FACULTY BELIEFS AND ORIENTATIONS TO TEACHING AND LEARNING IN THE LAB: AN EXPLORATORY CASE STUDY

by

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To my beloved family, Cristina, Clara, and Gui.

Without your support and love, this "American Adventure" would not be possible.

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ABSTRACT

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Laboratory education plays a paramount role in the education of engineers and engineer technologists. Laboratories allow students not only to learn essential concepts and principles, but also to develop fundamental skills to solve complex problems, work with complex systems, communicate effectively, work in teams, and reflect on the societal consequences of engineering activities. Also, engineering education labs have benefitted from the use of educational innovations such as the use of project- and problem-based learning approaches. Furthermore, virtual and remote technologies now contribute to the enrichment of the lab activities. However, despite these innovations, prior research indicates that the potential of laboratory education is not often fully explored by engineering and engineering technology educators. Among the main reasons for that situation, research indicates, is the influential role of faculty beliefs on the faculty decision-making processes.

This dissertation presents a two-phase multiple case study conducted to investigate the faculty beliefs regarding the integration of labs into engineering and engineering technology education and the relationship between such beliefs and the teaching practices adopted in the labs. In the first phase, an exploratory study grounded on a framework of beliefs was conducted to elicit the beliefs espoused by the participants. Interviews were used to elicit the participants' beliefs. The transcribed interviews were analyzed through the constant comparative method. Thirteen faculty members from the College of Engineering and Engineering Technology participated. In the second phase, a triangulation approach was used to investigate the relationships between the participants' beliefs and their corresponding teaching practices. The findings from phase one were triangulated with the data from interviews, questionnaires, and documents to elicit the relationships between beliefs and practices.

The results from phase one were arranged in nine different categories of beliefs and five orientations to teaching and learning in the labs. The orientations to teaching and learning in the labs reflected the idealistic beliefs espoused by the participants which could be related to their respective teaching practices. However, phase two revealed that if on the one side, the alignment between beliefs and practices is possible, on the other side, a series of tensions and mediating factors may cause difficulties or even prevent such alignment. Thus, a discussion about these tensions and mediating factors is presented to shed light on how the beliefs, together with the socio-cultural context may affect the teaching and learning processes in the labs. In conclusion, I present the implications of these findings for instruction, policy and professional development programs.

CHAPTER 1. INTRODUCTION

1.1 Background

Laboratory education plays an essential role in the education of skilled engineers (Sheppard, Macatangay, Colby, & Sullivan, 2008). Laboratories allow students not only to learn important concepts and principles, but also to develop fundamental skills to solve complex problems, work with complex systems, communicate effectively, work in teams, and reflect on the societal consequences of engineering activities (Feisel & Rosa, 2005; Wankat & Oreovicz, 1993). Indeed, the use of laboratories in engineering education in the U.S goes back to the first engineering courses offered in formal education. The Mann Report (1918), a historical document that described important characteristics of engineering education since its first steps in the United States, made strong claims about the use of laboratory work as a way to foster students' ingenuity and creativity. This report also revealed that the pedagogical approaches adopted in laboratories of many engineering courses were not appropriate to develop such skills. In other words, Mann presented a critique on the limited effectiveness of the traditional use of laboratories in engineering education that relied on cookbook instructions followed by a common report.

Since the seminal work of Mann, educational and pedagogical innovations have helped to transform the way laboratories are used in engineering education. Today, educators almost unanimously recognize that laboratories are essential in any engineering curriculum (Feisel & Rosa, 2005; Wankat & Oreovicz, 2015). Educators have also agreed on laboratory affordances to help students learn not only important engineering principles, but also develop essential engineering skills such as design, instrumentation, modeling, and data analysis, among others (Feisel & Rosa, 2005). Beyond traditional laboratory pedagogy, several approaches have been developed and successfully used in laboratory education (Domin, 1999; Prince & Felder, 2006, 2007). Project- and problem-based learning, inquiry-based learning, and discovery learning, among other active-learning approaches, make the use of labs more efficient and motivating for students (Alfieri et al., 2011; Gibbings, Lidstone, & Bruce, 2015; Jean, 2014; Uribe, Magana, Bahk, & Shakouri, 2016). In addition, new technologies are now pervasive in laboratories. The traditional hands-on lab is now sharing space with virtual and remote laboratories (Heradio et al., 2016; Ma

& Nickerson, 2006). The use of these technologies seems to create unlimited possibilities regarding students' learning experiences and helps educators overcome some of the limitations of hands-on laboratories, including cost and accessibility considerations (Machet, Lowe, & Gütl, 2012; Maiti, Maxwell, & Kist, 2014).

