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POST SECONDARY PROJECT-BASED LEARNING IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS

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Abstract

Project-based learning (PjBL - to distinguish from problem-based learning - PBL) has become a recurrent practice in K-12 classroom environments. As PjBL has become prominent in K-12 classrooms, it has also surfaced in post-secondary institutions. The purpose of this paper is to examine the research that has studied a variety of science, technology, engineering and mathematic (STEM) subjects using PjBL in post-secondary classrooms. Fourteen articles (including qualitative, quantitative and mixed methods) were included. Two tables and two figures are included. In this paper, theoretical backgrounds and key terms were identified, followed by a literature review discussing four themes: content knowledge, interdisciplinary skills, collaboration and skill development for future education and careers. Results suggested that there is a positive connection between content knowledge learning and PjBL in collaborative settings. However, some negative perceptions arose regarding teamwork situations. Interdisciplinary skills were achieved, but quite limited in post-secondary classrooms. PjBL and STEM were perceived to be important for future education and careers. Future research needs to be completed and institutional curriculum changes informed by the results of this research need to occur to further explore interdisciplinary courses and the use of PjBL.

Keywords – Project-based learning, Technology, Post-secondary, STEM.

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1 INTRODUCTION & BACKGROUND

Project-based learning (PjBL - to distinguish from problem-based learning - PBL) has become a recurrent practice in K-12 classroom environments. Teachers guide students towards in-depth inquiry with focused engagement on content matter to create a product, presentation or performance (Larmer, Ross, & Mergendoller, 2009). Often, these projects are based on real-world scenarios. As PjBL has become prominent in K-12 classrooms, it has also surfaced in post-secondary institutions (Barak & Dori, 2005; Hogue, Kapralos & Desjardins, 2011). Even though PBL and PjBL are both in-depth inquiry methods used in many classrooms, this literature review will focus on PjBL. PjBL was developed from a constructivist learning theory where learners generate knowledge using prior experiences and understandings through a meaning-making process (Driscoll, 2005). PjBL is a pedagogical application of these constructivist ideas. The purpose of this paper is to examine the research that has studied a variety of science, technology, engineering and mathematic (STEM) subjects using PjBL in post-secondary classrooms. In this paper, I will explore theoretical foundations and key terms, followed by a literature review of four main themes: acquisition of content knowledge, interdisciplinary skills, collaboration and skill development for future education and careers. I will also discuss teamwork, time restrictions and interdisciplinary factors with recommendations for future research to support further post-secondary institutions inclusion of PjBL and STEM courses.

1.1 Project-Based Learning (PjBL)

There are several key elements that allow teachers to design, assess and manage PjBL. The Buck Institute for Education (http://bie.org/), a non-profit organization providing professional development for teachers, has synthesized elements of a successful PjBL (Larmer et al., 2009). They have also suggested some fundamental similarities and differences between PBL and PjBL (see Table 1). For example, PjBL is often multi-disciplinary, involves authentic tasks and can require longer periods of time (Larmer et al., 2009).

Additionally, The Buck Institute for Education developed a list of essential elements of PjBL, including: significant content, 21st century skills, in-depth inquiry, driving question, need to know, voice and choice, revision and reflection, and public audience (Larmer et al., 2009). Constructivism is a foundation for many of these elements as it allows students to make connections with prior knowledge. These connections are encouraged by teachers through engagement and reflection (Driscoll, 2005; Matthews, 1994). Table 2 describes the essential elements identified by the Buck Institute for Education and how these elements act as epistemological connections to constructivist learning (Ralph & Currie, 2014).

Students' active engagements, based on curricular outcomes, are enveloped in complex concepts (Blumenfeld & Krajcik, 1994) through PjBL opportunities. An imperative goal for PjBL is students "doing" with understanding and not just "doing" for the sake of "doing" (Barron et al., 1998). For this to transpire Barron et al. (1998) have suggested four principles for understanding: "1) learning-appropriate goals, 2) scaffolds that support both student and teacher learning, 3) frequent opportunities for formative self-assessment and revision, and 4) social organizations that promote participation and result in a sense of agency" (p.273). These four principles encourage the deeper level of cognitive understanding.

