 10.1080/10508406.2013.812533

Chubb, I. (2015). Forward. In S. Innovation (Ed.), *Boosting High-impact entrepreneurship in Australia*. Canberra: Commonwealth of Australia.

Commonwealth of Australia. (2014). *Vision for a Science Nation. Responding to Science, Technology, Engineering and Mathematics: Australia's Future*. Canberra: Australian Government.

Dahlin, B. (2007). Enriching the theoretical horizons of phenomenography, variation theory and learning studies. *Scandinavian Journal of Educational Research, 51*(4), 327-346. doi: 10.1080/00313830701485437
Euler, D. (2017). Design principles as bridge between scientific knowledge production and practice design. *Educational Design Research, 1*(1), 1-15. doi: dx.doi.org/10.15460/eder.1.1.1024
Fishman, B. J., Penuel, W. R., Hegedus, S., & Roschelle, J. (2011). What happens when the research ends? Factors related to the sustainability of a technology-infused mathematics curriculum. *Journal of Computers in Mathematics and Science Teaching, 30*(4), 329-353.
Kahneman, D. (2011). *Thinking, fast and slow*: Allen Lane.
Leonard, S. N., Fitzgerald, R. N., & Bacon, M. (2016). Fold-back: Using emerging technologies to move from quality assurance to quality enhancement. *Australasian Journal of Educational Technology, 32*(2), 15-31. doi: http://dx.doi.org/10.14742/ajet.2196
Leonard, S. N., & Mulligan, J. (2016). *Using computer-assisted phenomenography to improve accounts of learning within a program*. Paper presented at the Building bridges between assessment and evaluation: the 8th biennial conference of EARLI SIG 1 - Assessment and Evaluation Ludwig Maximilians University, Munich, Germany.
Marton, F. (1986). Phenomenography: A research approach to investigating different understandings of reality. *Journal of Thought, 21*, 289-303.
Naeve, A., Yli-Luoma, P., Kravcik, M., & Lytras, M. D. (2008). A modelling approach to study learning processes with a focus on knowledge creation. *International Journal of Technology Enhanced Learning, 1*(1-2), 1-34. doi: 10.1504/IJTEL.2008.020228
Penn-Edwards, S. (2010). Computer Aided Phenomenography: The Role of Leximancer Computer Software in Phenomenographic Investigation. *The Qualitative Report, 15*(2), 252-267. Retreived from: http://www.nova.edu/ssss/QR/QR15-2/penn-edwards.pdf
Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What Makes Professional Development Effective? Strategies That Foster Curriculum Implementation. *American Educational Research Journal, 44*(4), 921-958. doi: 10.3102/0002831207308221
Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist, 39*(4), 213-223. doi: 10.1207/s15326985ep3904_3
Sandoval, W. A. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences, 23*(1), 18-36. doi: 10.1080/10508406.2013.778204
Sjøberg, S., & Schreiner, C. (2010). *The ROSE project: An overview and key findings*. Oslo: University of Oslo.
Tyack, D., & Tobin, W. (1994). The “Grammar” of Schooling: Why Has it Been so Hard to Change? *American Educational Research Journal, 31*(3), 453-479. doi: 10.3102/00028312031003453