

# From (the most) effective learning to more useful research? Problem-based learning, collaborative ‘complex problem-solving’, and outcomes-based interdisciplinary inquiry

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## Abstract

Learning models of applied problem-solving are an important key to transforming education so that graduates develop better skills, knowledge and attitudes to tackle the increasingly complex challenges which face fast-changing social and natural worlds. Universities should also prepare learners to more effectively practise related authentic problem-solving skills, knowledge, and attitudes which can or should be practiced in terms of both concrete and abstract forms of outcomes-based knowledge construction. This is especially so in terms of how the kind of systems model needed to address complex problems in nature and society presupposes the benefits as well as requirements of interdisciplinary inquiry or research for integrated, optimal, and sustainable solutions. To this end the paper will explore how the most effective problem-based learning might also represent a systems view of problem-solving and wider notion of outcomes-based knowledge-building.

*Keywords:* problem-based learning, complex problem-solving, outcomes learning and research; interdisciplinary knowledge-building

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## 1. Introduction

Once described as a *foundation* or *linear structure*, knowledge today is depicted as a *network* or a *web* with multiple nodes of connection, and a *dynamic system* – Julie Thompson Klein, *Interdisciplinarity and complexity*, p.2

In the 21<sup>st</sup> Century in a fast-changing, complex and often difficult world of endless challenges and accelerating crises people have to increasingly deal with what Kolko (2011) and others call ‘wicked problems’ – that is, problems without any simple solutions requiring greater collaboration and the linking of different areas or disciplines of knowledge. In this way it is no longer good enough for universities to merely reproduce knowledge as merely surface learning or descriptive research (Trilling & Fadel, 2009). Problem-solving is the basic human impulse to actively engage in changing and improving human knowledge in the adaptation to changing global as well as local contexts of relevance and importance (Armstrong, 2012). On one hand this may involve science and technology responses to increasingly complex adaptations to physical environments. On the other hand, from a rather a human or social science perspective this may also involve social, political and economic as well as cultural contexts of communities, organisations and whole societies trying to balance internal imperatives and external challenges as well. Philosophers such as Karl Popper and Bertrand Russell have long stressed the sophisticated ways in which problem-solving can or should be linked to the thinking process. However, as Socrates (whose elenchus method was a prototype for modern scientific methodologies) long ago pointed out, a problem-solving approach to thinking is one which is potentially open to anyone (or any learner) to negotiate the implications and omissions of the perpetual gaps between human knowledge and ignorance (Paul & Elder, 2004). In short, any kind of human problem-solving process is also inevitably a learning process – a key reason why formal education can be so readily and effectively enhanced by problem-based learning approaches.

Problem-based learning (PBL) is a developing movement in international universities with interdisciplinary as well as specialist implications for a diverse range of disciplines and knowledge areas besides the medical schools where it originated as a formal method of using authentic cases (Barrows & Tamblyn, 1980). As a concept the term has been further adapted as a generic approach to active or constructivist approaches to learning in schools as well as universities (e.g. Jonassen et al, 2003). In this way it has been linked to related notions of self-directed outcomes (Biggs & Tan, 2011), critical thinking or inquiry (Paul &

Elder, 2004), and also notions of collaborative or social learning (Wenger, 1999). However we believe it is most useful to consider how problem-based learning exemplifies what many call ‘higher-order’ and others ‘deep-level’ notions of learning applicable to practical as well as conceptual or theoretical domains in contrast to the lower or surface notions of learning as the mere transmission, reproduction or even imitation of content in the form of information or basic skills (Bailey, Hughes & Moore, 2003). In this way as a model of active or constructivist learning and knowledge inquiry, PBL has long also exemplified the challenges and resistances to traditional educational models of an exam-based curriculum and a teacher-centred pedagogy as well as curriculum (Hmelo-Silver, 2004).

In this paper we discuss a systems approach to problem-solving in general as well as to problem-based learning in particular. In terms of how PBL exemplifies the possible links between formal education and the pivotal human capacity for problem-solving, we further discuss how this also presupposes a related systems approach to better integrating methods or designs of pedagogy, curriculum and assessment as well as the learning process. The discussion below will be organised around two related sections. The first section will look at the link between PBL and a systems view of the distinction between simple and complex problem-solving. The second section will use a practical example to discuss how PBL might be recognised and applied as one of three central pillars of ‘active learning’ in terms of an integrated application also to curriculum design, assessment methods and learning process. It will do so in relation to how the particular subject provide a focus for also a design research and outcomes as well as evidence based approach to ‘complex problem-solving’ research.

## **2. The implications for PBL of a systems view of the distinction between simple and complex problem-solving**

Deriving in particular from Van Bertalanffy’s (1974) model of general systems theory, various related models of systems thinking or science share in common an interdisciplinary approach to or perspective on the link between different areas of knowledge. Most significant is how such theories or models are not only typically seen as applicable to both natural and human or social realms of knowledge but a means of linking what Bateson (1979) called the ‘the necessary unity... mind and nature’. Thus an emerging paradigm of ‘complex adaptive systems’ (and related models of complexity theory) has encompassed notions of homeostasis, feedback and emergence in natural systems of physical matter, chemistry, and biology (e.g. Laszlo, 1972, Prigogine & Stengers, 1984, Mandelbrot & Hudson, 2005) on one hand, and on the other corresponding notions of life cycles, supply chains and change dynamics in various forms of human organisation involving complex social, economic and cultural imperatives (e.g. Forrester, 1991; Barratt, 2006). The related importance then of multi-disciplinary collaboration and interdisciplinary problem-solving (Klein, 2006) to complement rather than oppose content knowledge specialisation is thus reflected by how human organizations also function as naturally complex adaptive systems of energy and information in relation to changing environments (e.g., Mitleton-Kelly, 2003). In other words there is a natural connection between systems theory and the inevitably interdisciplinary requirements of complex problem-solving in and across all areas of human knowledge.