1.2 Science, Technology, Engineering and Mathematics (STEM)

Science, technology, engineering and mathematics (STEM) in K-12 classrooms enhance motivation for learning and improve student interest through achievement in these multidisciplinary subjects (STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research, 2014). Initially, STEM education was a goal for K-12 classrooms; however, more recently it is also being proposed in university settings (Porter, Roessner, Oliver & Johnson, 2006; Redish & Hammer, 2009). Developing a pedagogical approach that integrates STEM was suggested to encourage the improvement of learning attitudes in the learning community (Tseng, Chang, Lou & Chen, 2013), while preparing students for post-secondary schooling (STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research, 2014). STEM is influencing the curriculum in undergraduate level courses (Porter et al., 2006; Redish & Hammer, 2009; Tseng et al., 2013). The explicit connections of STEM to PjBL are oriented towards increasing student understanding and self-efficacy through interdisciplinary studies (Barron et al., 1998; Blumenfeld & Krajcik, 1994; Lebow, 1995; STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research, 2014). Additionally, science and PjBL have encouraged the exploration of active engagement and participation (Polman, 2000). In summary, according to the literature, the pedagogical impact of STEM and PjBL can be very valuable.

Project Based Learning vs. Problem Based Learning	
Similarities	
Both PBLs: • *Focus on an open-ended question or task* • *Provide authentic applications of content and skills* • *Build 21st century 4 C's competencies* • *Emphasize student independence and inquiry* • *Are longer and more multifaceted than traditional lessons or assigments*	
Differences	
Project Based Learning	*Problem Based Learning*
Often multi-disciplinary	*More often single-subject*
May be lengthy (weeks or months)	*Tend to be shorter*
Follows general, variously-named steps	*Follows specific, traditionally prescribed steps*
Includes the creation of a product or performance	*The "product" may simply be a proposed solution, expressed in writing or in an oral presentation*
Often involves real-world, fully authentic tasks and settings	*More often uses case studies or fictitious scenarios as "ill-structured problems"*

Table 1. PjBL vs. PBL similarities and differences. Larmer, J. (2014). Retrieved from http://www.edutopia.org/blog/pbl-vs-pbl-vs-xbl-john-larmer (Originally published January 6, 2014 © Edutopia.org)

Elements of PjBL	***Description of element***	***Epistemic ideals of constructivism***
Significant content	*Students focus on "real-world problems"[2] that are based on curricular learning outcomes as the focus of learning key concepts[1]*	*Students are exposed to authentic activities through the application and understanding knowledge of "the target culture"[3]*
21stcentury skills	*Students exemploy "critical thinking/problem solving, collaboration and communication"[1] techniques that are transferable to all subjects, grades, and life needs; students work collaboratively and collectively[4] to develop information and communication technology literacy skills[1]*	*Students can collaborate, and view multiple perspectives, exchange ideas that allow them to see pluralism in the knowledge[3,5]*
In-depth inquiry	*Students should continuously be asking questions and developing answers while using a variety of resources[1]*	*Students can work in high degrees of complexity and concepts[3,5]*
Driving question	*Teachers create open-ended questions that are provocative, complex and linked to the learning outcomes[1]*	*Teachers encourage active engagement through the driving question that can support the intentional learning by giving their students a purposeful goal[3]*
Need to know	*Teachers provide a "hook" or entry event that allows students to be engaged immediately by building their interest and curiosity in the project[1]*	*Teachers rely on previous knowledge to coach students into the project will encourage active engagement and understanding for future tasks[6]*
Voice and choice	*Students make capable choices such as what is to be created, through teacher guidance[1]*	*Students have the ability to self-regulate and take, ownership through personal autonomy [3]*

Elements of PjBL	Description of element	Epistemic ideals of constructivism
Revision and reflection	*Students are encouraged to reflect on their own practices and make appropriate revisions, using feedback from each other to think about how and what they are learning and what additions or changes are needed to make the best product*[1]	*Students are encouraged to self-regulate and make mindful reflections on their work to plan, monitor and modify their work*[3,6]
Public as an audience	*Students are encouraged to present their work publically, not just to classmates*[1]	*Students can proudly take ownership of learning is encourage through presentation to a public audience*[3,6]

