International Journal of Innovation, Creativity and Change. www.ijicc.net
Volume 2, Issue 3, May 2016

The Potential Benefits of Divergent Thinking and Metacognitive Skills in STEAM Learning: A discussion paper

Marisha McAuliffe

Queensland University of Technology, Australia

In the wake of an almost decade long economic downturn and increasing competition from developing economies, a new agenda in the Australian Government for science, technology, engineering, and mathematics (STEM) education and research has emerged as a national priority. However, to art and design educators, the pervasiveness and apparent exclusivity of STEM can be viewed as another instance of art and design education being relegated to the margins of curriculum (Greene, 1995). In the spirit of interdisciplinarity, there have been some recent calls to expand STEM education to include the arts and design, transforming STEM into STEAM in education (Maeda, 2013). As with STEM, STEAM education emphasises the connections between previously disparate disciplines, meaning that education has been conceptualised in different ways, such as focusing on the creative design thinking process that is fundamental to engineering and art (Bequette & Bequette, 2012). In this article, we discuss divergent creative design thinking process and metacognitive skills, how, and why they may enhance learning in STEM and STEAM.

Keywords: **Thinking, divergent, convergent, design, STEM, STEAM, design process, education**

Introduction

Although the integration of the arts into STEM is not a new concept (there are countless historical examples such as da Vinci, Eiffel, and Brunelleschi), in the 20th Century in particular there has been a separation between STEM and the arts. This has possibly been in part due to the development of faculties and 'silos' in the higher education sector, with increasing evidence suggesting that this way of thinking has come at a cost to many disciplinary groups. Many faculty and practitioners in STEM have lost their ties to creativity, abstract reasoning and divergent thinking; similarly, many in the arts community had failed to keep up with rapidly evolving digital technology (such as 3D printing etc). Those who are able to appreciate, integrate and function across the STEAM (Sciences, Technology, Engineering, Arts, and Mathematics) disciplines are highly prized and whose value is increasingly recognised. Collaboration between the STEAM disciplines is increasingly promoted in research, development and literature as a new paradigm for primary, secondary, undergraduate and postgraduate education (Burns & Drake, 2004; Chute, 2009; Eisner, 2004; Ellis, 2011; Jakus 2015; Linton, 2009; Piro, n.d; Puffenburger, 2013; Root-Berstein, 2011; Shapiro, 2011; Storksdieck, 2011; White, n.d). For clarification purposes, STEAM disciplines include (but are not limited to):

- **Science:** Physics, Biology, Chemistry, Geosciences & Biochemistry (mixed), Biotechnology and Biomedical
- **Technology:** Construction, Production, Agriculture, Communication, Transportation, Power and Energy, Industrial Arts and Information Technology
- **Engineering:** Electrical, Computer, Chemical, Design, Aerospace, Mechanical, Industrial, Informechatronics, Medical, Materials, Ocean, Environmental, Fluid and Civil
- **Arts:** Physical, Fine, Motor, Language and Liberal (including; Design, Architecture, Sociology, Education, Politics, Philosophy, Theology, Psychology and History)
- **Mathematics:** Algebra, Geometry, Trigonometry, Calculus and Theory

One such example of this synergy between STEAM disciplines may include engineering or science education where the anticipated benefits include increased creativity, experience working in multidisciplinary collaborative teams, and appeal to a broader population of students who otherwise may not have explored engineering or science as a career path. In so considering the integration of such areas, the anticipation is that these synergies will enhance the thinking within such disciplines, but also benefit the various aspects of recruitment, retention and quality in STEAM education process.

The recent momentum for STEM education has seen a positive introduction to (with an emphasis on engineering) design thinking and design process to STEM disciplines, with some educators encouraging the artistic or creative process as becoming a critical aspects of STEM education (Land, 2013). In fact, Land (2013) suggests that traditional STEM degrees focus on *convergent* skills rather than *divergent* skills, which is typically the focus in art degrees, and "Having the ability to execute both at scale can better position our nation for global competitiveness" (Land, 2013, p. 547). Further to this, it can "re-invigorate the platform, providing not only an interesting approach, but also opportunities for the self-expression and personal connection new generations crave" (Land, 2013, p.548). Land argues that the "push for the STEAM platform derives from the lack of creativity and innovation in recent college graduates in the United States [where] our education system teaches students how to execute given tasks fluidly, but rarely fosters curiosity and self-motivation" (Land, 2013, p.548). Taking this into account, in this line of thinking, one might suggest that progression of innovation cannot come from the STEM disciplines alone, but the introduction of design thinking may aid in such.

