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Bringing Entrepreneurial methods into the scientific Classroom: A Case Study of Action Learning at *École polytechnique*

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ABSTRACT:

This research presents a qualitative study of action learning at École Polytechnique, a top engineering school in France. Though existing literature has theorized on methods and applications of action learning, notably within business and management, this work explores the use of such techniques in the context of fundamental science education. As a case study, we explore Polytechnique's "Le Projet Scientifique Collectif" (PSC) using in-depth interviews with a variety of key actors involved in an action-based program. We conclude our study by suggesting areas of future investigation using discussion points that explore barriers and opportunities of successful collaborative student projects.

Keywords: Action learning, entrepreneurship, fundamental science education, engineering school, resources, pedagogy, mentorship.

RESUMÉ:

Cette recherche présente une étude qualitative sur une expérience de formation-action ou *Action Learning* à l'École polytechnique (France). La littérature existante a théorisé les méthodes et les champs d'application sur *Action Learning*, plus particulièrement dans le domaine des affaires et du management. Ce travail examine le recours de cette approche dans le monde de la formation aux sciences fondamentales. L'étude de cas porte sur le "Projet Scientifique Collectif" (PSC) à l'École polytechnique. Elle mobilise des entretiens approfondis réalisés auprès d'acteurs clés de ce programme basé sur l'action. Les résultats soulignent les limites et le potentiel du succès de quelques projets collaboratifs portés par les étudiants. Ces premières indications permettent d'énoncer de futures pistes de recherche sur un champ et une pratique peu appliquée aux sciences fondamentales.

Mots clés: Action learning, entreprenariat, formation à la recherche fondamentale, école d'ingénieur, ressources, pédagogie, mentorat.

Introduction

Though action learning has been associated with a variety of disciplines, fewer scholars have explored the popular learning technique within the context of fundamental science education. This research presents a qualitative study of action learning at École Polytechnique (Polytechnique), a top engineering school in France. Existing literature has theorized on overall definitions, politics, methods and applications of action learning, but as the approach gains in popularity—spreading beyond the walls of management programs to other disciplines—it is necessary to explore the benefits and challenges of "learning by doing" in a diverse array of situations. Polytechnique's "Le Projet Scientifique Collectif" (PSC) provides an ideal vehicle for understanding how a school, traditionally renowned for rigorous, exam-based science education is applying action-based curriculum. In-depth interviews with a variety of key actors involved in PSC research and advising staff provides a set of perspectives useful for analyzing and beginning to understand the action learning approach through the context of Polytechnique. Initial review of the data examined include insights on (1) how second-year students navigate their projects, even stepping outside of the campus' borders to use corporate and private resources; (2) how the distant mentorship of faculty advisors shapes students' learning and project inventiveness; and (3) how administrative initiatives and programs can foster a culture of entrepreneurial problem-solving. The result is an exploratory survey of the role of resources in shaping outcomes of collaborative scientific research projects, shedding light on three main forms of resource constraint, including: physical accessibility, networks of practice and gatekeepers. In conclusion, we offer suggestions for future investigation of entrepreneurship teaching methods in within fundamental science settings, via a series of preliminary discussion points on the barriers and opportunities of successful collaborative student projects.

Since Reg Revans introduced action learning in the 1940s, it has been associated in practice and theory with a number of disciplines, yet, despite its popularity and strength as an approach for helping organizations, teams and individuals increase long-lasting learning within a short period of time (Revans, 1980, 1982; Marsick, 1992, Marquardt and Wadill, 2004), scholarship on action learning has predominantly drawn from the perspective of management education and critical management studies. In practice, action learning techniques are integrated into a wide spectrum of disciplines including everything from music education to government (Holloway, 2004; Kim, 2008). This research hones in on a lesser-studied area of action learning: fundamental science education.

Prevailing approaches to science education can be characterized by an *objectivist* emphasis on lecture-based learning that embody an approach to learning in which knowledge is seen as something that is imparted upon students. In his chapter on how students learn science (*Effective Teaching and Course Management for University and College Science Teachers*), William Leonard sums up the major hurdle facing colleges and universities: "The present way", he writes, "simply does not stimulate active learning" (Leonard, 2000).