Scientific and other models of knowledge are often viewed in terms of mere data and information accumulation but the human capacities for observation and reflection as well as experimentation in relation to new or changing contexts are clearly more effective when framed as focused problem-solving of some kind. This is so in relation to how a problem is perhaps most usefully defined as a ‘perceived gap between the existing state and a desired state, or a deviation from a norm, standard or status quo’ ([www.businessdictionary.com](http://www.businessdictionary.com)). A systems approach or perspective allows recognition that all human problems either directly or indirectly involve systemic complexity – even apparently simple problems. In contrast to both traditional mythology or superstition and various forms of typically de-contextualised or modern modes of positivism, reductionism and ‘either-or’ thinking, systems theory focuses on the interdependent as well as independent relation of wholes and parts in and across distinct systems in terms of the processes of interaction, change and transformation. As we have put it elsewhere (Richards, 2013, p.6):

Simple problems (e.g. a bacterial infection, a clogged up fuel filter, or a personality clash within a business organization) which may initially seem more serious and complex might well be quickly addressed and efficiently resolved. However good doctors, mechanics, and leaders all know that both simple and complex problems are all ultimately about restoring the natural and deep-level efficiency or health of a particular ‘system’ whether this be a patient, a car or a business organization. As the wicked problem concept illustrates, the world of actual human experience and organization as well as all nature generally is ultimately and intrinsically complex, interdependent, and open to perpetual change. Superficially ‘simple’ problems ever conceal a latent complexity, yet ostensibly ‘complex’ problems are ultimately quite simple in principle.

Figure 1 outlines a systems model of complex problem solving. It represents the three basic stages of addressing a complicated, difficult, and even an apparently impossible problem or challenge. Assuming that it has been established that we are dealing with a systemic or complex and not just superficial challenge or minor issue, the foundation stage then is to recognize and prioritize the various aspects of an identifiable problem of some kind. This main aim at this stage is to identify the key factors which might include both internal and external aspects, factors or ‘variables’. The second stage involves investigating and coming up with possible distinct remedies to each of the main contributing factors, as well as some macro remedies to the main problem. The third stage then is to consider an overall formula which makes use of also distinct ‘contributing solutions’ but also considers these might combine together in a strategic way to be part of an overall solution. As well as combinations of parts in space any overall solution must also incorporate the process of time to anticipate obstacles to any plan as well as productive interventions and requirements of implementation. The three stages reflect the hermeneutic arc of an initial situation or ‘naïve’ awareness giving way to critical or explanatory deconstruction then followed by an applied stage of synthesis, reconstruction, or transformation (Ricoeur, 1994).

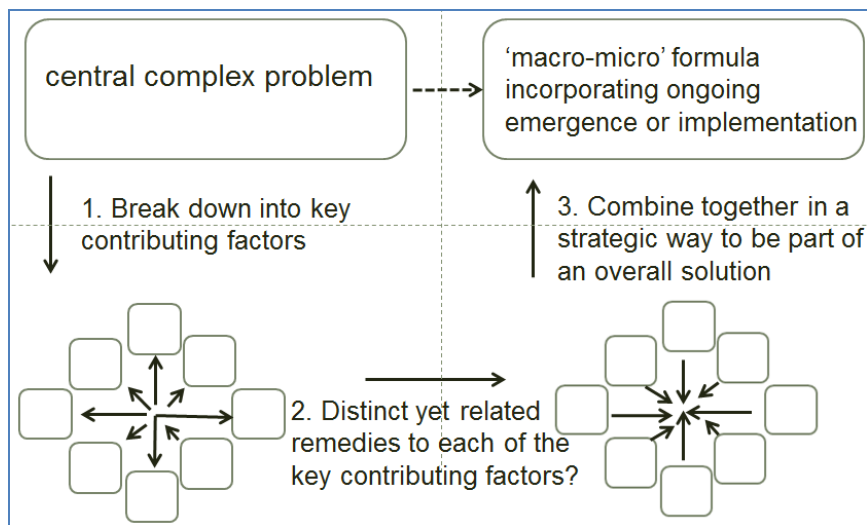


Figure 1. A systems model of complex problem solving

Figure 2 below further outlines an example of emergent *outcomes-based* rather than retrospective or rationalist *evidence-based* inquiry and problem-solving. It adopts the constructive version of the ‘law of three’ to outline a practical example of formulating a framework for addressing ‘wicked problems’. The initial phase involves achieving a provisional or working foundation. On this basis a second stage seeks to prioritise the various relevant internal and external factors or contributing problems. Following on from or simultaneous to this, a third phase seeks to develop an emergent and convergent solution. The implied strategy then is to ‘optimise’ the problem-solving process in terms of transforming any relevant data and information into applied knowledge and understanding. As the right-hand diagram illustrates, an integrated, optimal and sustainable approach to addressing a central or focus problem can be designed in terms of a knowledge-building structure which establishes a relevant foundation, is able to progressively prioritise related issues, and further facilitates not only the acquisition of data and information but its transformation into useful knowledge.

