Engineering Leadership Education: A Review of Best Practices

Robyn Paul, University of Calgary

Robyn is a Master of Science candidate in Civil Engineering at the Schulich School of Engineering, University of Calgary. Her research focuses on the impact that teaching engineers leadership has on early career success. She co-founded the Engineering Education Students' Society and is involved with initiatives to collaborate nationally to increase the conversation with students about engineering education.

Dr. Lynne Gradon Cowe Falls P.Eng., University of Calgary

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Abstract

In the past, intellectually talented engineers with strong technical skills were sufficient for the needs of society. In the 21st century engineers are now working in the corporate world, often disconnected from the hands-on aspect of engineering. Professional skills such as leadership have become critical for graduating engineers entering the workforce. A review was conducted of current engineering leadership programs' goals and competencies to determine consistencies and variations, and to suggest prominent themes. Five themes emerged for the fundamental goal of engineering leadership education programs: effective leadership, innovation and technology, independent learning, experiential learning and systems thinking. The analysis of the competencies found a diverse spread across the programs. Overall, six key competencies emerged: communication, innovation, creativity, execution, personal drive, and teamwork. This analysis provides insight on the focus of engineering leadership education and the progress of the field. The findings can be used for the development of new engineering leadership programs.

Introduction

As society drives forward and a new generation of engineers is just around the corner, we must ask if we are properly educating our engineers for the future. Professional skills such as leadership have become critical for graduating engineers entering the workforce[1]. Over the last decade there has been an increasing interest in the field of engineering leadership education. The literature provides a foundational review of the available programs, however it has quite a broad view and does not provide a comprehensive understanding. Thus the question is, based on engineering leadership programs' goals and competencies, what is the main focus of these programs?

Case studies of engineering leadership education programs were analyzed, including seminar courses, certificates, minors and bachelor programs. Specifically, the goal and competencies from each program were reviewed and analyzed in order to provide a more detailed understanding of the focus on engineering leadership education programs.

Engineering in the 21st Century

Many studies have shown that industry feels engineering graduates are well educated in the technical aspects of engineering, but they "lack qualities such as communication, self-management, problem solving, creativity as well as management & leadership competences"[2]. This lack of preparedness in skills such as leadership hinders innovation in engineering[3].

National engineering bodies have also recognized this need to educate engineers in leadership. In the report *The Engineer of 2020*[4], leadership was one of the key attributes mentioned that would be necessary to "support the success and relevance of the engineering profession in 2020 and beyond" (p.53). CDIO (Conceive-Design-Implement-Operate), an innovative educational framework for engineering, also addressed the need for engineering leadership in their most recent syllabus update. The syllabus extension includes ten different learning outcomes related to *Creating a Purposeful Vision* and *Delivering on the Vision*[5] (p.69).

In today's workplace, the knowledge and experience gained through engineering leadership education is valuable to all engineers, regardless if they plan to pursue managerial roles. The majority of engineering work is team oriented, thus engineers must be prepared to work on teams and take initiative when solving technical problems[6]. Leadership skills such as interpersonal skills, communications skills and an understanding of project management processes, are valuable regardless if an engineer is working as a team member or a team leader.

Definition of Engineering Leadership

When defining engineering leadership, consideration for the context is essential. For example, the definition of engineering leadership within an industrial defense firm may differ from the definition within a non-governmental organization[7]. All the same, the competencies of engineering leadership will typically be consistent and the difference will be seen in the emphasis or importance of these competencies based on the contextual application.

A definition of engineering leadership provided by the National Society of Professional Engineers (NSPE) covers a wide variety of concepts and will be used as reference. The definition states that engineering leadership is "the ability to assess risk and take initiative, the willingness to make decisions in the face of uncertainty, a sense of urgency and the will to deliver on time in the face of constraints or obstacles, resourcefulness and flexibility, trust and loyalty in a team setting, and the ability to relate to others" [8] (p.1).

Engineering Leadership Education

With the growing interest in engineering leadership education, over the last decade many different programs have arisen that focus on leadership development. There have been a few reports published which summarize the main program elements of current engineering leadership programs. In 2009, Graham, Crawley & Mendelsohn[9] published a white paper "to provide insight into current practice, highlight international variations in approach and identify examples of good practice"[9] (p.1). The team consulted with 70 different experts in engineering education and investigated over 40 programs[9]. This comprehensive review provided an excellent starting point for better understanding what was being done in the field of engineering leadership education.