1(Larmer et al., 2009); 2(Blumenfeld & Krajcik, 1994); 3(Lebow, 1995); 4 (Barron et al., 1998); 5(Matthews, 1994); 6 (Driscoll, 2005)

Table 2. Essential elements of PjBL and the relationship to epistemic ideals of constructivism. (Retrieved from Ralph, R.A. & Currie, L.M. (2014)

2 METHODS

Two large databases, Education Research Complete (ERC) and Education Resources Information Centre (ERIC), were searched for articles between 2000 and 2014. Authors and subjects were searched within these databases and an Internet search engine to identify any articles that might have been missed by the constrained search terms.

2.1 Search Strategy and Criteria

The following terms and combinations were used for the literature searches: “project based learning” AND the following terms: “science” AND “post-secondary education”; “university education” AND “science”; “college education” AND “science”; “higher education” AND “technology”; “science”, “engineering” AND “math”. The inclusion criteria included studies involving project-based learning in which any STEM subjects were used in post-secondary schools. In the initial search, 143 abstracts were identified. Articles that did not meet the inclusion criteria were removed: 48 articles were duplicates, 23 articles were removed because they did not report on research studies, 9 articles were reviews of other research, 12 articles were K-12 education, 8 articles were literature studies on the theory and 3 articles were specific guides and steps towards PjBL. A total of 40 abstracts were retained.

2.2 Quality Appraisal

The ReLIANT (Reader’s guide to the Literature on Interventions Addressing the Need for education and Training) instrument was used to identify the final literature based on four sections: study design, educational context, results and relevance (Koufogiannakis, Booth, & Brettle, 2006). A scoring system adapted from Thomas (2013) use of the ReLIANT tool was also used (see Table 3). Each article was assigned a score and articles achieving a score of a 1 or 2 were retained. This reduced the number of articles to 14.

Category	Definition	Rating
A	*Well conducted and reported (>75% overall score, with >50% in all 4 categories).*	*Yes = 2*
B	*There are some concerns, but not severe enough to reduce the validity of the findings (>75% overall score, but <50% in one or more categories).*	*In part =1*
C	*Serious concerns about design meaning the study may not be valid (<75% overall score, or <50% in first ‘design’ category).*	*No = 0*

Table 3. Quality Appraisal Score. Adapted from Thomas, J. (2013).

3 RESULTS

Of the 14 articles identified (including qualitative, quantitative and mixed methods) several themes emerged: six studies focused on the acquisition of content knowledge (CK), three studies discussed interdisciplinary skills, eleven studies addressed collaboration and six studies identified development of skills for the future.

3.1 Content Knowledge (CK)

Content knowledge (CK) is the specific subject matter students attain in classroom learning environments (Blumenfeld &Krajcik, 1994; Koehler & Mishra, 2009; Lebow, 1995; Milner-Bolotin, Fisher & MacDonald, 2013). These are generally based on Bloom's Taxonomy of cognitive understanding, including: knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, 1956). For example, CK would include comprehension and application of operating principles for light emitting diodes (LED) (Chang, Chen, Kuo & Shen, 2011). Six studies that focused on CK had a range of specific content goals. One study measured traditional methods of cumulative tests compared to continuous daily quiz assessments and PjBL through formative assessment (Shorter & Young, 2011). The results suggested that continuous assessment was the predictor of high student scores in the course (Shorter & Young, 2011). Moreover, higher scores occurred when continuous assessment was combined with PjBL (Shorter & Young, 2011). Other research demonstrated significant higher final exam scores in Chemistry after students had participated in PjBL (Barak & Dori, 2005).

In regards to summative assessment, Yildirim (2004) also suggests positive results between PjBL and the mastery of goals. One researcher revealed that a benefit of PjBL was the ability to retain a large amount of content (Frank & Barzilai, 2004). Moreover, Chang et al. (2011) participants commented on their increased understanding after their PjBL experience. Additionally, Arce, Miguez, Granada, Miguez and Cacabelos (2013) academic results demonstrated a successful course completion with all students passing the ordinary exam. Overall, the literature suggests there are positive results between PjBL and increased learning of CK.