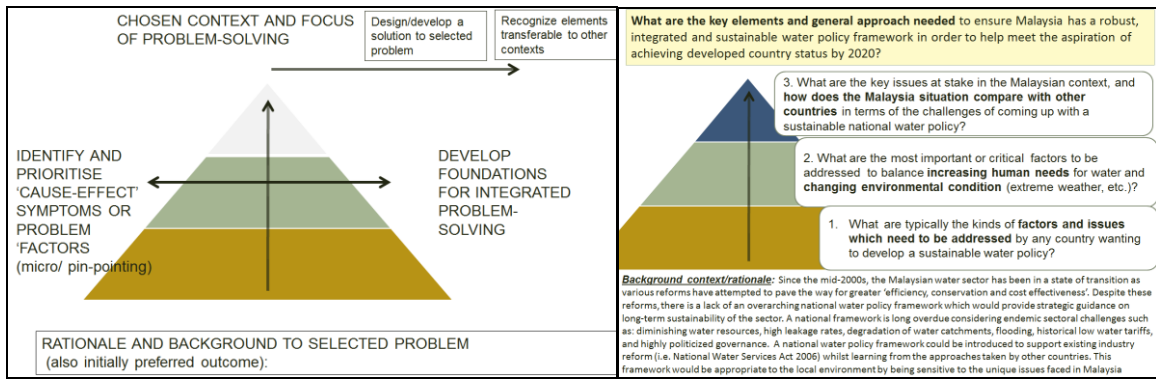


Figure 2. A knowledge-building approach to the challenge of complex problem-solving

This might be appreciated in terms of recognising the interplay of internal and external axes of inquiry which together constitute the so-called *data-information-knowledge-wisdom pyramid* (see Figure 3) used in such areas as ‘management information systems’ (e.g. Fricke, 2009). In such applications ‘wisdom’ is typically seen as unknowable or referred to only ironically. The accumulation and description tendencies of an external axis of empirical data and organised/rationalized information is redeemed or open to be transformed in terms of some focus outcome in relation to an internal axis of knowledge, experience, and understanding. In this way ‘wisdom’ need not be an accidental by-product or outcome of accumulation and complexity but actually a deep foundational process based on the quality of experience and understanding not quantity of information (Richards, 2011).

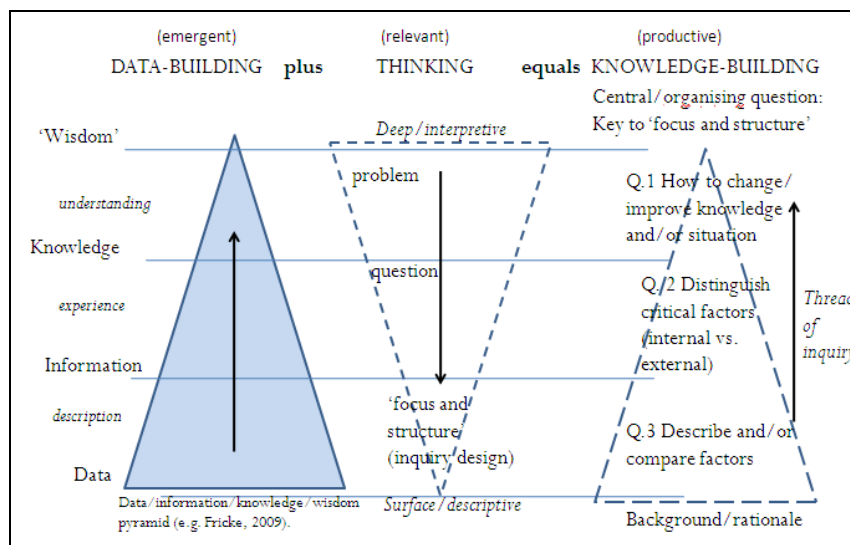


Figure 3. Thinking for problem-solving - the basis for transforming emergent data-building into productive knowledge-building. Adapted from Richards, 2012b

Figure 4 outlines a model for a paradigm shift from the linear and hierarchical assumptions of transmission and related reproductive learning models which tend to focus on the surface acquisition of skills or information. It further projects how an outcomes-based education approach aims to encourage deep learning outcomes associated with active or constructivist learning models (Spady, 1993). Whereas conventional learning outcomes ultimately represent a merely hopeful anticipation of the future often inadequately supported as an actual process of emergent knowledge building, an outcomes-based education approach works backwards from concrete notions of proficient and transferable performance in specific contexts to emphasize the crucial elements of pedagogical, curriculum and assessment design to support this as an actual process of emergent knowledge building. In this way we find it useful to make the distinction between conventional ‘learning objectives’ curriculum design and teaching on one hand, and on the other a truly ‘outcomes-based’ approach. This may be explained in terms of a related distinction between golf hackers who aim for the flag in a merely

hopeful way and those try to align their game with a visualization of the required length, direction and trajectory for the ball to ‘go in the hole’ (Gallwey, 2009). For outcomes-based education to work properly, learning activities need to be sufficiently aligned in practice with the process not just metrics of assessment or evaluation. Likewise the formative aspects of the assessment as well as learning process need to be sufficiently encouraged and also aligned with the rationale and framework of summative assessment procedures. This is why project work and other ‘culminating’ modes of learning activity are so useful in facilitating more systemic or deeper modes of learning.