Khattack, Ku & Goh[10] published a similar report in 2012 to "identify and investigate explicit and some of the non-explicit engineering leadership programmes offered by Australian and European universities"[10] (pg. 281). As well as providing an excellent review of the engineering leadership education programs in Australia and Europe, this report synthesized the data collected in order to propose an engineering leadership education program structure.

The current literature available outlines the importance of engineering leadership education and provides broad summaries of programs and recommendations for best practices. However it fails to provide an overview of the specific details of current engineering leadership programs. To further this field of research, this paper analyzes the specific program goals and learning outcomes of engineering leadership programs. The findings provide a comprehensive understanding of the focus of current programs, as well as a detailed summary of the key program competencies.

Summary of Engineering Leadership Programs Reviewed

Initially a list of over 40 engineering leadership programs was compiled, which was reduced down to the final eleven programs that were included in the review, as summarized in Table 1. The three main criteria for reduction and the associated rational are described in the following paragraphs.

Firstly, only programs whose main focus was leadership were analyzed. Some programs in the initial list were focused in other areas, such as project management or entrepreneurship, with a module on leadership. Secondly, the programs had to be based out of the engineering faculty or specific to engineering students. There are many leadership development programs available that are general to the entire student population. However, the engineering discipline has specific requirements in the rapidly changing 21st century, thus the fundamentals of traditional leadership education only partially satisfy the requirements of engineering leadership education[7].

The final criterion was that the program had to clearly define the program's goal and competencies. Programs that were newer or in development often had not yet developed a full definition of their goals and competencies. This criterion allows the review to provide a summary of engineering leadership education programs which have matured enough to be able to clearly define these elements.

Of the eleven programs reviewed, summarize in Table 1, eight were from the US, one from Australia and two from Canada. Nine of the programs were targeted to undergraduate students and two programs were geared towards a graduate audience. The programs reviewed included one seminar course, three extracurricular programs (non-credit), four certificate programs (credit), two minors and one Bachelor of Engineering Leadership program. Only three of the programs reviewed were launched prior to 2007, and all but one program was less than ten years old.

Fundamental Goal of Engineering Leadership Education

Each of the program goals were broken down into their main ideas and concepts, and the incidence frequency of each concept was determined. For example, the following was the program goal for Iowa State:

> "The program goal is to create an environment where future leaders can develop and engage in public life making social contributions above and beyond their traditional engineering roles"[11]

The main concepts included within this goal were: (1) future leaders, (2) develop public life, (3) engage in public life, (4) make social contributions, (5) go above and beyond traditional engineering. This process was repeated for all eleven programs' goals, and then the resulting list of concepts were grouped together. From this analysis, there were five main themes observed throughout the goal statements, each of which are briefly discussed below with supporting examples from the reviewed programs.

Table 1. Overview of Engineering Leadership Programs

University & Institution Name[1]		Source	Program Name	Program Type	Audience	Duration	Approx. Inception
Ohio University (Russ College of Engineering Technology)	Robe Leadership Institute	[12] & [3]	RLI Scholars Leadership Seminar	Seminar	Undergraduate, high achievers	Annual leadership class (stand-alone course)	1996
Iowa State University		[11]	Engineering Leadership Program	Supplemental to B.Sc.	Undergraduate	4-year program	Fall 2006[2]
University of Kansas		[13]	Self Engineering Leadership Fellows (SELF) Program	Supplemental to B.Sc.	Undergraduate, high achievers	3rd & 4th year, participate in activities outside classroom	Fall 2007
Monash University		[14]	Leadership in a Technological Environment (LITE)	Supplemental to B.Sc.	Undergraduate	3 years, activities outside classroom	2007
Massachusetts Institute of Technology	Gordon-MIT Engineering Leadership Program	[15]	Certificate of (Advanced) Engineering Leadership	Certificate	Undergraduate	2nd & 3rd year, courses & projects	2007
Northeastern University	Gordon Institute of Engineering Leadership	[16]	Gordon Engineering Leadership Program	Certificate	Graduate	1 year, 4 courses & 2 projects	2007
University of Toronto	Institute for Leadership Education in Engineering	[17]	Entrepreneurship, Leadership, Innovation and Technology in Engineering (ELITE)	Certificate	Graduate	4 courses anytime during degree	Fall 2014
University of Toronto	Institute for Leadership Education in Engineering	[18]	Certificate in Engineering Leadership	Certificate	Undergraduate	3 courses anytime during degree	Fall 2014
Lehigh University		[19]	Minor in Engineering Leadership	Minor	Undergraduate	5 courses over 2-3 years	Fall 2007
Penn State University		[20]	Engineering Leadership Development Minor (ELDM)	Minor	Undergraduate	Final year, 4 courses + capstone project	2005
University of Texas El Paso		[21]	B.Sc. in Leadership Engineering	B.Sc. Degree	Undergraduate	4 years	Fall 2014