In exploring the case of action learning at École Polytechnique, France's premier fundamental science institution, this study puts the spotlight on a case that demonstrates both the application of action learning within a uniquely scientific setting, as well as shedding light on a novel, entrepreneurial approach for teaching fundamental science[1].

1. Literature: Evolving 'action learning'

Action Learning is widely accepted as an educational tool used in a variety of industries including human resource development, healthcare, government and education (C. Brook et al, 2012). Also referred to as "action labs", "experiential learning" or "learning by doing", students within an action learning setting go through the first-hand experience of solving of a real-world problem.

Active learning models became prevalent beginning in the 1970s when researchers such as Revans began stressing that the "active view of learning encourages students" to "learn form the problems they are trying to solve, and secondarily from their teachers or lecturers" (Macnamara et. Al).

Despite the popularity of this method of teaching, there is much debate within the action learning literature on a variety of topics including: the role of "action" in action learning, the need to inject criticality into practice, the need to inject emotion and politics and the proper definition of action learning with scholars providing slightly different definitions of action learning (C. Brook et al). For the purposes of this research, action learning is defined in its simplest form as an experience through which learning occurs between peers who must deal with the "complexities of everyday life" (Revan, Yeadon-Lee and Worsdale, 2011; p.179). This process usually takes place within a group called a "set," roughly a half-dozen people working together to solve individual problems. Collectively, these individuals make up an action-learning team that Revans refers to as the "comrades in adversity" (Revan, Yeadon-Lee and Worsdale, 2011; p.179).

Creativity and education has seen a documented growth in Europe and other parts of the world (Shaheen, 2010) with policy being created with the goal of encouraging students to think and critically solve problems in a way that has a "real effect on society", (Kettunan, 2011; p.1). For example, Finnish national higher education objectives were recently updated to encourage institutions to increase collaboration with "working life and other parties within the innovation system" and, group-based learning has emerged as a popular teaching tool within U.S. colleges, particularly management schools.

Despite the rich discussion within organizational science, education and business literature on a range of topics related to action learning, there are important limitations in the existing dialogue. First, existing research focuses primarily on *how* action learning takes place and the various tools and pedagogical approaches to action learning. As academic institutions look to action learning curriculum, our

[1] Much of the value of action learning comes from the approaches' flexibility toward application in both action and learning for a wide range of learning scenarios including individuals, teams and organizations (Dilworth & Willis, 2002; Marquardt, 1998, 2003; Pedler, 1997). But while action learning has been used worldwide in hundreds of organizations, as well as academic institutions (Marquadt and Wadille, 2004), there is little mention in the existing literature on how it is used within fundamental scientific education.

understanding of the complexities of action learning should extend beyond definitional discourse and move toward understanding organizational complexities of collaborative learning within a variety of settings.

Second, the action learning case literature, thus far, primarily focuses on examples from management, organization and education, leaving large holes in our ability to understand the complexity and variation in how action learning is used today.

This research uses the case of action learning at *École polytechnique (Polytechnique)*, a top science and engineering college near Paris. Le Projet Scientifique Collectif (PSC) is a nine-month action learning curriculum introduced at Polytechnique in 2002 as a way to encourage collaboration amongst students working across diverse academic concentrations. Historically, Polytechnique's curriculum has focused on lecture style courses, in which students work independently to study and demonstrate their knowledge through exams. Until recently, internships in labs or industry were the primary method in which students were introduced to the professional realities of scientific research and business. Through in-depth qualitative interviews of students at Polytechnique, we examine how students use action learning to collaborate and solve problems within the context of PSC. In doing so, action learning is revealed as a *process* that *exposes* students to resource constraints that aid in defining and contextualizing their work - through a complex process of navigating resources (ex. networks of practice, access to funding and research facilities).

2. Case study: Le projet scientifique collectif, understanding action learning in science

For many students, PSC offers a first exposure to collaborative problem solving and applied scientific research. When solving complex problems, group based learning has a variety of advantages when a multidisciplinary approach or variety of expertise is needed to solve a problem (Kischner, Beers, Boshuizen and Gijselaers, 2008). The PSC project takes place over the course of the student's second year. Teams are formed in groups of five to seven students under the guidance of a supervisor who oversees projects which are largely student-driven. Formal presentations give students the opportunity to show-case progress in the initial, mid-term and final stages of their research.