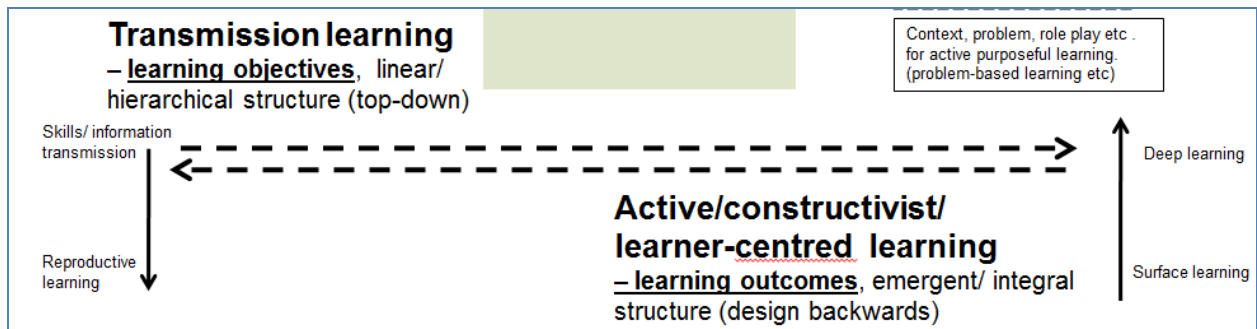


Figure 4. How outcomes-based education should ‘reverse’ not reinforce conventional and surface modes of transmission learning

As indicated above, active or constructivist learning models generally emphasize the associated alignment of related axes of critical thinking and applied performance on one hand, and on the other various complementary notions of surface and deep learning. This is why exams may well remain a useful part of an integrated assessment strategy and should not be seen in an either-or relation to project work, assignments, and related modes lending themselves to encouraging active or constructivist learning. We have also elsewhere argued that related models of problem-based learning, inquiry-based learning and project-based learning represent the three key pillars of the various permutations of active or constructivist learning (Richards 2004). This is on the basis of not only how such models correspond to the elements and stages of Kolb’s (and also Schon’s) learning cycle but also in relation to how problems, questions and tasks framed in authentic or imaginary contexts of learning activity lend themselves to a related alignment between formative and summative assessment as well as of surface and deep aspects of the learning process. Notions of surface learning are typically associated with the reproduction of information or skills where as deep learning is a mode of optimal performance or applied understanding transferable across different contexts (e.g. Biggs & Tan, 2011). Figure 5 thus depicts how a culminating learning task or activity provides the focus and structure for developing a ‘knowledge ecology’ foundation for optimal and sustainable learning application or performance.

As indicated earlier there are different applications of PBL in different areas of knowledge or for distinct outcomes. Some versions of PBL are promoted in terms of specific cases involving specialised knowledge (e.g. the use of PBL cases in medical education) whereas as others espouse interdisciplinary or ‘across-the-curriculum’ collaborative learning (Jonassen, et al, 2003). However either directly or indirectly PBL designs or approaches can most effectively enhance learning where some form of ‘problem-solving’ is linked to an alignment of focused outcomes and meaningful culminating activity. As Kolb (1984) suggests, the most effective cycle of learning involves active experimentation linked to concrete experience as well as to related processes and stages of reflective observation and abstract conceptualisation. In this way PBL can and should replicate the practical problem-solving experimentation of natural scientists as well as the thought experiments of the human and social sciences. In other words, the most effective PBL is typically conceived in terms of either authentic or imaginary ‘problems’ framed in variety of ways including cases, scenarios, questions, challenges, issues, and so on.

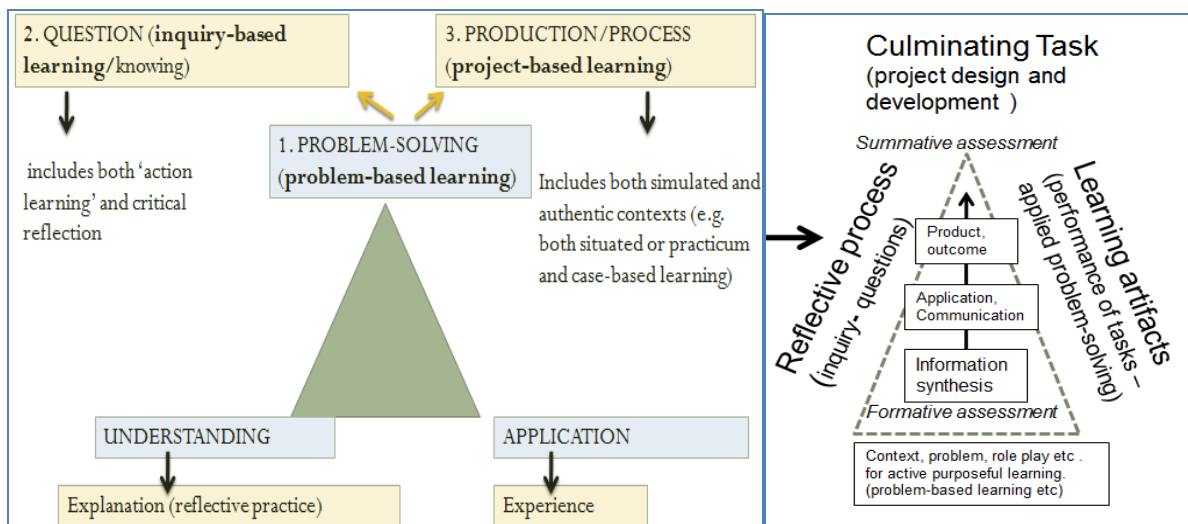


Figure 5. The three pillars of active or constructivist learning translated into an emergent learning-assessment framework