1.2 Statement of the Problem

Despite important advances in technology and pedagogy, laboratory education seems to face the same problems that affect Science, Technology, Engineering and Mathematics (STEM) education in general. These problems can be summarized by a lack of adoption of educational innovations in STEM fields (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Froyd, 2011; Seymour, DeWelde, & Fry, 2011a). Indeed, recent studies indicate that a large part of laboratory education still relies on traditional practices based on cookbook instructions; and very often, these practices do not explore the full potential of laboratories as an educational tool (Duderstadt, 2008; Seymour, DeWelde, & Fry, 2011b; Sheppard et al., 2008). Sheppard and her colleagues, in a study of more than a hundred universities in the U.S., revealed that most laboratory activities focused on complementing lectures instead of developing important engineering skills (2008). Similarly, Duderstadt (2008) argued that current laboratory courses are "of questionable utility for teaching the most important technical skills of engineering: the integration of knowledge, synthesis, design, and innovation" (p. 33).

For institutions in higher education, the creation of laboratories represents a considerable investment, not only in equipment, but also in infrastructure such as large buildings that require compressed air, electricity, and water supply, among other things (Abdulwahed & Nagy, 2014; Achumba, Azzi, Dunn, & Chukwudebe, 2013; Bhargava, Antonakakis, Cunningham, & Zehnder, 2006). The use of educational labs also requires investment in staff and faculty development, and it demands faculty dedication and time to prepare instructional materials and develop the instructional design (Magana & Silva Coutinho, 2017). Laboratory activities are often more time consuming than traditional lectures, and that fact is not always recognized by institutions.

Therefore, it is fundamental to understand why laboratories, despite the considerable investment, seem to fail in developing engineering skills among students. While a significant part of the current literature in the field seems to focus on exploring the characteristics and affordances of different types of laboratories, including physical, remote and simulation labs (e.g., Heradio et al., 2016; Ma & Nickerson, 2006), this study investigated another important component of the learning equation: the faculty. Indeed, as reported by Jamieson and Lohman (2012), the faculty are those ultimately responsible for the implementation of pedagogical innovations in classrooms or laboratories. In their executive summary, these authors argued, "While a quality higher education experience involves many stakeholders, the responsibility for the quality of the engineering educational experience rests with the engineering faculty and administration"(Jamieson & Lohman, 2012, p. 6).

1.3 The importance of laboratories in engineering education

> *Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of humankind.* (Duderstadt, 2008, p. 24)

As we can see from Duderstadt`s definition, reflecting the conceptions of many engineering societies, engineering is a very applied profession that requires individuals to integrate different domains of knowledge and different skills in order to build the world we live in. In addition to this broad definition, ABET established a set of outcomes that all engineering baccalaureate graduates should possess. They are (ABET, 2015):

(a) an ability to apply knowledge of mathematics, science, and engineering;
(b) an ability to design and conduct experiments, as well as to analyze and interpret data;
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, and political, ethical, health and safety, manufacturability, and sustainability;
(d) an ability to function on multidisciplinary teams;
(e) an ability to identify, formulate, and solve engineering problems;

(f) an understanding of professional and ethical responsibility;

(g) an ability to communicate effectively;

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;

(i) a recognition of the need for, and an ability to engage in, life-long learning;

(j) a knowledge of contemporary issues; and

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

A critical analysis of these students' outcomes stresses the importance of the practice in the education of engineers. This practice can be naturally and safely provided by laboratory activities. The following section discusses some of these intended outcomes in the light of the learning experiences that can be developed in laboratories.