Research topics must be scientific, meaning it should use a scientific process and fall within one of the nine fields taught at Polytechnique[2]. PSC projects are largely self-driven by self-selected student teams that choose topic, research question, advisor and the content of their final deliverable which is presented in the form of a final presentation depicting overall process, analysis and final outcomes.

Though many articles have theorized on overall definitions, politics, methods and applications of action learning (mostly within a business, management and leadership context), few have explored how action learning processes operate within the context of scientific research and problem solving. By investigating these

[2] Including: biology, chemistry, economics, human social sciences, computer science, applied mathematics, mathematics, mechanics or physics.

processes in parallel, *this research aims* to *further understand the role of action learning and scientific research*.

By exploring this relationship, several novel insights are further revealed in this study including the influence of resources on the development of student research questions and ultimately, their results. In particular, the role of *physical resources* (funding, connections, lab space, etc.) and *social resources* (alumni connections, student associations) are examined as possible externalities that serve to influence scientific inquiry and research.

Given the increased interest in improving access to resources for innovation and entrepreneurship at universities and campuses worldwide, it's necessary to examine how they are navigated and used by students. As such, this study sought to understand the process through which individuals currently access resources needed for scientific research. Applied to our case, we hope to understand:

1. How PSC students' navigated resources and;
2. How resources influenced the direction and outcomes of their scientific inquiry.

The outcome of this early research also has practical implications. The in-depth accounts of student experience illuminate how action learning can be improved to better meet the needs of learning within a scientific setting. It also presents a series of preliminary discussion points on the barriers and opportunities of successful collaborative student project are proposed, offering an entry point for future research and investigation.

As action learning techniques continue to gain in popularity—spreading beyond the walls of management programs to other disciplines—it is necessary to explore the benefits and challenges of "learning by doing" in a diverse array of situations. Science and engineering provide a particularly compelling place to begin such an inquiry given increasing attention toward "learning labs" and "learning by doing" at universities and colleges.

3. Method

3.1. Population Studied

This research project used semi-structured interviews as the primary data collection method. All told, 20 interviews were conducted with 13 students, 3 faculty members, 3 administrators and 3 alumni of the PSC program. Students' areas of academic concentration varied with all interviewees focused on a scientific major (primarily physics, life sciences or informatics). All students lived on campus at the time of the interview in Palaiseau and although we did not specifically gather socio-economic data, students generally voiced being from a variety of geographic backgrounds (Paris and suburbs). Sampling methods involved using the Polytechnique PSC mailing list and referrals. Secondary subjects (faculty, admin and alum) were identified using referrals and personal outreach.

3.2. Data Collection & Coding

Separate interview scripts were written for each group (students, faculty, alumni and administrators). In-depth interviews followed an open-ended protocol focused on understanding how student researchers navigate and access resources in an action learning setting. Conversation[3] were transcribed along with the interviews themselves and coded using selective coding.

3.3. Data Analysis

Though a variety of codes were used in analyzing the data, the most meaningful relationship was seen in the comparison of how students used f*ormal and. informal resources. Informal resources* indicate dedicated or contractual relationships such as funding from a department, an official advisor, dedicated laboratory space or partnership with an outside firm. *Informal resources* were defined as those resources that are given without *a priori* agreements that can include informal conversations with mentors or taking advantage of the students' personal or family resources.

4. Results

The findings of the study reveal three novel understandings of how and why access to physical and social resources matters for action learning.

Most importantly, resources influence scientific research primarily when they are *physically accessible* to students. Students working on research topics requiring access to laboratories or one-on-one interactions with advisors benefitted from being close to such resources. Advisors often travelled to Polytechnique to meet with students of successful projects, and overall the PSC teams interviewed tended to utilize resources within a short distance from campus. Students who regularly travelled as part of their projects voiced difficulty in accommodating transit into their schedules.

Additionally, evidence from the data suggests that *networks of practice*—horizontal social networks that facilitate information exchange between individuals and across organization—were a particularly valuable resource to student researchers. Students' social lives via informal gatherings and organized sports and associations played a significant role in helping to form teams and, in turn, disseminating information about potential PSC topics. Teams were also included to use social networks to learn about the progress of other projects and to generally debrief or compare and contrast experiences with classmates.