As Biggs & Tan (2011) outline, outcomes-based learning and assessment should link to provide a supporting framework designed to assist learners to achieve specific learning outcomes aligned with various activities and processes of active or constructivist learning. Inadequate applications of the outcomes-based education model tend to merely confuse outcomes with objectives and also ignore how there should be a crucial as well as constructive alignment of meaningful and effective outcomes with not only learning activities and processes but the formative as well as summative process of assessment. The conventional view of lesson-planning, syllabus design, and curriculum development has tended to emphasize linear and hierarchical content-focused models of skills or information acquisition. But active learning models rather emphasize the importance of interesting and engaging introductory contexts which also link to a process of knowledge synthesis and application in examples – emphasizing the importance of an integrated process of learning which also links reflection and activity. Thus a systems view and application of outcomes-based education should promote assessment *for* and not just *of* learning. It should also provide an integrated and structured educational but also inquiry ‘space’ (and not just classroom ‘environment’) for the emergent of effective learning as both understanding and explanation in terms of an effective linking also of macro level concepts, attitudes and general knowledge together with more micro level skills, content and detailed modes of knowledge. Good teaching and curriculum design should promote and encourage deep and not just surface learning transferable to other contexts. A systems approach, then, is useful in promoting deep learning.

### 3. Wicked problems and policy-builders of the future? Curriculum and assessment designs to support authentic problem-based learning for authentic policy challenges of sustainability

PBL has been particularly discussed above in terms of its application to promote assessment *for* and not just *of* learning. Various kind of authentic or imaginary learning ‘problems’ can either directly or indirectly encourage and support an associated mode of effective outcomes-based learning. We discuss below a recent example where we had the opportunity to apply a systems approach to teaching, curriculum and assessment within a completely new course. The module *MFT1053 Sustainable STI Policy Development* was unexpectedly added at the last moment to the initial 2012 offering of a new Masters program (Richards, in press). Short notice was received to conceive and develop this. However it was clearly a course which lent itself to a PBL approach with its focus on the challenge of sustainable policy studies linked to the similarly important concept of ‘science, technology and innovation’ (e.g. Christensen, 1997, Meissner, Gokhberg, & Sokolov, 2013).

We will discuss below three aspects of how we applied a PBL framework relevant for this particular course in relation to a similarly ‘systems approach’ to encouraging an authentic problem-solving orientation for authentic purposes linked relevant or possible cases, challenges, and issues which students could choose to focus on. The first section will outline how students were required to undertake a course project in pairs where they needed to identify, address and design a possible working solution to some distinct and authentic problem



related to issues of sustainability also linked to aspects of science, technology and innovation. The second section will discuss how this encouraged and framed in relation to a digital portfolio assessment also involving related reflections and activities done individually to reflect, support and link to the culminating project and the related achievement of projected course outcomes. This involved an innovative yet effective assessment framework applied as a mark-sheet which, for space reasons, could not be included here. A third section indicates one of many conceptual tools used in this class which epitomises an outcome-based approach to ‘integrated, optimal and sustainable’ complex problem-solving.

### *3.1. Designing a problem-based learning project task in sustainable STI studies*

The integrated program of teaching, curriculum and assessment in this course was built around the student development of a project involving a relevant focus problem. The classes of MFT1053 were conducted as a set of regular presentations linked to related tutorials. In addition to weekly presentations on course topics, each week students were required to individually present seminars on a topical new case of a policy problem from the local newspapers where they asked to identify interesting and exemplary STI-related policy problems of sustainability and also came up with initial suggestions of possible solutions. These presentations then were linked to tutor-lead discussion, and online as well as face-to-face class activities. For their presentations as for their main project, students were expected to produce a ‘knowledge-building pyramid’ which consisted of the translation of their chosen policy problem into an inquiry rationale as the basis for also identifying and engaging with a central question in terms of three supporting questions which might structure the inquiry towards emergent solution options. This regular linking of practical, interesting and authentic cases to aspects of theory, evaluation and the construction of design solutions became the foundation for students to later take on a more developed project which functioned as a culminating task synthesizing the stages and aspects of sustainable policy development as complex problem-solving in this particular subject.

Figure 6 below outlines how students were provided with options and supporting templates to support the development of their project inquiry in terms of three stages and corresponding parts of their required project write-up: (a) identify a brief rationale, background and supporting inquiry structure to address the selected policy issue or challenge; (b ) critically break down central problem of selected policy issue into main contributing aspects, elements and factors, and (c) design and outline a proposed sustainable solution which would simultaneously address contributing challenge and central problem. The PBL project was expected to build upon the course foundations of ‘sustainable STI’ knowledge, case studies, and applied problem-solving. In this way it should represent a culminating activity of the overall course encouraging students to synthesise and apply what they have learnt so far in terms of projected key course outcomes.