[1]if the engineering leadership program is not run directly through the University's engineering school (Institution may be embedded within)

[2]the ELP program was a pilot program that began in Fall 2006, and based on the learnings from ELP, in Fall 2010 the E2020 program was launched replacing the ELP[22]

Effective leadership. The most commonly seen theme across the statements was the idea of creating students who would be "more effective leaders"[19], and thus be able to "better service their professions and society"[12]. Other statements included descriptions of being "able to effectively contribute to real-world" projects[15] and to "handle complex, human challenges"[23]. This theme emphasizes that the goal of engineering leadership education is not only to teach engineers to be leaders, but to ensure they become effective leaders within the context of the engineering profession. It has been shown that participation in leadership that includes service-based design activities enhances both leadership and technical skills in engineering students[24].

Innovation and technology. The second most commonly observed theme was the "ability to invent, innovate and implement" engineering projects and technologies[16]. The programs expressed goals to develop graduates who could "manage innovation"[17] and who had "a passion for technology"[13]. This theme highlights that leadership is essential to innovation, as there must be someone who will champion and lead the development of innovative technology[3].

Independent learning. Another common theme observed across the goals was about helping students learn how to be an independent learner. This is shown through statements such as "further engages students in their education"[20], "offers students the opportunity to discover"[14] and develop "the student into an action-driver leader"[21]. These emphasize the fact that regardless of how well designed an engineering program is, the responsibility to learn rests with the students[7]. It can also help students understand that they are capable and can succeed, but there is always room for improvement and they must continue learning and improving[3]. Recent research discusses the importance of reflection in the continued and independent learning process[25,26].

Experiential learning. The majority of the program descriptions included emphasis on the use of experiential and project-based learning. Comments included "provide a blend of education and practice opportunities"[15] and create an environment where students can "engage in public life making social contributions"[11]. Experiential and active learning approaches have been shown to increase student motivation, integrate multidisciplinary curriculum knowledge, develop skills problem solving with a systems approach, enhance interpersonal skills, and build a community among students[27]. Many of these are parallel with leadership skills, thus it would be predictable that experiential learning would be beneficial for teaching engineering leadership.

System thinking. The final theme observed was the idea that "engineers are taught to think analytically and systematically"[23] and that this must include an "interdisciplinary integration of skills and knowledge"[21]. Much of the background literature emphasized that engineers of the 21st century must be able to solve engineering systems challenges, in other words, taking an integrated approach to addressing the technology, management, and policy aspects of societal problems[28]. Our complex society requires engineering leaders who have this system thinking capacity that integrates the technology and arts[29].

The majority of these themes are not just about educating leaders, but ensuring that students understand how their leadership skills will be applicable within their engineering career. A key element of the design of many engineering leadership programs is that it is integrated within an engineering context[2]. Engineering leadership is not separate from other engineering skills, but rather should be integral[5].

It is worthwhile to remind the reader that the "the process of characterizing the objectives and outcomes of an engineering leadership program is as dynamic as the changing world we live in and in the end involves a degree of subjectivity"[7]. Although these five themes may be viable today, it is important to remember that continuous evaluation and improvement is essential to the success of any program, particularly in the dynamic field of engineering.

Competencies of Engineering Leaders

There was a high level of diversity in the competencies outlined by the eleven programs, with a total of 72 different competencies listed. Figure 1 shows a word cloud visualizing the large variety of the competencies, with the size of each word indicating their approximate frequency. There were six competencies observed in at least five of the eleven programs and these six will be discussed in detail below.

Figure 1. Visualization showing the frequencies of competencies in engineering leadership education programs.