Individually, these findings might seem slight or inconsequential but taken as a whole they shed light on a series of constraints that shaped the research process and outcomes of interviewee projects.

Lastly, student projects were greatly influenced by resource *gatekeepers* in the form of advisors and departments which provided both project guidance and feedback

[3] Conversation length ranged from 30 to 90 minutes with the average interview lasting roughly an hour.

but also access to key resources such as financial funding. The informants reported variation in the amount of feedback and level of resources provided by their advisors and the departments associated with student projects.

Arguably, access to resources can be a product of individual characteristics such as personal resources, and the breadth of a personal network. However, the purpose of this research is to elucidate the underlying resource network of students and to make general claims about the types of resources that students are accessing. Therefore, the variations in personal characteristics were controlled for to the extent possible during the data analysis process.

4.1. Physical accessibility: Proximity to resources

Existing work within the field of economic geography sheds light on the benefits of proximity, specifically that locating like institutions and organizations leads to benefits in the form of what Alfred Marshall characterized as four benefits of clustering: knowledge spillover, skilled labor pool, development of support industries and shared resource input (Marshall, A. 1920). The PSC students seemed to benefit from certain spillover advantages, particular in the form of knowledge from nearby corporations and use of existing, complementary resources (Marshall, A. 1920; Kazuo).

One of the most striking observations emerged from the collected data was the role that proximity played in students' ability to conduct research. Students uniformly expressed how EP's location - isolated on the Saclay plateau roughly 45 minutes from Paris - made working on or close to the campus important. As one interviewee said, isolation and long hours commuting on the train is something that Polytechnicians "just have to deal with[4]".

Students were aware of the challenges of working with advisors or companies located outside of Palaiseau, with most interviewees preferring to organize their projects around advisors and resources close to campus. Proximity was especially important for students in need of physical lab space or a permanent place to store hardware and equipment. One student whose team worked at a Polytechnique lab described his team's dedicated workspace as an advantage over students who made the long commute to Paris to work with off-site professors and advisors.

Staying close to Polytechnique meant students also tended to make use of campus resources not specifically designated for PSC research. The campus track, swimming pool, and a nearby pond were used to test hardware devices of teams. Desk research and computer-intensive work such as writing code was often conducted in libraries and dorm rooms. Cafeterias and dorms were popular sites for team meetings and work sessions:

> "We didn't want to have a big room because the ideas flow more when you're comfortable. The ideas just come and everyone is able to say anything – if we don't

[4] As reflected in this comment, transportation is a known barrier for students. PSC projects which required regular travel to Paris shifted as much as three productive work hours a week toward travel, a significant amount given that most teams reported working roughly 5 to 7 hours on their projects weekly.

> think it's good, we'll be [more likely to say so] because it's all over coffee, just like at home. If we wanted to be more formal we went to a classroom with a projector, with all of us on our computers, etcetera...."

While teams had little trouble using informal spaces for their projects, some teams faced difficulties in obtaining official research space. This was especially true for students working on hardware-intensive projects, interviewees said. One team spoke about the challenges of working alongside faculty researchers who complained about noise generated by the project; students were also not allowed to use tools within the space because of liability concerns. Another group struggled to gain access to the appropriate type of space (e.g. a place where valuable hardware could be securely stored).

Proximity also played a role in how quickly teams could revise prototypes and models with feedback from advisors. For example, one team partnering with a food corporation located 15 minutes away, used the companies professional food laboratory to create several iterations of a nutritional yogurt substitute. Staff at the lab worked with the students to train them on equipment and the variety of ingredients available to them and students perfected their recipe over the course of several weeks: "It was vital because the instrument is more complex and we could calculate the milligrams", described a team member.

4.2. Networks of practice: The social side of action-learning

The terms "networks of practice" and "communities of practice" have been used by scholars to describe networks of people with similar practices and resources that exchange information, and in the process form a common identity (Brown and Duguid, 2000). In the interviews, PSC teams identified two primary networks of practice—peers and alumni—that influenced the scope of their scientific projects.