<b>MFT1053 Sustainable STI Policy Development</b>	
<b>Project - STI Case Study in sustainable policy-building</b>	40%
<p>Class topics and activities will aid with the skills, knowledge and procedures which might assist in undertaking a detailed case study of a chosen topic. Students will be asked to structure their project around provided templates which will assist to develop two stages of STI policy-building: (a) identifying a particular STI Policy challenge, issue or problem, and (b) outlining a provisional strategy of sustainable planning or decision-making to address this. The project may be developed as a collaboration in pairs harnessing the power of cooperation and team-work as well as individual insight and applications. The chosen example should have at least some indirect connection to an aspect or focus of 'science, technology and innovation' and also the need for some kind of policy-building collaboration between organisations or interests from government, private/commercial, community and/or university sectors. For instance...</p>	
<ol style="list-style-type: none"> <li>1. <b>Exemplary higher education – industry – government – society collaborations</b> involving both aspects of (a) science and technology and (b) sustainable policy-building implications.</li> <li>2. <b>Authentic social and/or environmental issues, problems and challenges</b> which might be most effectively addressing with an integrated approach to linking 'science and technology' to knowledge management or organizational strategies of planning and decision-making</li> <li>3. <b>Harnessing and applying existing science and technology</b> to address social and/or environmental challenges or problems (and/or associated economic challenges/business opportunities)</li> <li>4. <b>Exemplary instances of cutting edge/future 'science and technology'</b> (bio/nano-technology, renewable energies, digital technologies, etc.) with sustainable policy-building implications (green technology, sustainable development, innovation economy, and commercialization of research)</li> </ol>	
<p><i>General Criteria: project development, teamwork (if done in pairs), case study analysis and application, innovation of policy solutions, demonstration of 'sustainable' policy-building</i></p>	

Figure 6. Summary overview version of MFT1053 project task

As indicated, sustainable policy studies linked to the emerging field of science, technology and innovation includes options which range from more specialised perspectives to interdisciplinary modes of complex problem-solving. Students were provided with models and templates to assist with this in terms of a how a sustainable problem-solving framework typically involves four distinct aspects and requirements or elements of integrated problem-solving and policy-building reflecting corresponding modes of human knowledge: 1. (communication, consensus and inter-dependence of) *stakeholder perspectives*; 2. *knowledge management* (of organizational vs. niche/individual/local human resources and performance) 3. *science and technology innovations* (applied knowledge building as extension); and 4. *complex environmental adaptation* (to changing natural vs. socio-economic contexts in time). These aspects provide the focus for outcomes-based problem-solving geared towards the 'optimization' of natural and human resources, an innovative as well as green approach to new science and technology solutions, and the process of achieving a foundation for sustainable 'change and improvement' in terms of a sufficient consensus of common purposes. As outlined such an approach requires a systemic alignment of the distinct if ultimately convergent axes of human knowledge-building. Students did not directly apply this framework in their projects but could use it to develop their selected problem focus in relation to the provided options.

### 3.2 Activity-reflection e-portfolios as an overall 'culminating task'

As the culminating course task of problem-based learning, the MFT1053 project undertaken was also part of an overall e-portfolio assessment framework supported by a range of supporting individual reflections and activities. These had a formative as well as summative purpose in allowing progressive feedback to students about their achievement of course outcomes. The concept of an activity-reflection e-portfolio (Richards, 2005, 2013) builds on Kolb's notion that the most effective learning is that which constitutes an interplay of thinking and doing involving meaningful tasks to also harness the power of digital media to support such learning. As suggested earlier, the possibilities of achieving 'active learning' modes as an extended process across a particular syllabus or academic context are most fully realized in various kinds of project-based learning which involve the notion of a 'culminating task'. In various forms of problem-based and inquiry-based learning conducted as an authentic task or even as imaginary role-play and scenario, the notion of a culminating task of assessment synthesizes as well as supports an 'ecology' of targeted or projected outcomes linked to a central outcome or culminating task. Whilst the presentation of some kind of portfolio of reflections as well as applied



learning tasks can be sufficient in itself to encourage this, the most effective curriculum framework for such optimized learning is to construct some particular project outcome.

Figure 7 below illustrates a sample activity-reflection e-portfolio from the MFT1053 course. In this particular course the e-portfolio involved a simple Word document saved as a html file with a hyperlinked file. Nonetheless it still provide a comprehensive and accessible learning profile in terms of formative as well as summative purposes tracking and archiving the related reflections and activities supporting the main project. Students are typically encouraged to develop such a profile into a professional e-portfolio beyond the purposes of the course. For assessment purposes, the e-portfolio further comprehensively maps and archives evidence of the outcomes achieved in the course. It supports the associated assessment marksheet used which as well as likewise providing a portfolio of critical feedback in relation to key items also lends itself to a formula for reconciling rubrics and criterion-based assessment and likewise converting qualitative indicators into an overall quantitative ranking.