1.3.1 Application of mathematics, science and engineering knowledge

Laboratory experience allows students to apply their knowledge of mathematics, science, and engineering. Indeed, the laboratory is a place where students get in contact with practical applications of engineering. It is a place where students have opportunities to perform tasks in a very safe way, free from the uncertainties and possibly unsafe conditions of the real world. The best way to learn how to apply knowledge is through applied problems, in which students have opportunities to play the "whole game" of engineering (Perkins, 2009). There is no better and safe place to practice engineering than in the laboratory. In a laboratory setting, students can be in contact with different equipment and perform tasks as if they were in real situations. To help students learn how to apply knowledge to solve problems, instructors should assign activities that lead students to use the different laboratory resources such as instruments, machines, and computers. In sum, the laboratory links theory and practice. Through manipulation, test, exploration, and discovery, students have opportunities to not only validate the theories learned in the classroom but also to explore new ideas and connections between theory and practice. This exploratory space, the lab, helps students to relate concepts and principles with the real world and, thus, provides conditions for a deep understanding of those concepts and principles.

Beyond improving conceptual understanding, laboratories also allow students to learn to solve more hands-on and concrete engineering problems. In courses without laboratory activities, on the other hand, students usually learn by reading textbooks, taking notes from lectures, and solving abstract problems that barely resemble the real problems engineers face in professional spaces. This learning process leads students to what Sheppard and her colleagues (2009) called “knowing that” (the learning of principles, theories, and concepts) in opposition to “knowing how” (the learning of how, when, where, and why to use theories and principles to solve problems). To know how, students must face real challenges that make them reflect, research, plan, design a solution, collect and analyze data, make decisions and conclusions, and present a solution. The lab makes many of these activities possible. In the lab, students can apply their knowledge by manipulating equipment, gathering and analyzing data to verify hypotheses and theories, building prototypes, simulating reality, and many other activities that would be impossible without the safe and real space of the labs.

1.3.2 Working in teams and communication skills

Since engineering work requires extensive collaboration (Bucciarelli, 2003), communication skills are essential to the profession (NAE, 2004). Laboratory work also provides opportunities for students to work in teams and develop important social skills such as teamwork. Some scholars may argue that group activities performed in general classes also engage students in collaborative work. However, in laboratories, the collaborative work goes beyond solving hypothetical problems. In the labs, students must deal with practical applications, with real problems. In laboratories, students may have to deal with the tensions that arise when working with real life situations, including a scarcity of resources, troubleshooting, task management, and decision making. In addition, laboratory work results typically in student-generated reports describing activities, analysis and results. Student presentations are also very common. Thus, laboratory experiences foster the students’ ability to function on multidisciplinary teams and help students develop communication skills. Students literally “learn by doing.”

1.3.3 Supporting cognitive development

Laboratory activities support students’ cognitive development and foster the progression to higher levels of reflective judgment. Sheppard and colleagues (2008) asserted that engineering students usually enter academia still in an early phase of cognitive development, and the educational process plays a fundamental role in the professional and individual development of these students. Reflective judgments, as described by King and Kitchener (1994), “are the judgments individuals make about ill-structured problems for which there are multiple possible solutions.” This type of judgment is essential to engineering professions and helps engineers deal with problem-solving and design activities. Thus, engineering education must facilitate students’ progression from a low level of reflective judgment, at which they believe knowledge to be fixed and absolute, to the highest level of critical thinking, where they acknowledge that knowledge is a result of the inquiry, evaluation, synthesis, and argumentation. Well-designed laboratory activities may allow students to get involved in situations in which inquiry and investigation, analysis and synthesis, discussion and critique are at the core of the learning process. For example, instead of using cookbook exercises where students just follow instructions without any critical judgment, educators may present a problem and ask students to evaluate the many possible solutions through the use of the laboratory resources. This latter approach would go beyond the traditional validation of theory or acquisition of conceptual understanding. I should note that the transition from low levels of reflective judgment to the highest levels requires a long process and may be achieved through well-designed engineering programs.

1.3.4 Professional practice

Laboratory education promotes learning of professional practice. New approaches to engineering education acknowledge the importance of laboratory activities as an essential component to provide professional practice to students (Clive et al., 2005; Feisel & Rosa, 2005; Ionescu, 2015). In fact, laboratories are much more than just a place where lectures are reinforced. Laboratories usually offer an expensive structure that may include equipment, machines, computers, and all the sort of things necessary to the conduct of experiments as if students were in a working space (Lima, Alves, & Viegas, 2015). Laboratories may also help students to learn design (Clive et al., 2005; Dallas, Berg, & Gale, 2012). Within a lab environment, students may have opportunities to perform activities by integrating the knowledge already acquired in previous studies with new knowledge and skills to solve real-life problems.