3.2 Teamwork

Learning CK through PjBL is strongly influenced by collaboration or teamwork. Eleven studies assessed the impact of teamwork in the PjBL environment. Merriam Webster defines teamwork as the work done by people who work together to do something (Teamwork. (n.d.). Retrieved October 20). Participants in several studies expressed positive views towards teamwork. Three of these studies described how group members encouraged collaboration and assisted each other when misunderstandings occurred (Crowder & Zauner, 2013; Shorter & Young, 2011; Zhou, 2012). Another study demonstrated that 70% of students preferred group work as it encouraged the promotion of self-evaluation as well as initiated negotiations when disagreements occurred (Papanikolaou & Boubouka, 2011). Teamwork skills, such as how to communicate effectively and how to problem solve, were also developed (Andres & Shipps, 2010; Arce et al., 2013; Chang et al., 2011; Frank & Barzilai, 2004; Lipson, Epstein, Bras & Hodges, 2007; Yildirim, 2004; Zhou, 2012). Furthermore, students perceived teamwork as valuable as they believed this reflected possible future experiences (Crowder & Zauner, 2013; Hall, Palmer & Bennett, 2012). Unfortunately, not all students experienced positive group work.

Several studies identified negative aspects of teamwork. The foremost issue was team members who were not making significant contributions (Frank & Barzilai, 2004; Hall et al., 2012; Lipson et al., 2007). There were a range of issues from students lack of contributions, to lack of attendance that impacted the group dynamics. In one study, students felt that team learning increased productivity; however, when using technology-mediated collaboration as opposed to face-to-face interactions, there was a breakdown in communication through misunderstandings (Andres & Shipps, 2010). Nonetheless, teamwork, whether positive or negative, is a part of the 21stcentury skills that encompasses PjBL.

3.3 Interdisciplinary Knowledge

Teamwork and CK are both embedded in multiple subjects. Interdisciplinary learning represents multiple subjects, such as biology, chemistry and technology (Frank & Barzilai, 2004). It is aggregated learning across more than one discipline. This is directly related to the goals of STEM education and PjBL (Larmer et al., 2009; STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research, 2014). For example, biology and/or chemistry were paired with technology (Barak & Dori, 2005; Frank & Barzilai, 2004). Both studies, that reflected interdisciplinary courses, established that one benefit of PjBL was the acquisition of interdisciplinary knowledge. PjBL allows and encourages interdisciplinary work as many real-world tasks require knowledge across many subjects (Larmer et al., 2009). Moreover, interdisciplinary courses encourage a comprehensive understanding. For example, the Biologically-Inspired Robots course in Southampton, UK “shows the connections between mechanical engineering, electrical and electronics engineering, and computer science” (Crowder & Zauner, 2013, pp. 82). Interdisciplinary learning should be further explored to contribute to future learning in a variety of courses.

3.4 Development of Skills for Future Endeavors

Interdisciplinary knowledge and PjBL encourage experiences that can transfer to future coursework and careers. Hogue et al. (2011) research focused on CK video game development. They discovered an overwhelmingly positive result of 87% of students who wanted to continue with video game development beyond that class assignment. Three studies identified that the context of real-world applications assisted in transferring skills from the classroom to future career settings (Crowder & Zauner, 2013; Hall et al., 2012; Lipson et al., 2007). Moreover, other research expressed the students perceived importance of engineering skills for professional work (Arce et al., 2013; Hall et al., 2012; Tseng et al., 2013). The literature suggests that many students saw PjBL as a catalyst to their future career aspirations.