MFT1053 Sustainable STI Policy Development Learning Portfolio - Name	
	<b>Personal/Professional profile</b> E..... is a student in UTM university in Malaysia. She is undertaking a <u>Masters</u> degree in Science, Technology, and Innovation Policy. Her prior academic study was a Bachelor degree in Chemistry. She has had about eight years of experience in international business management.
<b>Professional philosophy for sustainable policy-building and integrated problem-solving [developing sustainable solutions for STI-related policy problems or challenges]</b> The concept of sustainable development is directed to provide a long-term vision for the society. For a community to function and be sustainable, the basic needs of its residents must be met. A socially sustainable community must have the ability to maintain and build on its own resources. It should also have the resiliency to prevent and/or address problems in the future. There are two types or levels of resources in the community that are available to build social sustainability (and, indeed, economic and environmental sustainability)- individual or human capacity, and social or community capacity. By improving innovative and sustainable problem solving, we can help organizations to better identify and focus on those problems they need to solve.	
<b>MFT1053 Collaborative project [with S.....]</b> <b>Abstract:</b> Social observers believe that obesity is an increasingly significant problem which needs to be <u>be</u> better dealt with in terms of public awareness. It is also a growing problem in Malaysia as well as many other countries. A particular aspect of this problem which our project focuses on is the challenge of getting government to require that the labeling of packaged foods include more accurate information about ingredients and nutritional value. In other words the policy challenge we want to investigate is how more accurate labeling might assist with the promotion of public awareness about the importance of health and nutrition in general, and the challenge of obesity in particular.	
<b>MFT1053 Project Artifacts</b> 1. <a href="#">Bookmark file including relevant folders and links of STI resources and case studies</a> 2. <a href="#">Project policy-building pyramid (and/or other planning items)</a>	
<b>MFT1053 Reflections</b> <a href="#">Week 2: Introduction to the sustainability dilemma: Discuss the related social and technological issues represented by the Lynas Rare Earth Issue – and possible options for future directions with this.</a> <a href="#">Week 5: Requirements of a more sustainable public-private sector collaboration [re: smartphone or water industry examples discussed in class]</a>	

Figure 7. Sample activity-reflection e-portfolio profile from the UTM MFT1053 class

Students were expected to submit regular reflections in response to provided focus questions through out the semester. They did this by email in this course but could have uploaded to an e-learning content management program. In this format they receive feedback and have the option to respond to this in the final version of the e-portfolio. In this course the series of reflections supported both the development of their main project and supporting activities. For instance, the Week 5 reflection asked students to respond to the following:

Wk 5: 1. As various examples from the newspapers show, STI policy-building often takes places in relation to industry – government – society collaborations which may also involve universities (especially for R & D and education/training). A focus of this week's class is to look at the challenge of achieving sustainable collaborations. Briefly discuss how a more sustainable public-private sector collaboration might be needed or achieved in relation to either the smartphone or water industry examples discussed in class

#### 4.3 The enneagrammatic structure of 'integrated, optimal and sustainable' complex problem-solving

Students undertaking the MFT1053 course received weekly opportunities to consider possible solutions to authentic case studies in the challenges of achieving sustainable STI-related policy solutions. They were encouraged to adopt an outcome-based problem-solving approach which thus lent itself very appropriately to the outcomes-based learning and assessment approach adopted within the educational framing of the course. As outlined in the first section of this paper this involved approaches which not only would seek to break down complex problems in terms of their key contributing factors but also consider possible outcomes solutions and the issues of integration and implementation which would be needed to support these. One such model applied which also integrated some of the key aspects of sustainable knowledge-building promoted in the course is outlined in Figure 8 below. The enneagram model of ‘integrated, optimal. and sustainable’ complex problem-solving promotes the notions of transformative as well as sequential or cumulative stages of inquiry. But it also provides an exemplary framework for designing an outcomes approach to problem-solving in terms of a systems perspective and model.

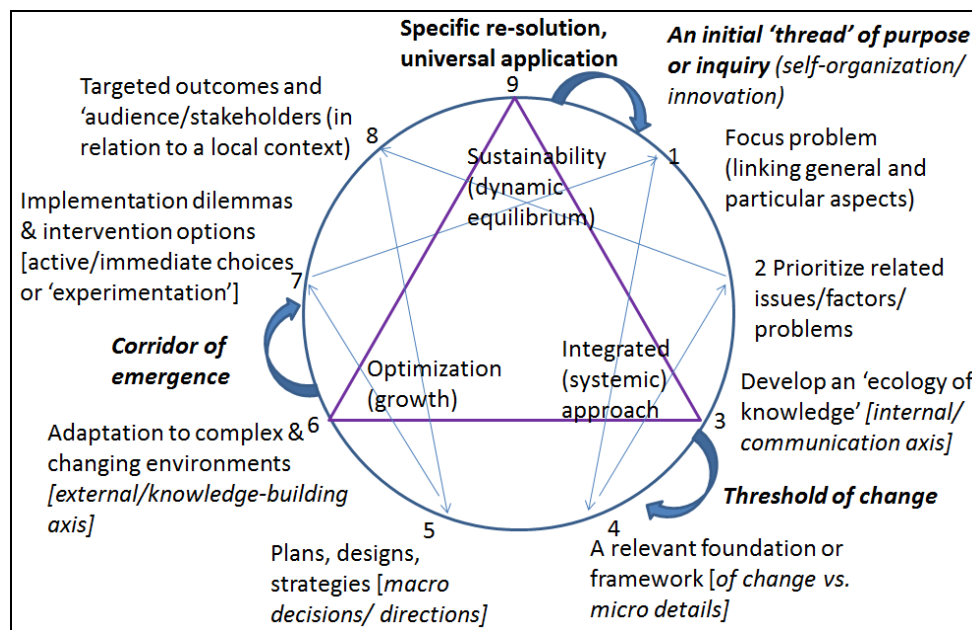


Figure 9. The enneagrammatic formula of integrated, optimal, and sustainable problem-solving. Adapted from Richards, 2013