1.3.5 Student motivation

Laboratory activities play a crucial role in students' motivation (Koh et al., 2010; Krivickas & Krivickas, 2007; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011; Salim, 2013). Motivation, in turn, plays a fundamental role in student learning (Eccles & Wigfield, 2002; Pintrich, 2003; Schunk & Pintrich, 2002; Wen-jin, Chia-ju, & Shi-an, 2012). Thus, we can conclude that laboratory activities play a critical role in student learning. In fact, research on motivation reveals that students feel more motivated to learn when they engage in activities that connect theory and practice using real-world problems (Smith, Sheppard, Johnson, & Johnson, 2005). Thus, laboratory activities provide a confluence of all these factors which foster students' learning.

In sum, the integration of laboratories in undergraduate engineering education helps educators to support students' development of competencies that otherwise would be lost in lecture-based courses. These competencies are normally developed when students learn by doing; by experimentation; by discovery and exploration; by trial, error, and failure; by working in teams; by creating, evaluating and solving real world (practical) problems. Thus, laboratory education helps students learn because it leads students to go beyond the theory. The laboratory helps educators bring the real world to the school environment.

1.4 Faculty attitudes toward laboratory education

Research on faculty attitudes toward teaching indicates that faculty decisions regarding educational practices are influenced by different factors including individual, institutional and external factors (Coutinho, Stites, & Magana, 2017). Individual factors include faculty beliefs about students' learning, as well as personal experiences and background (e.g., Oleson & Hora, 2014). Institutional factors include departmental culture (Campbell & O'Meara, 2014; O'Meara, Terosky, & Neumann, 2008), reward systems (Lagowski, 1994; O'Meara, 2011), logistical constraints and supports (Hora, 2012), and type of institution (Beddoes, Jesiek, & Borrego, 2010; Bland, Center, Finstad, Risbey, & Staples, 2006). Finally, external factors include professional societies, accreditation bureaus, and funding agencies, among others (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Jamieson & Lohmann, 2012). While these studies reveal important influences on the faculty decision-making process, they often do not address laboratory education as an essential and usually independent component of the curricular design. Indeed, there are few studies reporting how faculty plan, conduct and assess laboratory instruction in undergraduate engineering education (Dumon & Pickering, 1990; Feisel & Rosa, 2005; Lee, 1972).

Although there is scant literature on faculty decision making processes regarding laboratory education, a significant body of literature indicates the strong influence of faculty beliefs on instructional practices (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Hora, 2014; Pajares, 1992; Samuelowicz, 1999; Samuelowicz & Bain, 2001). For example, Gess-Newsome and colleagues (2003) investigated how faculty beliefs mediate reform efforts in the US. The authors found a strong consistency between the instructors' beliefs and their corresponding teaching practices. Similarly, Trigwell, Prosser, and Taylor (1994) found that faculty who believed that teaching is the transmission of information adopted teacher-centered approaches, while those who believed in conceptual development or change chose student-centered strategies. What is not clear in the literature is whether and how these beliefs affect faculty decisions regarding laboratory education.

Furthermore, engineering education research in the US spans two different but closely related types of degree programs: engineering and engineering technology. ABET defined two separate sets of student outcomes and created two different accreditation commissions (see www.abet.org) to distinguish these programs. Although different, the two sets of student outcomes have strong similarities, and it is important to investigate how these differences reflect on the beliefs and instructional practices of the faculty within the two programs. In addition, faculty in these programs may have similar backgrounds such as graduation in engineering programs, and master's or Ph.D. degrees in engineering. Table 1.1 compares the criteria proposed by ABET for engineering and engineering technology programs. While engineering programs focus on the theory and conceptual design, engineering technology programs must focus on application and implementation.