Using the imagination (through creative or divergent thinking) during the design process is a critical part of how designers – including engineering designers – design, using it in the analysis-synthesis phase to generate ideas and find creative solutions to a given problem. Exercising the imagination aids those in design to become more skilled in creative design analysis-synthesis practices which explore various temporal, existential and physical qualities in future spaces and objects, as well as be able to articulate the seemingly 'mysterious' aspects of the design process (McAuliffe, 2013; McAuliffe, 2016). As STEAM is discussed in an educational context in this paper, the focus is on higher education in the Australian context.

In this paper, the author discusses divergent thinking (which includes design thinking and metacognitive skills), why it may benefit STEAM education, and why the introduction of such skills included as an explicit and fundamental component of STEAM education process may be of use to future graduates – but only if integrated in a considered and truly interdisciplinary manner.

Background

This paper focuses on thinking, a critical aspect particularly relevant to the analysis-synthesis component of the design process. It typically consists of the 'magical' stage in the design process which utilises the internal mental processes that result in creativity. There are many mental processes involved with creativity and research reflects this. Ward and Kolomyts (2010) combined these processes under the term 'creative cognition', which "is concerned with explicating how common cognitive processes, available to virtually all humans, operate in stored knowledge to yield ideas that are novel and appropriate for the task at hand" (Ward and Kolomyts, 2010, p.93). Among these processes suggested in creative cognition are divergent thinking, convergent thinking, and knowledge.

According to Duck, 1981), convergent and divergent thinking are two poles apart on a spectrum of cognitive approaches to problems and questions. Divergent thinking seeks multiple perspectives and multiple possible answers to questions and problems. On the other hand, convergent thinking assumes that a question has one right answer and that a problem has a single solution (Kneller, 1971). Typically, divergent thinking resists 'accepted' ways of doing things and seeks a variety of alternatives. Convergent thinking, the bias of which is to assume that there is a *correct* way to do things, is "inherently conservative; it begins by assuming that the way things have been done is the right way. Divergent thinkers are better at finding additional ideas, whereas convergent thinkers have a more difficult time finding additional ideas. Convergent thinkers run out of ideas before divergent thinkers" (Kim & Pierce, 2013).

Divergent thinking alone does not result in true creativity; convergent thinking is needed to sift through and evaluate the confusion created by divergent thinking. Convergent thinking is important in the synthesis and evaluation phases of the design processes of Jones (1963) and Sasaki (1950), but fits into the creative phase of Archer (1984).

Knowledge, the third process involved in creative cognition, is also an important component of creativity. Too much and too little pre-existing knowledge may be detrimental to effective novelty. If the individual lacks sufficient knowledge in a given realm, they will not be able to able to be creative, as is typically the situation in novice designers. Conversely, if a person is too familiar with the precedents of any given realm, they could become entrenched and rely upon old solutions rather than generating new ones (Mumford & Gustafson, 1988; Martinson, 1995). This can occur often in convergent thinking, particularly if divergent thinking is not utilised (Land, 2013).

STEAM and thinking about thinking

Whilst there is a significant amount of discussion – and indeen rhetoric – about the huge potential that STEAM offers, crossing the boundaries between arts and science was always anticipated to be a fluid integration between the disciplines with expectations that a synergy would result. However, whilst the *theory* of a close relationship between the two areas is innovative and forward-thinking, the *reality* is that the implementation of two traditionally opposing disciplines means it becomes the task of the educator to develop and/or implement the curriculum. STEAM is indeed cross-curricular collaboration, but those involved in designing STEAM units, subjects and activities must be truly multidisciplinary in their thinking, approach and knowledge, and those from each specialisation must be willing to co-coordinatoe, co-plan and co-teach. Ideally, each content area has an equal amount of learning and teaching material.

For example, if an engineering teacher and design teacher implement a STEAM unit or subject, both new engineering and design skills should be introduced as equally important concepts, but fundamentally, how each discipline's way of thinking requires open dialogue and exploration, as both are remarkably different in their approach – particularly in the analysis stage of the design process. This requires those in learning and teaching roles to demonstrate and teach the ability to simultaneously decompose a complex problem using convergent thinking and then apply the corresponding solution to the real world using divergent thinking. It is here that visualising, design thinking, and metacognitive skills can be of use: "The core element of design thinking is the need to empathise with others, their situations and experiences, and is vital to designers, who need to be sensitive to 'the user' (those who use the products or interact and use spaces and places)" (McAuliffe, Martin, Cameron & Hankinson, 2015, p.5).