4.2.1. Student peer networks

One important aspect of action learning is achieved through group discussion with peers, write MacNamara, Meyler and Arnold (1990) on the challenges of action learning. Rather than learning "through answers handed down from those in authority", action learning provides an opportunity to learn others facing similar challenges.

In the PSC interviewees, intentional and unintentional social interactions amongst students were associated with the development of PSC projects, especially in the early stages of identifying research questions and research topics. Many informants reported identifying project ideas or narrowing down on teammate selection through sports clubs, courses and even social networks that go back as far as being from the same high school as teammates in another instance. One interviewee recalled how she identified teammates for her PSC project a party where she was introduced to new international students visiting from the Netherlands. Informants often eluded to the fact that group dynamics and finding a good personality "fit" was more important than finding teammates with specific abilities or interests.

Whether or not such social interactions are connected to positive action learning outcomes is debatable. However, it could be argued that if students are more likely to get along, they are more likely to focus on the project at hand. In collaborative, action-learning, interpersonal relationships can be key to working through complicated, challenging problems.

Past connections also played a role, with some teams choosing to collaborate based on previous social connections, as was the case with one student who described how he came to be on a PSC team with several students who attended his preparatory school in an affluent Parisian neighbourhood:

> "Alexis, Marc Antoine, Remi and I were in the same preparatory school so I guess that's how we ended up together and then Camille and Pierre were both in the handball team so I guess during practice we discussed it so we got together as a group. And since Pierre was from EPFL, Lucien came with us and we worked on it. That's how the group formed. It's just our preparatory school, and then matches with people from the handball team".

Some students who created teams from scratch tried to work with groups that reflected a variety of skills sets—these teams were often established with the help of the PSC portal, a website used by students and advisors to share information about project ideas. For these teams, advertisements and use of the portal acted as an online facilitation tool helping to identify and pair students with complementary skills while sharing a general interest in the topic at hand. Despite the tendency to exchange general ideas and information about their projects during parties, meals and social events with peers, interviewees said they rarely provided feedback specific on the research of other teams.

Although students reported being interested in the work of other classmates, they received little to no formal peer feedback on their projects. Given the common task set before all 80 teams, the lack of team-to-team PSC feedback emerged as a missed opportunity for knowledge-sharing among participants.

4.2.2. Alumni networks

Just as informal social networks are a key resource for students, so too, are more formal alumni networks. Students are given access to an updated directory-listing graduates who are known for actively helping fellow alumni. In a meeting with a recent grad who recently switched from consulting to starting his own healthcare IT startup, he described Polytechnique's alumni network as playing a critical role in helping him gain access to healthcare professionals and managers.

For current students, these networks open doors even before students leave campus. Exposure to the work and connections of alumni on campus occurs through formal and informal means. One example of an informal event is Startup Café, a student run gathering that invites alum working in a venture or entrepreneurial capacity in which they share with prospective students' stories of how they navigated building new ventures. Alum also serve as advisors on academic projects, including PSC projects, while others provide students with informal advice, industry connections or topic expertise. For students, finding alum is as easy as opening the directory and making a phone call. One student described the experience of calling an alum at a major company to ask for a project sponsor as simple and straight forward:

> “he knew how it worked at Polytechnique so it was easier to explain [things]” and then he met us and he explained that there was a small team working on innovation at [his company]… I think the [directory] with the former students plays a vital role for internships and projects like this”.

The benefits of working with alum have advantages that go beyond simply “opening doors”. Given their structured curriculum, and unique experience as students and military officers, former students are also inclined to understand the work process, skillset and general constraints of current Polytechnique students.

4.3. Gatekeepers feedback & funding

4.3.1. Feedback and mentorship

Sociologists established the concept of “gatekeeping” in the 1940s (Lewin, 1947; 1951). Though originally used to explain the forces of social change in communities the concept of gatekeepers has been explored in numerous fields including management, law, political science and information science (Barzilai-Nahon, 2008). In the case of PSC, gatekeeping takes place as faculty control access to information about funding and access to formal physical research and laboratory space.

Many teams worked independently for much of their project, conducting research that was independent of faculty or client needs (though student projects tended to overlap with the needs of collaborators). Of the students interviewed for this project, faculty advisors and clients (corporations, alum or private organizations and individuals) served as the primary source of feedback for students. Despite having minimal time with mentors and clients (1-3 times a month) students described their interactions with mentors as playing a pivotal role in helping them to: identify topics, define scope of projects and, most importantly, in helping them to identify whether or not their project was successful in the end.