Table 1.1 Similarities in ABET criterion 3: Student outcomes

Engineering	Engineering Technology
(a) an ability to apply knowledge of mathematics, science, and engineering;	(a) an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities; (b) an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
(b) an ability to design and conduct experiments, as well as to analyze and interpret data;	(c) an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, and political, ethical, health and safety, manufacturability, and sustainability;	(d) an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
(d) an ability to function on multidisciplinary teams;	(e) an ability to function effectively as a member or leader on a technical team;
(e) an ability to identify, formulate, and solve engineering problems;	(f) an ability to identify, analyze, and solve broadly-defined engineering technology problems;
(f) an understanding of professional and ethical responsibility;	(i) an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
(g) an ability to communicate effectively;	(g) an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature;
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;	(j) a knowledge of the impact of engineering technology solutions in a societal and global context;
(i) a recognition of the need for, and an ability to engage in, life-long learning;	(h) an understanding of the need for and an ability to engage in self-directed continuing professional development;
(j) a knowledge of contemporary issues;	
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	(k) a commitment to quality, timeliness, and continuous improvement.

1.5 Research Questions

Recognizing the importance of laboratory education to the education of skilled engineers, and being aware of the relevant advancements not only in terms of new pedagogical approaches but also in terms of the integration of new technologies, I made the case that laboratory education is not often exploring the full potential of instructional laboratories. Among the potential reasons for that situation, faculty beliefs seem to play a significant role in faculty decisions regarding instructional practices in the laboratory. This hypothesis is supported by a series of studies both in K-12 and higher education that indicate a relationship between teachers and faculty beliefs and instructional practices (Hativa, 2000b; Pajares, 1992; Simmons et al., 1999). However, these studies were conducted in classroom settings, and none of them explored faculty beliefs about laboratory education and how these beliefs relate to instructional practices in laboratories. Therefore, the purpose of this study is to investigate the faculty beliefs regarding the integration of laboratories into engineering education. In addition, I will investigate the relationship between faculty beliefs and their instructional practices. To do that, I will investigate the following research questions:

1. What are the faculty beliefs about the integration of laboratories into engineering education?
2. How do faculty beliefs relate to their current teaching practices in laboratory education?

1.6 Relevance

This study contributes to a broader discussion about the diffusion of innovations and change in engineering education. Currently, the engineering education community is searching for answers to explain the low rate of adoption of innovative teaching practices in engineering (Besterfield-Sacre et al., 2014; Froyd, 2011; Seymour, DeWelde, & Fry, 2011). Siddiqui and Adams (2013) argued that

> There is a sense of frustration in the engineering education community that despite a good awareness within the community for improved educational goals and practices, as well as significant research-based support for the effectiveness of such practices, the level of change in education is limited and slow. (p. 1).

While some scholars search for answers using a framework of diffusion of innovations (Froyd, 2011; Lattuca, 2011; Rogers, 2003), and explore different ways through which the educational innovations propagate within the community, another group of researchers calls for attention to the importance and role of the educators (Siddiqui & Adams, 2013). Siddiqui and Adams (2013) argued that initiatives toward change in engineering education must focus on transforming faculty beliefs and values in the process of transformative learning. Matusovich and colleagues (Matusovich, Paretti, McNair, & Hixson, 2014) stressed the importance of faculty motivation in the change process. This study will explore the beliefs, values and motivational factors that affect faculty decisions regarding laboratory education. The findings will support the development of new initiatives, including professional development programs and policies, which contribute to a change in the laboratory instruction in undergraduate engineering education.

1.7 Structure of the Dissertation

This dissertation presents a study aimed to investigate faculty beliefs regarding laboratory education in undergraduate engineering programs. The study is grounded in a two-phase multiple case study design. In the first phase, an exploratory study answers the research question one focused on identifying faculty beliefs about laboratory education. The second phase incorporates additional data from participants to triangulate their beliefs with practices.

Chapter one discusses the context of the study, the research questions, the relevance of the study, and reinforces the importance of laboratory education to prepare engineering graduates with the skills and attitudes demanded by society.

Chapter two presents the literature review, which first introduces a historical perspective on the integration of laboratories into engineering education and then reviews current trends in the literature. Next, I present some critique regarding the use of laboratories in U.S. engineering programs and discuss how important scholars view the lack of innovations in engineering education. I conclude the chapter by highlighting the paramount role of faculty beliefs in the adoption of innovations in engineering education.