Communication. Effective communication is absolutely essential in engineering, thus unsurprisingly the theme of communication emerged most prominently from the competencies. One study showed that engineers spend 60% of their time communicating with other people[10], and this figure would likely be higher for engineers in leadership positions. Within the context of leadership, communication is essential for being able to intentionally listen, question with the purpose of defining problems and determining motivations, and concisely summarize important points, such as lessons learned or action items[3].

Innovation. Innovation was also a theme that emerged in the goal statements analysis, emphasizing that innovation is an incredibly important element of engineering leadership education programs. Innovation has been discussed at great length recently in literature, and specifically the importance for engineering leaders to also be innovative leaders[30].

Creativity. Creativity was described in different ways, such as "breakthrough thinking"[19], "tapping creativity"[9] and "creative problem solving skills"[13]. Creativity and innovation were often mentioned hand in hand. As explained by Penn State, their program has been designed to "promote creative thinking and innovative actions as these were considered integral to being at the forefront of engineering (i.e. an engineer leader)"[7]. This complements the notion that "creative and spatial abilities are allies in innovation: an innovator must visualize what does not yet exist." [31] It is no longer sufficient to solely be a qualified engineer, but one must also be creative to be desirable, particularly as an engineering leader.

Execution (Results! Get it done!). This theme was expressed differently in each program, however the message was the same – engineering leaders need to take action. The different statements included "strongly goal orientated"[13], "getting the job done"[9], "resourcefulness – get it done"[16], "excellence in execution"[18], and "results oriented"[7]. CDIO addresses this theme in their syllabus, describing the attitudes of leadership to include taking initiative to make decisions, being perseverant, and having the urgency to deliver[5]. The ability to execute is a character trait that underlies many of the other professional skills of engineering leaders.

Personal Drive. This theme emphasized that engineering leaders should not only take action, but that they should have the "energy and drive"[11] to achieve a "personal vision"[15]. Anyone who has worked on an engineering project understands this need for leaders to strive for the best and be the champion for the implementation of innovations[3]. This theme relates to the concept of self-management, where engineering leaders must be able to work efficiently, manage their time, and have a strong work ethic in order to achieve their personal vision[2].

Teamwork. Regardless of one's role, engineers are almost always required to work in a team setting. It is therefore logical that teamwork would be an essential part of engineering leadership. Competencies within this theme were phrased both as "teamwork with diverse groups"[19] and "building a successful team"[11]. The latter example implies that leaders in engineering should not only possess the skills of teamwork, but also be able to help others gain these skills in order to function as an effective team. It is important to understand that leadership within a team is not just about the team leader, but it is also important for the team members to possess skills of leadership and self-leadership in order for the team to be most effective[10].

The findings from this analysis determined the most essential competencies to be addressed within an engineering leadership education program based on the case studies used. As mentioned previously, there is a large variety of engineering leadership competencies, and depending on the specific role and situation there may be a different emphasis on each competency. Figure 2 depicts the ten broad themes observed within the 72 competencies. These ten broad themes are divided into three groups: Technical, Others and Self with Responsibility spanning all three groups. Having ethical responsibility is important within an engineer's technical work, but also within their work with others, and to themselves.

These three groups provide the basis for engineering leadership programs and are consistent with much of the literature. University of Texas El Paso's recently introduced Bachelor of Engineering Leadership describe the three pillars of engineering leadership: Competence,

Capacity and Character[21]. These three pillars map without difficulty to the three groups that emerged, respectively Technical, Others and Self.

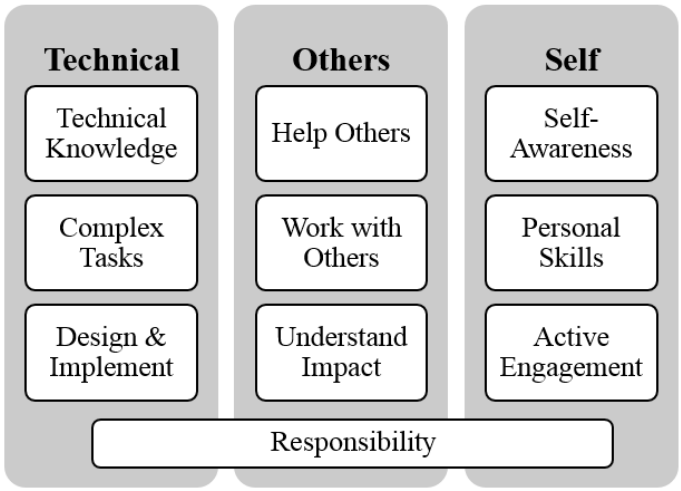

Figure 2. Ten broad themes of the engineering leadership program competencies, divided into three main groups: Technical, Others and Self.