Until relatively recently, there was little informed understanding and exploration around divergent thinking that occurs during the design process, and how this is translated into physical form (McAuliffe, 2013; 2015; 2016). Thinking in design, but in particular, design thinking (which includes visualising and empathy) is a process of creative and critical thinking that allows an openness and acceptance in gaining information and the processing of ideas. The concept was born out of the design process; it is a means of creating new and innovative ideas and solving problems. What is critical to design thinking is the manner in which the designer solves the problem; divergent thinking.

Recent research by McAuliffe (2013; 2015; 2016) explores divergent thinking in design, in particular, how designers think and imagine during the design process; what they 'see' when they draw and design (McAuliffe, 2013). However, she argues that "even with this knowledge, more importantly, how can these skills be taught to designers?" (McAuliffe, 2015, p. 4).

There can be no doubt that the cultural, pedagogical, and economic aims of STEM are highly valuable, but as the world grows more complex, so also are the issues surrounding these disciplines. As such, there has been numerous literature concerning the benefit from integrating creative ways of thinking into disciplines that traditionally design using certain structured methods, formulae and thinking. However, conventionally, when people speak or think of creativity, they mistakenly think of it as having only to do with the visual arts or design. In the past, thinking divergently has not been a strong focus of STEM education; in fact, these are sometimes considered tacit skills in some educational institutions and are therefore not taught as explicit skills. Coupled with this is the issue that divergent thinking (creative thinking) has for many years been an immeasurable phenomenon, thus researchers often fail at defining creativity and thus be unsuccessful in measuring it – at least quantitatively (Basadur and Hausdorf, 1996; Vincent, Decker and Mumford, 2002; Malhotra and Poovaiah, 2015; Cropley, 2016).

As stated above, the 20th Century homogenisation and compartmentalisation of various disciplines has not been of benefit to each area, with team diversity not greatly utilised in some instances, and departments working in isolation and autonomy. However, with the STEAM agenda, it is now understood that an effective team must rely on individuals with widely varying skill sets and ways of thinking. The integration of ideas, thinking and perspectives from diverse backgrounds is essential to an optimal design of complex systems (Coates, 2000), and a truly creative and effective solution requires contributions from disciplines outside of one's own field.

There is a plethora of research surrounding STEM education and the increased benefits when those in STEM education communicate both within their disciplines *as well as* to a broader audience of educators working in the arts disciplines. In such literature, there is an increasing call for creativity and divergent thinking to contribute to the STEM disciplines.

Design and divergent thinking

"Design education is the study of aesthetics and utility of items in our daily lives (Van de Zande, 2010, p. 249), where both design process and creative process engender a certain kind of thinking and intended outcomes – divergent thinking. In using *only* a convergent approach, several organisations have argued that teaching a STEM design process that ignores divergent thinking inherent in almost every form of functional design may shortchange futures graduates and compromise the theoretical arguments that underpin current national academic standards espousing the interdisciplinary nature of STEM learning (NRC, 2011; AAAS, 1993; ITEA, 2000).

A theorist who was an early (and perhaps unintentional) protagonist of STEAM and design thinking was Jones (1992), who suggested that the design process is integrated into intuition and logic, and gradually moves towards the rational. According to Jones (1992), design consists of analysis, synthesis and evaluation, where each phase utilises three different forms of thinking (Figure 1):

- Analysis: Divergent thinking
- Synthesis: Transformation thinking
- Evaluation: Convergent thinking

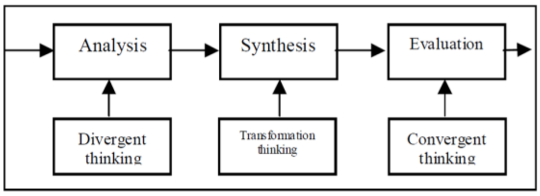

Figure 1: Design stages and thinking

Each specific design phase situates the appropriate type of thinking accordingly, with no form of thinking being considered more important than the other. Each stage of design is iterative and overlaps, depending on the context or design 'problem'.