Topic identification occurred early on in the project often with substantial guidance and feedback from advisors. During this period, students reported gaining the most benefit from advisors who provided teams with a research topic (often related to their own research) and helped teams focus their projects. In the final phase of their PSC work, teams reported advisors serving a key role as advocates who provided praise and encouragement while times advanced to the finish line.

The earliest engagement with advisors played a vital role in project development and learning, according to students. Early project deadlines forced students to communicate with teammates, advisors and clients for more information. Many described this (along with the last phase of work) as the period where they worked the most on the project.

Alternatively, some teams pointed to lack of feedback as detrimental to projects, with some students struggling to find time with industry advisors which led to lost time and lack of project direction.

4.3.2. Funding & resource constraints

Access to resources can have both negative and positive effects on opportunity identification by entrepreneurs (Hoegl, Gibbert and Mazursky, 2008). Numerous scholars have written on the role of resource constraint in driving innovation (Katila and Shane, 2005) and creativity.

The role of resource constraint amongst PSC interviewees provided an interesting glimpse at how access to funding influenced the scientific process. While the vast majority of student resources were intangible (mentorship, information, social networks), some interviewees also required financial funding for the purchase of equipment or materials related to their research projects. The speed of fulfillment and amounts of funding varied for interviewees.

Hardware and software funding were the primary cost for students working on projects that involved specialized modelling or coding. The speed at which funding was approved for these purchases varied for teams depending on whether or not groups had access to an advisor or research lab or department that could process the purchase.

In scenarios where costly materials were needed to complete a project, advisors played a critical role in advocating for approval of expenditure, said students. For example, in the case of project that required specialty math software, an instructor was able to get the students a copy of the program. For another team, which was building a physical prototype from scratch, interviewees said slow advisor approval of expenses delayed progress by weeks, said students. Teams seeking nominal amounts of funding, where students paid for the cost from their own pockets or the items being purchased could be later used by the department, were quickly reimbursed students reported.

While studies have looked at the effect of resources on aggregate scientific output, less has been written about the influence of resources on individual project development. From this research it is easy to see how slow funding for projects could ultimately change the speed and overall development of research, especially those involving hardware.

Overall, students voiced a lack of consistency and clarity on funding for PSC projects. While some projects cost had little to no budget, other students worked on projects that cost several thousand euros. Approval processes for each team project varied as well with some students citing advisors, departments or client partners as their main funding sources.

Students consistently spoke to the role of resource constraint in shaping the design and direction of their projects. By investigating the role of resources constraints within the PSC process, the result of this study adds to our understanding of action learning within the context of applied scientific research, revealing external constraints that influenced the scope, focus and final outcome of students' projects. Such constraints —which arguable ground student research with limitations reflective of the real world— offer participants a rare opportunity to practice scientific problem solving while also learning how to navigate physical, social and financial resources.

Of course, as students at one of the most respected school in France, it is likely that the findings from this study cannot be easily generalized across institutions. These results do, however, point to a need to explore further the influence of physical, social and financial resources on scientific inquiry. Would we find similar results at a school with weaker alumni organization? Would students in a more urban setting have access to more resources?

This exploratory study identifies several limitations of the PSC approach. Multiple factors shed the light on student's insufficient interest in further pursuing their projects: the lake of allocation of proper time and funding, the absence of clear pathway, the inexistence of sense of "ownership" due to intellectual property rules. Students end-up viewing entrepreneurial projects as being an activity not aligned with the school's priorities (i.e. new ventures are something created *after* receiving a Ph.D. or working in industry); This spectrum of factors finally hampers the rise of promising projects that could otherwise lead to the emergence of potential start-ups.

Conclusion & Discussion

Universities and colleges play a fundamental role as sources of scientific and economic innovation in the form of knowledge and the creation of technologies and highly skilled workforce. In this study we examined the case of action learning at Polytechnique where action learning is being used in the context of collaborative scientific research.