Summary and Conclusions

It is clear that engineering leadership education is essential to developing an engineer that will succeed in the 21st century. The analysis of the case study programs gives insight into the best practices surrounding the program goals and competencies. The findings provide a starting point for engineering institutions looking to develop a leadership education program.

The five themes that emerged for the fundamental goal gives insight into what the focus of engineering leadership programs should be. These five themes – effective leadership, innovation and technology, independent learning, experiential learning and systems thinking – are not necessarily the definitive answer, but they are useful as a guidance measure.

The amount of information and research available on engineering leadership competencies can be overwhelming. Even within the engineering leadership programs currently offered, there is a wide range of competencies expressed. The three groups of competencies that emerged, Technical, Others and Self, will provide a foundation for engineering leadership education programs. As well, the six core competencies – communication, innovation, creativity, execution, personal drive and teamwork – are essential competencies for any institution providing engineering leadership education.

A more detailed literature review comparing the results from this study to other similar research may provide additional insight. Further research is also required in order to confirm the results, and a wider range of programs should be investigated to include in the analysis. As well, a proximity study of the competencies would assist in grouping them into program components.

References

[1] S. Kumar and J. K. Hsiao, "Engineers Learn 'Soft Skills the Hard Way': Planting a Seed of Leadership in Engineering Classes," Leadership Management Engineering, vol. 7, no. 1, pp. 18–24, 2007.

[2] G. Hillmer, R. Wiedenbrueg, and a Bunz, "Chapter 26: Competences Required by Industry from Early- Career Engineering Graduates – Developing Management & Leadership Skills in Engineering Education," Innovations, pp. 291–304, 2012.

[3] D. J. Bayless, "Developing Leadership Skills in Engineering Students – Foundational Approach through Enhancement of Self-Awareness and Interpersonal Communication," in Canadian Engineering Education Association Conference, 2013.

[4] National Academy of Engineering, The Engineer of 2020: Visions of Engineering in the New Century. Washington, D.C.: National Academies Press, 2004.

[5] E. F. Crawley, J. Malmqvist, S. Östlund, D. R. Brodeur, and K. Edström, Rethinking Engineering Education: The CDIO Approach, 2nd Ed. Springer International Publishing, 2014.

[6] P. Phyllis, "Proposal to add a Minor in Engineering Leadership Development," Maryland, 2007.

[7] R. J. Schuhmann, "Engineering Leadership Education – The Search for Definition and a Curricular Approach," J. STEM Education, vol. 11, no. 3, pp. 61–69, 2010.

[8] NSPE, "NSPE Position Statement No . 1752 — Engineering Education Outcomes," National Society of Professional Engineers, 2010. [Online]. Available: http://www.nspe.org/sites/default/files/resources/GR downloadables/Engineering_Education_Outcomes.pdf. [Accessed: 01-Dec-2014].

[9] R. Graham, E. Crawley, B. R. Mendelsohn, W. Paper, B. M. Gordon, M. I. T. Engineering, and L. Program, "A snapshot review of international good practice," 2009.

[10] H. Khattak, H. Ku, and S. Goh, "Courses for teaching leadership capacity in professional engineering degrees in Australia and Europe," European Journal of Engineering Education, vol. 37, no. 3, pp. 279–296, Jun. 2012.

[11] K. S. Athreya and M. T. Kalkhoff, "The Engineering Leadership Program: A co-curricular learning environment by and for students," J. STEM Education, vol. 11, no. 3 & 4, pp. 70–75, 2010.

[12] Ohio University, "Robe Leadership Institute," 2014. [Online]. Available: http://www.ohio.edu/engineering/academics/leadership-integrity/robe.cfm. [Accessed: 15-Dec-2014].

[13] The University of Kansas, "SELF: Self Engineering Leadership Fellows Program - Current Students." [Online]. Available: http://www.engr.ku.edu/self/current/. [Accessed: 10-Dec-2014].