Zeisel (1981, 1984) defined design process as having three elementary design activities: imaging, presenting and testing, and these are undertaken iteratively. They are essentially the same three stages that Jones (1992) suggest and are most commonly expressed externally through drawings of varying abstraction in order to be 'tested' by the designer or used to invite feedback by others. Imaging is an internal process and is described as "forming a general, sometimes fuzzy, mental picture of part of the world" (Zeisel, 1984, p. 6); this is most commonly considered divergent thinking.

Research carried out by Sommer (1978) revealed the flexibility and non-material character of images and their ability to allow unusual transformations in the design process. Singh (1999) also observed the role of divergent thinking in the architectural design process, identifying that mental imaging plays an important role in the design process and that first, the "flexibility and speed available in mental imaging is far more superior than sketching or modelling…enabling a student to experiment and choose between options at higher rate than sketching or modelling" (Singh, 1999, p. 4).

Outside design disciplines, divergent thinking is used childhood studies, research on Asperger's, and for business strategy. Hart and Sharma (2004) argue that "Unfortunately, most companies still tend to focus management attention only on known, salient, or powerful actors to protect their advantages in existing businesses", and that "imagining future sources of competitive advantage requires divergent thinking by managers to identify the unmet needs of both existing customers and new, yet-to-be-served markets. Divergent thinking is also necessary to envision new, disruptive technologies and business models that enable the firm to deliver functionality to existing and new consumers faster, better, or cheaper than competitors can" (Hart & Sharma, 2004, p.11) .

Metacognitive skills

"Despite the fact that metacognitive skills are critical in formulating our understanding of who we are and what we do in everyday life, these skills are considered to develop as a gradual and uncertain process that is dependent upon the quality of education and training individuals receive and cannot be assumed to be a cultural given in commonplace and everyday activity" McAuliffe, Martin, Cameron and Hankinson, 2015, p.2)

In higher education, besides domain-specific knowledge, students need to develop crucial skills such as reflective and critical thinking, as it is considered important for an educated individual to "be able to make well-informed judgements, be able to explain their reasoning and be able to solve unknown problems" (Thomas, 2011, p.26). Being able to think critically, analyse and reflect should be developed from first year of university studies in order for students to cope with their future studies and to be of most use to future employers.

Graduates who are able to make well-informed judgements as well as be capable of making sense of the connections between what they learn at university, and what they will practice in their chosen field should be a fundamental aspect of undergraduate education. In a rapidly changing world future graduates will need to deal with the unknown and solve problems that may not even exist currently. In Australia, it is a requirement for all universities to state what graduate attributes they develop in their students, and is it usual that those attributes will include critical thinking or higher order thinking, which includes divergent thinking. There have been numerous descriptions of "critical thinking" in literature, and the definition, since the seminal work of Glaser (1941), has related to its being an individual cognitive skill with three distinct characteristics:

1. An attitude of being or state of mind to thoughtfully consider the problems and subjects that come within a range of one's experiences;
2. Knowledge of the methods of logical enquiry and reasoning; and,
3. Some skill in applying those methods.

In discussing thinking and metacognition, it is important to consider reflective thinking. Paul (1993) describes critical thinking as cognition or the intellectual work of the mind that involves reasoning and self-discipline using particular skills, whilst reflective thinking is considered to be metacognition or a level of consciousness that exists through executive cognitive control and self-communication about experiences (Flavell, 1979). Both these types of thinking are regularly used conceptually in a variety of ways to understand and explain the dynamics of problem-solving and reasoning in a variety of practices. Many higher education institutions as well as professional bodies (such as nursing) require such characteristics in graduate outcomes.

In order to be successful in the highly technological and globally competitive world today, an individual is required to develop and use a different set of skills than were needed in the past (Shute & Becker, 2010). Along with critical and analytical thinking, design thinking is another skill that has increasingly gained attention over the past decade. It is a problem solving method which supports the consideration of socially ambiguous aspects of a design problem and is in contrast to orthodox engineering design paradigms. The core element of design thinking is the need to empathise with others, their situations and experiences, and is vital to designers, who need to be sensitive to 'the user' (those who use the products or interact and use spaces and places), be able to understand them, their situation, and experiences. Koskinen and Battarbee. (2003) explore the role of empathy in design and argue that empathy is a necessary quality for developing products that meet customer needs. Mattelmäki and Battarbee (2002) and Fulton (2003b) stress the need for qualitative research to inform and inspire designers to create 'more useful and enjoyable things for people [they] may never meet'. Empathy supports the design process as design considerations move 'from rational and practical issues to personal experiences and private contexts' (Mattelmäki and Battarbee, 2002).