The enneagram model used below represents a particular knowledge-building tool or method deriving from the Pythagorean tetractys which is also used for purposes of organisational learning, strategic leadership and decision-making (e.g. Knowles, 2003). As we have also discussed further elsewhere (Richards, 2013), it also exemplifies the structure of natural or human systems of knowledge. The intrinsic properties of the enneagram represent an interesting linking of geometric progression and a ‘transformational’ view of numbers in terms of the Pythagorean conception of the base 10 system. The triangular relation of the 3-6-9 numbers representing integration, optimisation and sustainability frame the 1-4-2-5-7-8 sequence which also is the intrinsic decimal pattern of any seventh fraction. Our representation here links to a number of related terms sustainable policy and knowledge building – notions of a ‘threshold of change’, a ‘corridor of emergence’, and the challenge of achieving ‘dynamic equilibrium’.

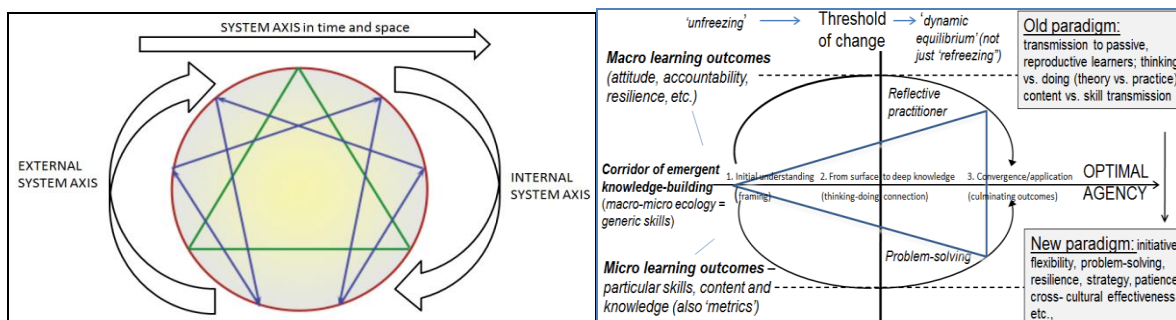


Figure 8. The enneagram and the convergent axes of 'unity' which inform human knowledge-building. Adapted from Richards, 2013

However our interpretation is that this is also usefully represents two linked systemic stages of outcomes-based knowledge transformation. As Figure 8 indicates, the enneagram functions as an exemplary model of how self-organising systems (especially those involving complex adaptation to changing contexts) typically involve internal or external axes of alignment which in human groups should involve both organisational functions of accountability or self-organisation and negative-vs. positive feedback loops. The related right-hand diagram indicates how it usefully exemplifies the corresponding processes of learning and inquiry. A new paradigm of integrated, optimal and sustainable problem-solving in learning thus involves the emergent knowledge reflected in the interplay of both macro and micro learning processes and outcomes. It thus also exemplifies the potential of the most effective problem-based learning designs and structures (Cf. also Pledge, 1983).

## Conclusion

This paper has focused on how the natural human imperative for problem-solving in terms of adaptation to social as well as natural environments provides the key to the most effective learning, inquiry and also knowledge-building research (Powell & Ryzhov, 2012). It has discussed how the increasingly influential concept of problem-based learning has evolved in recent decades from its particular use in medical education for studying authentic cases to an interdisciplinary central pillar of the active or constructivist learning paradigm in schools and universities. The influence that a convergent PBL model has had on encouraging enhanced collaborative inquiry and problem-solving in professional as well as academic and even technical or competency-based education is also one that can and should be replicated in terms of more interdisciplinary, collaborative and outcomes-based (and not just evidence-based) inquiry within and beyond university contexts of partnership. After all the University students should ideally also learn in terms of active modes of thinking and knowledge-building applicable to both authentic real-life contexts and the additional university purpose of encouraging and supporting effective research in various senses of the term.

A general model of PBL in schools has typically encouraged cross-disciplinary collaboration and knowledge sharing (i.e. it is common for members of school problem-based learning projects to take on different roles, purposes and modes of knowledge-building). This has not typically been the case in higher or continuing professional education contexts where the emphasis is often on specific cases in terms of specialised knowledge. The paper has developed an argument that a convergent model of PBL exemplifies as well as encourages the kind of approach needed to address the increasingly complex and diverse 'wicked' problems facing the world in every aspect of both the social and natural domains of human life and activity. Thus the final section of the paper has outlined the cross-disciplinary inquiry implications of how a generic model of complex problem-solving which systematically proceeds in terms of a basic three-stage method of: (a) breaking down overriding or central problems into their main contributing domains and factors; (b) also focusing on these domains and factors separately as well as together in terms of seeking feasible solutions, and (c) building towards an overall strategy and proposed solution in terms of an integrated and systemic approach which reflects 'the whole as well as the sum of its parts'. The further discussion of an 'enneagrammatic formula of integrated, optimal, and sustainable problem-solving' has served to exemplify the possibilities of an integrated systems approach to problem-based learning as well as the generic problem-solving process in every aspect of both social and natural domains of human knowledge.

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