Chapter three discusses the theoretical frameworks that supported this study. First, I present some definitions associated with the concept of "belief" and then discuss some theories about beliefs and its role in educational settings. Finally, I present the orientations to teaching and learning framework which guided the interview protocol development and provided additional background for the data analysis.

Chapter four discusses the research design and details of the research methods. First, I present the research design. Second, I present the two phases of this multiple case study. The first phase aimed to answer the research questions one. In this phase, I used interviews as a method of data collection, and the constant comparative method to conduct the data analysis. The second phase aimed to answer the research question two. In this phase, a triangulation approach was used to analyze how beliefs and teaching practices were related. Thirteen individual cases were analyzed. The primary data sources were the interviews conducted on phase one, and educational documents such as syllabi, manuals, and lab assignments. The documents were analyzed using content analysis. Triangulation was used to analyze the relationships between beliefs and practices, and also to reinforce the trustworthiness of this study.

Chapter five explores the faculty beliefs regarding the integration of labs into engineering and engineering technology education. It describes the characteristics and findings from phase one. First, I summarize the methods of data collection and data analysis. Second, I present the findings in terms of nine categories of beliefs. Then, using a qualitative approach, the participants' patterns of beliefs were grouped and arranged in five different orientations to teaching and learning in the labs. These orientations and the respective beliefs were compared to identify similarities and divergences between participants from the colleges of engineering and engineering technology.

Chapter six explores the relationships between faculty beliefs and their teaching practices in the labs. It describes the characteristics and findings from phase two. First, I summarize the methods of data collection and data analysis. Second, I present the findings of the thirteen cases studied, followed by a discussion regarding the similarities and differences between the cases. In addition, I present different factors that seem to mediate the relationship between beliefs and practices.

In Chapter seven, I provide a larger discussion regarding the study, and its implications. I frame the discussion in five main areas, including the relation between the findings and other relevant studies in the literature, and implications for educators, policy-makers, and faculty and staff professional development.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview

This chapter reviews the literature related to the integration of laboratories into engineering education. Section 2.2 presents a short historical perspective based on important reports that helped to shape engineering education in the United States. Section 2.3 describes some pedagogical approaches and their impacts on laboratory education. Section 2.4 discusses current trends in the literature about the integration of labs into engineering education. Section 2.5 reports findings from two relevant research scholar studies conducted to explore the engineering education system in the United States. Finally, section 2.6 provides a rationale for the importance of studying faculty beliefs about laboratory education.

2.2 Historical perspective

The use of laboratories in engineering education in the U.S. dates back to the times of the first engineering courses. The Mann Report (1918), a historical document that described essential characteristics of engineering education since its first steps in the United States, helps us to understand some of the traditions in laboratory work that persist until now. According to this report, laboratory work has been used as a supplement to lectures since the very beginning of engineering education in the United States. Laboratories have also been described as places where students "reproduced standard reactions, measured known constants, verified theories, visualized principles, and acquired skill in manipulating delicate instruments" (Mann, 1918, p.37). Mann also described some pedagogical approaches adopted in engineering education laboratories of that time. He wrote,

> The course consisted of a series of simple experiments illustrating fundamental principles or scientific methods of study and involving the use of important instruments. The administration of the work was made practicable by having complete apparatus for each instrument ready for use together with carefully prepared written directions for its correct manipulation. When a class entered the laboratory, each member received a number directing him to the apparatus and written directions for making the required measurements

> and recording the results. In this way, Professor Pickering was able to care for a class of twenty-five students at one time, because, as he himself tells us, the written directions prevented the students from making serious mistakes. (p. 37)

Although Mann seemed to be an enthusiast of the ideas of Pickering (Mann, 1918), he also described some weaknesses of this approach. He wrote,

> In the laboratory work, the methods and aims defined by Professor Pickering in 1869 are still dominant everywhere. About one-third of his original experiments are still in use, and the new ones that have been introduced have as their objects the verification of some known law, the visualization of some known fact, or the determination of some known constant. When the same experiments are used year after year, as is the case at most schools, the students soon discover that the number of failures and low grades in physics can be materially reduced if the results of the physics experiments are carefully preserved from year to year and judiciously used as occasion may require. Projects of the form "Which of these S electric motors is the best for the price?"—A question that cannot be answered without making the experiment—are almost never used. The prevailing type is "Measure the efficiency of this electric motor." In other words, physics instruction, like that in chemistry, aims to stock the student's mind with information as preparation for solving real problems should they ever arise. (p. 40)