Understanding the user and their experience is central to user centred design (Sanders and Dandavate 1999; Koskinen and Battarbee 2003; Sleeswijk Visser *et al.* 2005). By 'empathic design' (Koskinen and Battarbee, 2003), designers attempt to get closer to the lives and experiences of (putative, potential or future) users, in order to increase the likelihood that the product or service designed meets the user's needs. In short, designers need to 'step into the user's shoes' and 'walk the user's walk' in order to design products that fit the user's life. In doing so, the designer engages in a series of steps designed to experiment, create and prototype models, gather feedback, and redesign in an iterative manner.

In the context of design, Lawson (2006) describes metacognition as the processes which guide our internal processes, or "productive thinking" (Lawson, 2006, p. 140). If, as discussed above, creativity is a set of internal cognitive processes, it stands to reason that if we can become more aware of these processes, we can implement them more often in our thinking, which in theory should be able to boost our own creativity (Hargroves, 2012). Having metacognitive skills aid in consciousness of an individual's own mental processes. Thinking about how we think enables the processes of creativity, allows creativity to be more efficient (Hargroves, 2012); in many instances, design process can be considered metacognitive in nature.

Metacognitive knowledge also includes knowledge about one's own learning process; learning strategies, and knowing when and how to use those strategies. It is centred on the learners' ability to monitor their own learning, set goals, plan, as well as evaluate the outcomes of these strategies. Metacognitive activities provide insights on one's learning process, which in turn, helps facilitate the ability for the learner to regulate cognition. This ability to self-regulate enables a more positive learning experience and thus links to the issue of motivation (Lai, 2011).

In learning about design - whether it be architecture, engineering or technical - grasping the design process is challenging, as it relies on more than a single skill. Learners require and benefit from learning a variety of skills, not least of which are metacognitive skills to optimise learning (Azevedo & Cromley, 2004; Winne and Hadwin, 1998). It is important to embed these metacognitive skills as part of the learning process within learning how to design instead of asking students to learn these in isolation, for example in a subject specifically dealing with learning about thinking. Assuming that students will tacitly learn these skills, or adding them into other units is known as the "bolt-on" approach (Bennett, Dunne, & Carre, 2000). The "built-in" approach (as we suggest in this paper) proposed by Wingate (2006) is where learning is developed through the subject taught. One of the many limitations of the "bolt-on" approach is that often students do not make the connection between these skills and how to apply them to their subject (Drummond, Nixon, & Wiltshire, 1998; Durkin & Main, 2002).

Moreover, according to Kolb (1984) effective learning takes place when learners experience a problem, reflect on their action, form concepts on the basis of their reflection and apply these concepts in new situations. Therefore the "bolt-on" or assumption of tacit learning approach permits little opportunity for students to experiment and experience learning in a relevant or ongoing, iterative process. As design process itself is iterative, so also should be the integration of metacognitive skills.

Discussion and conclusion

Introducing those in the STEM disciplines to divergent thinking can help broaden an understanding about the artistic/creative process, divergent thinking, and the value of design thinking and empathy, whilst aiding in developing metacognitive skills. Exploring and integrating thinking styles between the STEAM disciplines help to blur the boundaries between art, design, and STEM disciplines, developing "thinking dispositions that are valued both within and beyond the arts" (Hetland, Winner, Veenema, & Sheridan, 2007).

Continuing the 'silo' disciplinary approach that focuses on convergent thinking that is typically used in STEM through problem solving, arguing from evidence, and reconciling conflicting views (Angier, 2010) does not develop the disciplinary knowledge our future graduates will require. Thoughtfully developed STEAM curricula can truly engage sustained cross-disciplinary discussion and learning in education settings.

When designing curricula and teaching it, educators should not mask deeper differences between the disciplines when implementing STEAM activities to improve student learning. Where subject areas are integrated, there is a serious risk that one area will be paid lip service, counted as being covered, but in fact not honoured. There is a significant need to discuss and examine - in depth - the value and appropriateness of each type of thinking in its individual context.