[14] Monash University, "Leadership in a Technological Environment (LITE) program," 2013. [Online]. Available: http://www.eng.monash.edu.au/current-students/merit/leadership/entry.html. [Accessed: 10-Dec-2014].

[15] MIT GEL, "Bernard M. Gordon MIT Engineering Leadership Program." [Online]. Available: http://gelp.mit.edu/. [Accessed: 10-Dec-2014].

[16] Northeastern University, "The Gordon Engineering Leadership Program," 2014. [Online]. Available: http://www.northeastern.edu/gordonleadership/. [Accessed: 15-Dec-2014].

[17] University of Toronto, "Entrepreneurship, Leadership, Innovation and Technology in Engineering (ELITE) Certificate," 2014. [Online]. Available: http://gradstudies.engineering.utoronto.ca/professional-degrees/elite-certificate/. [Accessed: 15-Dec-2014].

[18] iLead, "Our Vision, Mission & Values," University of Toronto, 2014. [Online]. Available: http://ilead.engineering.utoronto.ca/about-ilead/our-vision-mission-values/. [Accessed: 15-Dec-2014].

[19] Lehigh University, "Minor in Engineering Leadership: Developing Leaders." [Online]. Available: http://www.lehigh.edu/~inleader/leaders.html. [Accessed: 10-Dec-2014].

[20] Penn State, "ELDM: Engineering Leadership Development Minor," 2011. [Online]. Available: http://www.eldm.psu.edu/leadership/index.php. [Accessed: 15-Dec-2014].

[21] UTEP, “Bachelor of Science in Engineering Leadership,” 2014. [Online]. Available: http://e-lead.utep.edu. [Accessed: 10-Dec-2014].

[22] K. S. Athreya, N. Bhandari, M. T. Kalkhoff, D. T. Rover, A. M. Black, E. Eda, and S. K. Mickelson, “Work in Progress - Engineering Leadership Program : A Thematic Learning Community,” in Frontiers in Education Conference, 2010.

[23] University of Toronto, “Certificate in Engineering Leadership.” [Online]. Available: http://www.undergrad.engineering.utoronto.ca/Programs/Minors_Certificates/Engineering_Minors_Certificates/certificates/leadership.htm. [Accessed: 15-Dec-2014].

[24] R. Shelby, F. Ansar, E. Patten, L. Pruitt, G. Walker, and J. Wang, “Implementation of Leaderhip and Service Learning in a First-year Engineering Course Enhances Professional Skills,” International Journal of Engineering Education, vol. 22, no. 1, pp. 1-14, 2013.

[25] J. Andrews, R. Clark, and B. Glew, “A Matter of Professionalism? Reflection & Reflexivity in Continuing Engineering Education & Practice,” in World Engineering Education (WEE), 2011, pp. 25-28.

[26] N. Sierwiorek, L. Shuman, M. Besterfield-Sacre, and K. Santelli, “Engineering, Reflection and Life Long Learning,” in American Society for Engineering Education (ASEE), 2010, session AC2010-1586.

[27] R. Bruce, and S. Reiser, “Take Chances, Make Mistakes, Get Dirty,” in IEEE SoutheastCon, 2010, pp. 181-184.

[28] D. L. Farber, “Understanding Engineering Systems Futures : Using Scenario Analysis and Planning to Develop Engineering Systems Leadership,” Social Science Research Network, 2011.

[29] D. C. Aragon, P. Golding, R. V Gonzalez, G. J. Moreno, D. Natera, R. F. O’Brien, R. T. Schoephoerster, S. A. Starks, E. Q. Villa, W. S. Walker, I. N. Webb, V. P. Manno, R. K. Miller, R. Martello, M. Somerville, L. A. Stein, J. D. Stolk, and J. Townsend, “Model Collaboration for Advancing Student-Centered Engineering Education,” in IEEE Frontiers in Education Conference, 2013, pp. 212–214.

[30] W. Karwowski, T. Ahram, and B. Amaba, “A system-of-systems engineering approach to leadership and innovation : Sustainable STEM education and workforce development through the Smart Cities initiative,” in QScience Proceedings (World Congress on Engineering Education 2013), 2014.

[31] S. Coxon, “Innovative Allies: Spatial and Creative Abilities,” Gifted Child Today, vol. 35, no. 4, pp. 277-284, 2012.