4 DISCUSSION

4.1 Teamwork at a Post-Secondary Level

As the literature suggests, there were positive and negative views of teamwork when collaborating in a PjBL situation. When working together several dichotomies emerged, including: focused engagement vs. floundered disengagement and conflicts within the group vs. successful interactions (Lipson et al., 2007). Even though some participants suggested apprehensions towards teamwork, the overall sentiment was positive. For example, an undergraduate engineering student stated that he enjoyed the group aspect and had positive interactions with staff members (Crowder & Zauner, 2013). It is interesting to note that the majority of students will have worked in group situations in their K-12 education, and yet similar negative and positive issues arose (see Figure 1). These issues were primarily concerned with the type of group members involved. Groups were made up of diligent workers, lackluster workers, absent contributors, and distracted members. Regardless, students' experiences with negative issues provided them resolving opportunities, such as increasing the amount of discussions, which in turn influenced brainstorming sessions.

A major element of PjBL is the social aspect of participation in the project (Polman, 2000). Teamwork can be perceived as valuable even when negative situations develop. The ability to negotiate through conflict is an employable skill. As a teacher, I wish to provide my students many opportunities for group work for a number of reasons. Firstly, social construction is essential to understanding. As students construct knowledge, peer pedagogy transforms overall understanding. Secondly, I think learning how to negotiate challenging group situations is extremely useful for both education and life situations. In brief, teamwork is part of PjBL that assists in future projects or careers regardless of positive or negative situations.

4.2 Time Restrictions

While teamwork may create negative and positive experiences, time restrictions mainly reflected negative sentiments. Time is a fundamental aspect and the determining factor in structuring tasks in school (Polman, 2000). Complex projects require in-depth inquiry (Larmer et al., 2009), which can be quite time consuming. Some participants identified time demands as detrimental to PjBL (Crowder & Zauner, 2013; Hall et al., 2012; Shorter & Young, 2011; Zhou, 2012). Moreover, students concerns or obsessions with time may restrict effectiveness of PjBL. Teachers need to provide sufficient time for students' in-depth exploration. Unfortunately, limited amounts of time may restrict the decision to use PjBL (Polman, 2000). For example, teachers encounter difficulties when designing and applying PjBL as it requires more resources and more planning than traditional methods (Arce et al., 2013). As these complex problems are explored, deeper understanding is achieved, but cannot be obtained if time is an issue. Personally, I have had difficulties assessing time allotments for major PjBL units; however, I have also felt restricted by my curricular expectations. Perhaps changes need to be made at an institutional level to reduce curriculum demands to encourage more time for PjBL.

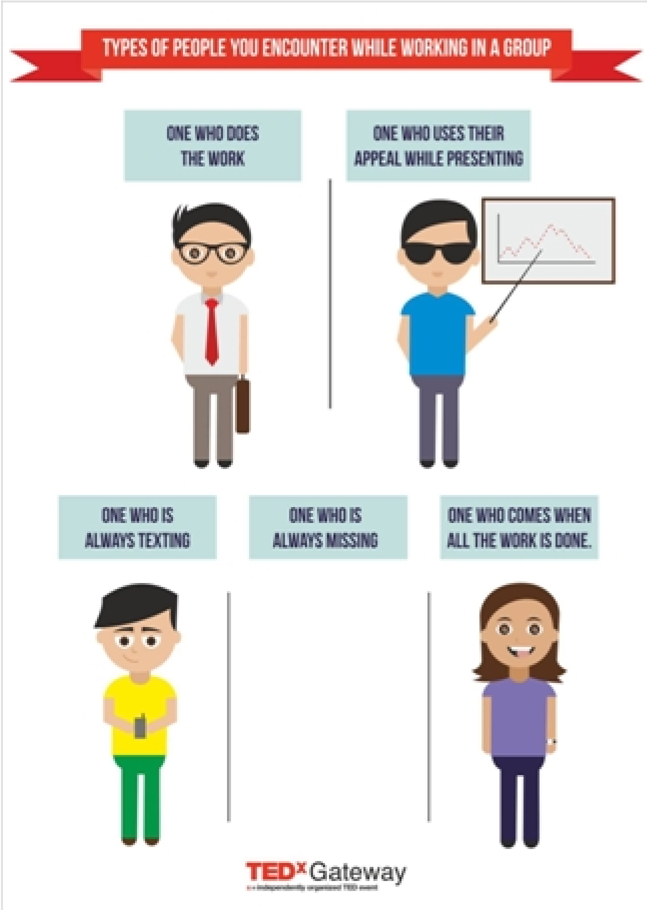

Figure 1. Types of people you encounter while working in a group. TedXGateway. (2014). Retrieved from http://www.tedxgateway.com