Understanding diverse thinking styles and the value of metacognitive skills will help diversify and truly integrate subject and knowledge areas in STEAM disciplines. The cross-disciplinary fertilisation of such thinking and skills might further enhance the synergy with STEM but will also assist in preparing our graduates for the real multidisciplinary world in which we work, play and interact. In deploying pedagogy and curricula that encourages students to be curious, experiment, and take risks – key dispositions of divergent thinking habits of mind engender.

Whether it is labelled as STEAM or something else in the future, we argue that the arts and design education community must include advocating for elevating the prominence of divergent and metacognitive skills – essential elements of arts and design - in STEM learning. By highlighting these essential elements and how these inform STEM, educators can stress why STEAM warrants ongoing local and national support which is as important as the current STEM agenda. The creative process is not one that STEM teachers have typically been prepared to address or discuss in depth, so art and design educators need to advocate for their expertise in any discussion of STEM curriculum. Further research that questions the merits of STEAM and whether this approach improves education or serves the public good is also required. Research should "explore when disciplinary differences and similarities are highlighted and when they are ignored, and how students engage these ideas. Can we conceptualize key components of design thinking in both art and engineering disciplines and isolate overlapping cognitive and procedural dispositions?" (Bequette and Bequette, 2012) How does the integration of metacognitive skills and divergent thinking benefit STEM and the arts, and how can student engagement, learning, and interest be fostered by more integrated art and engineering curricula and teaching? And lastly, can STEM be engaged to strengthen the arts?

In a time where 'silo thinking' is considered out of touch with the reality of 21st century cultures and practices, it is important that STEM discipines taught in lecture halls and classrooms are far more than compositional (i.e. the formalist arrangement of certain formulae, principles and elements). When STEM educators approach *divergent thinking* as a core element of the curriculum, *convergent thinking* can be complimented in the design process of engineering, science, products, environments, graphic design, information architecture, and interactive elements that are involved in contemporary STEM situations. Both divergent and convergent thinking should be better integrated in STEM curricula, and communicating this inclusion opens up enormous possibilities for cross-curricular collaboration. Student involvement and engagement with the arts and design is then truly embedded and integrated within STEM disciplines.

References

American Association for the Advancement of Science (1993). *Benchmarks for science literacy, project 2061*. New York: Oxford University Press.

Angier, N. (2010). STEM education has little to do with flowers. *The New York Times,* October 4, 2010. Retrieved April 26th, 2016 from www.nytimes.com/

Archer, L, B. (1984). Systematic design method for designers. In Cross, N. (Ed.)

Athavankar, U. A. (1997). Mental imagery as a design tool. *Cybernetics & Systems*, *28*(1), 25-42.

Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of educational psychology*, *96*(3), 523.

Basadur, M., & Hausdorf, P. A. (1996). Measuring divergent thinking attitudes related to creative problem solving and innovation management. *Creativity Research Journal*, *9*(1), 21-32.

Bennett, N., Dunne, E., & Carré, C. (2000). *Skills Development in Higher Education and Employment.* London: The Society for Research into Higher Education and Open University Press.

Bequette, J. W., & Bequette, M. B. (2012). A place for art and design education in the STEM conversation. *Art Education, 65*(2), 40-47.

Burns, R.C. & Drake, S.M. (2004). *Meeting standards through integrated curriculum.*

Calvino, I. (1974). Invisible Cities. 1972. *Trans. William Weaver. New York: Harcourt Brace Jovanovich.*

Coates, J. 2000. "Innovation in the Future of Engineering Design." *Technological Forecasting and Social Change.* Vol. 64. pp. 121-132.

Chute, E. (2009). STEM education is branching out: Focus shifts from making science, math accessible to more than just brightest. *Pittsburg Post-Gazette.* Retrieved April 25th, 2016, from http://www.post-gazette.com/ pg/09041/947944-298.stm

Cropley, D. H. (2016). *Creativity in engineering* (pp. 155-173). Springer Singapore.

Duck L. (1981). Teaching with charisma. Burke: Chatelaine Press

Durkin, K. and Main, A. 2002. Discipline-based study skills support for first-year undergraduate students. *Active Learning in Higher Education* 3(24), pp. 24-39.

Eisner, E. W. (2004). *The arts and the creation of mind.* N.P.: Yale University Press.