Through this research, several key insights emerged which reveal how action learning influences the outcomes of scientific research. Specifically, three key resources were identified as influencing the scope and outcome of student scientific research project:

1. *Physical Accessibility*—demonstrated through students' proximity to resources;
2. *Networks of Practice*—defined through two primary mechanisms a) informal student interactions b) alumni networks[5];
3. *Gatekeepers*—primarily through the role of advisors who control the level of a) feedback, and b) funding a team will receive.

These three findings offer preliminary discussion points on the barriers and opportunities of successful action learning projects within a fundamental science education setting. PSC student projects were motivated and shaped by constraints that could also be faced by business, entrepreneurship or management teams using action learning approaches.

While action learning has long been associated with problem-based learning (Marquadt and Wadille, 2004), there is an opportunity to further connect the approach to the existing education and action learning literature. This is especially

[5] The school's unique and powerful alumni network allowed Polytechnicians to transcend the barriers of being removed from urban resources. But even with their robust network and connections, PSC participants still faced funding and resource barriers that slowed the development of some projects.

true given an interest within the education literature in exploring alternatives to objectivist learning approaches in the sciences[6]. Interest in the education literature on constructivist approaches offers an opening for scholars to examine how action learning techniques could be useful in college-level science education.

The entrepreneurial behaviour (ex. refocusing projects based on funding, leveraging professional networks and partnerships with private sector partners) of PSC participants illuminates an opportunity for further study of how entrepreneurship can be integrated as a constructivist approach to science education.

As scientific research and opportunities for student projects grow, there will be an opportunity to learn more from programs that promote entrepreneurial problem solving within science education. Further study of PSC and similar programs—in a diversity of countries and academic systems—could provide a productive path for expanding the existing action learning literature while shedding further insight on constructivist approaches to science education.

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References

Albers C. (2008). "Improving pedagogy through action learning and scholarship of teaching and learning", *Teaching Sociology,* Vol. 36, No. 1, pp. 79-86.

Barzilai-Nahon K. (2008). "Toward a Theory of Network Gatekeeping: A Framework for Exploring Information Control" *Journal of the American Society for Information Science and Technology*. Vol. 59, No. 9, pp. 1493-1512.

Brook C. (2012). "Some debates and challenges in the literature on action learning: the state of the art since Revan" *Human Resource Development International,* Vol. 15, No. 3, pp. 269-282.

[6] Constructivists assert that learning approaches should allow learners to build upon personal, previous experiences, and that "knowledge is not primarily received, but actively built and that the function of is adaptive and serves the organization of the experiential world" (von Glasserfeld, 1987.) The literature points to instances of constructivist approaches including increased facilitation by teachers, quiz-based group learning and action research (An NSTA Press, 2002) which suggest that science practitioners are looking increasingly to active learning approaches in the classroom.

Brook C., Pedler M. and Burgoyne J. (2012). “Some debates and challenges in the literature on action learning: the state of the art since Revans”, *Human Resource Development International,* Vol. 15, No. 3, pp. 269-282.

Brown J.S. and Duguid P. (2000). *The Social Life of Information*, Harvard Business School Press, Boston.

Dilworth R. L. and Willis V. J. (2003). *Action learning: images and pathways*, Krieger, Malabar.

Gieryn T.F. (2008). “Laboratory design for post-Fordist science” *Isis*, Vol. 99, No. 4, pp. 796-802.

Holloway M.S. (2004). “The use of cooperative action learning to increase music appreciation students' listening skills”. *College Music Symposium*, The College Music Society.

Hoegl M., Gibbert M. and Mazursky D. (2008). “Financial constraints in innovation projects: When is less more?” *Research Policy,* Vol. 37, No. 8, pp. 1382-1391.

Katila R. and Shane S. (2005). “When does lack of resources make new firms innovative?”, *Academy of Management Journal*, Vol. 48, No. 5, pp. 814-829.

Kettunen J. (2011). “Innovation pedagogy for universities of applied sciences”, *Creative Education,* Vol. 2, No. 1, pp 56-62.

Kolb A. and Kolb D. (2005). “Learning styles and learning spaces: Enhancing experiential learning in higher education”, *Academy of management learning & education,* Vol. 4, No. 2, pp. 193-212.

Kremer M. and Williams H. (2010). “Incentivizing innovation: Adding to the tool kit” *Innovation Policy and the Economy*, Vol. 10, pp. 1-17.