4.3 Interdisciplinary Factors in Post-Secondary Classrooms

Institutional changes to adjust curriculum, in order to reduce barriers to the inclusion of PjBL, could also encourage interdisciplinary learning. Post-secondary institutions should practice engaging students at the same meaningful level in STEM that is occurring in K-12 classrooms. Students recognized the importance of STEM towards future careers and applications to daily life (Tseng et al., 2013). Moreover, instructors suggest benefits for more comprehensive interdisciplinary understanding, in particular across engineering fields (Crowder & Zauner, 2013). Post-secondary institutions often have a limited range of interdisciplinary courses. Many students focus their courses and education around single subjects, which prevents the cross-curricular situations found in real-world STEM applications. Often in the sciences or other STEM courses, math is a foundation (Tseng et al., 2013), but cross-curricular interaction is rare.

Redish (2014) explained the University of Maryland made curricular changes and established an interdisciplinary learning situation in a physics course. Significant changes to the required physics courses for biology students fostered interdisciplinary transfer encouraging active engagement through biology and physics connections (Redish, 2014). Institutional curricular change was a critical necessity. Redish (2014) explained that changes to the MCAT allowed for changes to the courses as many elements were eliminated or reduced. If this is the case, then perhaps other courses will also have the opportunity to make significant changes to create more interdisciplinary STEM courses. Generally, STEM interdisciplinary opportunities need to be addressed at a post-secondary level.

5 FUTURE RESEARCH

This literature analysis of research has unveiled a number of opportunities for future researchers. In regards to the negative experiences of teamwork in PjBL settings, one suggestion is to addresses the structuring of groups in STEM classrooms. For example, further research could measure the structure of groups by how many group members are more or less effective in terms of the project or in terms of conflict situations that arise during PjBL STEM experiences. Moreover, assessing the group make-up based on the diversity of skills of each member to reduce conflict situations could be explored.

Time was also a determining factor of success. If this is the common concern, future research could address what is an appropriate amount of time for various PjBL STEM projects and make suggestions to institutions to increase course length or perhaps dividing the course into more than one term. Additional curricular changes to reduce course load and increase in-depth understanding would foster future PjBL use.

Another key area of exploration is STEM at a post-secondary level. Addressing a STEM skills gap will prepare students for STEM based careers (Dobson & Burke, 2013). Future research could address STEM using PjBL and if it is more effective, more motivating or tracing the development of various STEM skills. As this is beginning to be addressed in engineering, other subject areas can be explored. Additionally, more in-depth qualitative analysis within the post-secondary engineering field should be conducted. This could hopefully lead to some administrative changes and movement towards more interdisciplinary learning.

6 CONCLUSION

This literature analysis uncovered that students in post-secondary courses were experiencing a range project-based learning activities in a variety of science, technology, engineering and math classrooms. Most students' opinion was positive towards the achievement of content knowledge, interdisciplinary skills, and the use of PjBL in their courses. Additionally, the literature suggests that students believed the skills they learned from PjBL would benefit them in future classroom and career settings. I believe this is a common feeling amongst many students, as they want to develop a variety of employable skills. Even though there were a number of negative feelings towards teamwork, most students found it beneficial. The ability to adapt to teamwork settings, including positive and conflict infused situations, is important for classroom and career situations. The ability to adapt to these situations was impinged by time restrictions. However, this suggests comprehensive institutional curricular changes that need to occur. These changes need to be enacted in order to influence the positive implementation of PjBL. Similar curricular changes need to transpire before additional interdisciplinary courses are introduced. For future STEM classrooms to succeed, it needs to be a change at the institutional level. Overall, PjBL has had an impact in post-secondary STEM courses. Future research addressing the above concerns needs to occur in order to encourage future success.

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