Ellis, A. 2011). *Silos belong on Farms. College and University Professional Association for Human Resources.* The Higher Education Workplace. Retrieved April 25th, 2016, from: http://www.cupahr.org/knowledgecenter/files/heworkplace_vol3no2_fresh_ideas.pdf

Flavell J. (1979) *Metacognition and cognitive monitoring: new area of cognitive-developmental inquiry.* American Psychologist 34, 906–911.

Fulton Suri, J., 2003b. Empathic design: informed and inspired by other people's experience. *In*: I.Koskinen, K. Battarbee, and T. Mattelmäki, eds. *Empathic design, user experience in product design.* Helsinki: IT Press, 51–57.

Glaser, Edward (1941). *An experiment in the development of Critical Thinking.* Teacher's College, Columbia University.

Greene, M. (1995). *Releasing the imagination: Essays on education, the arts, and social change.* San Francisco, CA: Jossey-Bass Publishers.

Hart, S. L., & Sharma, S. (2004). Engaging fringe stakeholders for competitive imagination. *The Academy of Management Executive*, *18*(1), 7-18.

Hetland, L., Winner, E., Veneema, S., & Sheridan, K. (2007). *Studio thinking: The real benefits of visual arts education.* New York: Teachers College Press.

International Technology Education Association and National Science Foundation (2000). *Standards for technological literacy: Content for the study of technology.* Reston, VA: ITEA.

Jakus, B. (2015). Why is a STEM + ARTS partnership important to innovation in…? In *Changemakers.* Retrieved April 25th, 2016, from http://www.changemakers.com/groups/stem/discussion-3

Jones, J. (1963;1992). A Method of Systematic Design. In Jones, J. C. and Thornley, D. G. (eds), *Conference on Design Methods,* Oxford: Pergamon.

Kim, K. & Pierce, R. (2013). Convergent Versus Divergent Thinking. In *Encyclopaedia of Creativity, Invention, Innovation and Entrepreneurship* (pp. 245-250). Springer New York.

Kneller GF. Introduction to the philosophy of education. 2 ed., rev. New York: Wiley; 1971.

Kolb, D.A. (1984) *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, N.J.: Prentice-Hall.

Koskinen, I. and Battarbee, K., 2003. Introduction to user experience and empathic design. *In*: I. Koskinen, K. Battarbee, and T. Mattelmäki, eds. *Empathic design, user experience in product design.* Helsinki: IT Press, 37–50.

Land, M. H. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. *Procedia Computer Science*, *20*, 547-552.

Lai, E. R. (2011). Metacognition: A Literature Review: Pearson Research Reports. http://www.pearsonassessments.com

Lawson, B. (2006). *How designers think: the design process demystified.* Routledge.

Linton, G. (2009). The silo effect in academia and its consequences. Higher Education Pedagogy & Policy. Retrieved April 25th, 2016 from http://glinton.wordpress.com/2009/01/14/the-silo-effect-in-academia-and-itsconsequences/ on April 26th, 2016

Maeda, J (2013). "STEM + Art = STEAM," *The STEAM Journal,* 1(1), pp.1-5. Available from http://scholarship.claremont.edu/steam/vol1/iss1/34

Malhotra, A., & Poovaiah, R. (2015). The Riddle of Design Problem. In *DS79: Proceedings of The Third International Conference on Design Creativity, Indian Institute of Science, Bangalore.*

Mann, D. 2001. "An Introduction to TRIZ: The Theory of Inventive Problem Solving." *Creativity and Innovation Management.* Vol. 10. pp. 123-125.

Mattelmäki, T. and Battarbee, K., 2002. Empathy probes. *In*: T. Binder, J. Gregory, and I. Wagner, eds. *Proceedings of the participatory design conference 2002*. Palo Alto CA: CPSR, 266–271.

McAuliffe, M. B. (2016). Inside the Designer: Understanding Imagining in Spatial Design. Oxford Global Press, London.

McAuliffe, M. B. (2015). On imagining in spatial design. *International Journal of Innovation, Creativity and Change*, *2*(2).

McAuliffe, M. B. (2013). Imagining in the spatial design process. PhD Thesis, Queensland University of Technology.

McAuliffe, M. B., Martin, P., Cameron, L., & Hankinson, J. (2015). Embedding metacognitive skills in spatial design. *International Journal of Innovation, Creativity and Change*, *2*(2).

National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Paul, R. (1993) Critical thinking: basic questions and answers. In *Critical Thinking How to Prepare Students for a Rapidly Changing World* (Willsen J. & Binker J.A., eds), Foundation for Critical Thinking, Santa Rosa, CA.