Leonard W.H. (2000). “How do college students best learn science?” *Journal of College Science Teaching,* Vol. 29, No. 6, pp. 385-388.

Lewin K. (1947). “Frontiers in Group Dynamics: II. Channels of Group Life; Social Planning and Action Research”, *Human Relations*, 1, pp. 143-153. Lewin, K. (1951) *Field Theory in Social Science: Selected Theoretical Papers*, Harper, New York.

MacNamara M., Meyler M. and Arnold A. (1990). “Management education and the challenge of action learning”, *Higher Education,* Vol. 19, No. 4, pp. 419-433.

Malinen A. (2000). *Towards the essence of adult experiential learning: a reading of the theories of Knowles, Kolb, Mezirow, Revans and Schon*, University of Jyväskylä.

Marquardt M. (1998). “Using action learning with multicultural groups”, *Performance Improvement Quarterly*, Vol. 11, No.1, pp. 112-127.

Marquardt M. (2003). “Developing global leaders via action learning programs: a case study at Boeing”, *Thai Journal of Public Administration*, Vol. 3, No. 3, pp. 133-157.

Marquardt M. and Waddill D. (2004). “The power of learning in action learning: a conceptual analysis of how the five schools of adult learning theories are incorporated within the practice of action learning”, *Action Learning: Research and Practice,* Vol. 1, No. 2, pp. 185-202.

Marshall A. (1920). *Principles of Economics. Library of Economics and Liberty*, MacMillan, London.

Marsick V.J. (1998). “Transformative learning from experience in the knowledge era” *Daedalus*, Vol. 127, No. 4, pp. 119-136.

Marsick V. J. (1992). “Experiential-based executive learning outside the classroom”, *Journal of Management Development*, Vol. 9, No. 5, pp. 50–60.

NSTA (2002). “Innovative techniques for large-group instruction”, National Science Teachers Association Press.

Pan Suk K. and Jongsoon J. (2008). “Action learning and its applications in government: The case of South Korea”, *Public Administration Quarterly,* pp. 193-213.

Pedler M. (Ed.) (1997). *Action learning in practice*, Gower, Aldershot.

Raelin J.A. (1997). “Action learning and action science: are they different?” *Organizational Dynamics,* Vol. 26, No. 1, pp. 21-34.

Rasmussen Einar A. and Sørheim R. (2006). “Action-based entrepreneurship education” *Technovation*, Vol. 26, No. 2, pp. 185-194.

Revans R. (1980). *Action Learning: New Techniques for Management*, Anchor Press, London.

Revans R. (1982). *The origin and growth of action learning,* Chartwell-Bratt, London.

Revans R. (1984). *The Sequence of Managerial Achievement.* MCB University Press, Bradford.

Revans R. (1991). “Action Learning and the Third World”, *The International Journal of Human Resource Management,* Vol. 2, No. 1, pp. 73-91.

Revans R. (1998). *ABC of Action Learning,* Lemos and Crane, London.

Reynolds M. and Russ V. (2004). “Critical Management Education and Action-Based Learning: Synergies and Contradictions”, *Academy of Management Learning & Education*, Vol. 3, No. 4, pp. 442-456.

Von Glasserfeld E. (1987). *Learning as a constructive activity. In Problems of Representation in the Teaching and Learning of Mathematics*, ed. C. Janvier. Hillsdale, New Jersey.

Shaheen R. (2010). “Creativity and education”, *Creative Education*, Vol. 1, No. 3, pp. 166-169.

Souitaris V., Zerbinati S. and Al-Laham A. (2007). “Do entrepreneurship programmes raise entrepreneurial intention of science and engineering students? The effect of learning, inspiration and resources”, *Journal of Business Venturing,* Vol. 22, No. 4, pp. 566-591.

Sydow J., Lindkvist L. and DeFillippi R. (2004). “Project-based organizations, embeddedness and repositories of knowledge: Editorial”, *Organization Studies*, Vol. 25, No. 9, pp. 1475-1489.

Yeo R.K. and Gold J. (2011). “The inseparability of action learning: unraveling Revans’ action learning theory for Human Resource Development”, *Human Resource Development International*, Vol. 14, No. 5, pp. 511-526.

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