Piirto, J. (2011). *Creativity for 21st century skills* (pp. 1-12). Sense Publishers.

Piro, H. (n.d.) "Going from STEM to STEAM: The arts have a role in America's future, too" *Education Week.* Retrieved April 25th, 2016, from <http://www.edweek.org/ew/articles/2010/03/10/24piro.h29.htm>

Polaine, A. (2011). Design Research-A Failure of Imagination. In *Researching Design Education: 1st*

International Symposium for Design Education Researchers (pp. 41-51).

Puffenberger, A. (2013). The STEAM movement: It's about more than hot air. *National alliance for media art + culture*. Retrieved April 25th, 2016, from http://www.namac.org/node/24925

Roam, D. (2008). The Table Stakes of Visual Thinking. *Marketing Research*, *20*(1).

Root-Bernstein, T. (2011). *The art of scientific and technological innovations: The art of science learning*. Retrieved April 25th, 2016, from <scienceblogs.com/art_of_science_learning/2011/04/the_art_of_scientific_and_tech_1.ph>.

Sasaki, H. (1950). Design process. In Swafield, S. (Ed) *Theory in landscape architecture: A reader*. (pp. 35-37). Philadelphia: University of Pennsylvania Press.

Shute, V. J., & Becker, B. J. (2010). *Innovative assessment for the 21st century*. New York, NY: Springer-Verlag.

Sanders, E. and Dandavate, U. (1999). Design for experiencing: new tools. *In*: C.J. Overbeeke and P. Hekkert, eds. *Proceedings of the first international conference on design and emotion*, 3–5 November 1999, The Netherlands: Delft University of Technology, Delft, 87–92.

Shapiro, D. (2011). Reaching students through STEM and the Arts. In *Meartsed*. Retrieved April 25th, 2016, from http://meartsed.wordpress.com/2010/01/11/reaching-students-through-stem-and-the-arts/

Shulman, L.S. (1986). *Those who understand Knowledge Growth in Teaching*. Educational Researcher 15(2), 4-14

Singh, A. (1999). The potential of mental imaging in the architectural design process.

Sleeswijk Visser, F., *et al.*, 2005. Contextmapping: experiences from practice. *CoDesign*, 1 (2), 119–149.

Sommer, R. (1978). *The mind's eye: Imagery in everyday life*. Delacorte Press.

Storksdieck, M. (2011). STEM or STEAM. *The Art of Science Learning*. Retrieved April 25th, 2016, from http://scienceblogs.com/art_of_science_learning/2011/04/stem_or_steam.php

Tafel, E. (1979). *Years with Frank Lloyd Wright: apprentice to genius*. Courier Corporation.

Thomas, T. A. (2011). Developing first year students' critical thinking skills. *Asian Social Science*, *7*(4), p26.

Van de Zande, R. (2010). Teaching design education for cultural, pedagogical, and economic aims. *Studies in Art Education* 5(3), 248-261.

Vincent, A. S., Decker, B. P., & Mumford, M. D. (2002). Divergent thinking, intelligence, and expertise: A test of alternative models. *Creativity research journal*, *14*(2), 163-178.

Ward B. T. & Kolomyts Y. (2010). Cognition and creativity. In Kaufman, J. and Sternberg, R. (Eds.) The Cambridge Handbook of Creativity (pp. 93-112). New York: Cambridge University Press.

White, H. (n.d.). Our education system is not so much "broken" - as it is totally outdated! In *STEAM*. Retrieved April 25th, 2016, from http://steam-notstem.com/articles/our-education-system-is-not-so-much-broken-asit-is-totally-outdated/

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Drummond, I., Nixon, I. and Wiltshire, J. (1998) Personal transferable skills in higher education: the problems of implementing good practice. *Quality Assurance in Education,* **6**, 44–58.

Wingate, U 2006, 'Doing away with "study skills"', *Teaching in Higher Education*, 11:*4*, pp. 457-469.

Zampetakis, L, and Tsironis, L.2007. "Creativity development in engineering education: the case of mind mapping." *Journal of Management Development.* Vol. 26 No. 4. pp. 370-380.

Zeisel, J. (1981). Inquiry by design. *Cambridge: Press Syndicate.*

Zeisel, J. (1984). *Inquiry by design: tools for environment-behaviour research* (No. 5). CUP Archive.