In his final recommendations, Mann suggested that laboratory work must be used in a more applied fashion; that is, through problems and projects linked to real-world situations. In a very similar critique, William Wickenden (Society for the Promotion of Engineering Education, 1930), who presented a comparative study of engineering education in Europe and in the United States, argued that at that time students were spending much time in “manipulating, observing, descriptive writing and compiling, but little on the critical analysis of the project.” (p. 259)

In 1955, the well-known Grinter Report (Grinter, 1955) stressed the importance of science and mathematics in the engineering curriculum. This report was a result of a deep evaluation of engineering education, and proposed a series of actions that still influence engineering education in the U.S. (Froyd, Wankat, & Smith, 2012; Harris, DeLoatch, Grogan, Peden, & Whinnery, 1994; Lucena, Downey, Jesiek, & Elber, 2008). Regarding laboratory education, this report criticized both “the value of a set of stereotyped experiments” (Harris et al., 1994, p. 82), and also the stereotyped reports. To Grinter and his committee, “the development of a smaller number of experimental problems by the students themselves under effective guidance will have much greater educational value.” (p.82)

In another American Society for Engineering Education (ASEE) report, Walker, Pettit, & Everitt (1968) anticipated the impact of the technology in higher education but stressed the lack of adoption of educational innovations in engineering education. Among their critiques, these authors mentioned the extensive use of the “ten-year old cookbook experiments.” (p.394) In a similar way, the advisory committee to the National Science Foundation Directorate for Education and Human Resources, after analyzing over 150 letters from leaders in science, mathematics, engineering and technology community, listed the poverty of traditional cookbook laboratory approaches as one of the main barriers to improvement of engineering undergraduate education in the U.S. (National Science Foundation, 1996).

During the first ten years of the twenty-first century, the tradition of studies and reports proposing a change in engineering education continued and reinforced the views of the prior reports (e.g., National Academy of Engineering, 2005; National Research Council, 2003a, 2003b; PCAST, 2012). For example, in a report to the President, the President’s Council of Advisors on Science and Technology stressed the importance of laboratory instruction and called for the replacement of traditional laboratory courses with more innovative approaches. According to them, “Traditional introductory laboratory courses generally do not capture the creativity of STEM disciplines. They often involve repeating classical experiments to reproduce known results, rather than engaging students in experiments with the possibility of true discovery.” (p.4). This report describes almost the exact same problem with laboratory education as Mann in 1918.

As discussed above, during the last hundred years, a series of reports have helped to shape engineering education in the U.S. These reports, have reflected different times and societal needs. These reports have also depicted the contemporary status of engineering education, proposed actions that in a greater or lesser degree, influenced and transformed engineering education in the United States. As a common characteristic, these reports criticized the use of old practices in laboratory education and recommended the adoption of innovations that could lead students to advance their engineering skills.

2.3 Pedagogical Approaches in Laboratory Education

During the late 20th Century, a series of new pedagogies arose to support the kinds of learning that lecture-based pedagogy could not adequately foster. Among these pedagogies, problem-based learning, project-based learning, inquiry-based learning, and discovery learning were identified as well-suited to laboratory education. Together with the traditional laboratory approach, new laboratory pedagogies have been successfully used in different domains such as science (de Jong, 2006), health (Wood, 2003), and engineering (Prince & Felder, 2007). This section discusses the main characteristics of these laboratory pedagogies.

2.3.1 Traditional approach to laboratory education

In general, laboratory work has been seen as a complementary activity to support the theoretical components of engineering courses (Grinter, 1955; Sheppard, Macatangay, Colby, & Sullivan, 2008). This traditional approach comprises lectures and lab activities. During the lab activities, students have to conduct a series of cookbook or well-structured instructions as defined in the laboratory manuals. Students have to record the data, do some analysis, and write up a report. According to Sheppard et al. (2008), this type of instruction is appropriate for low-level engineering science courses and aids the learning of fundamental concepts. Similarly, Wankat & Oreovicz (2014) stressed that cookbook instructions might be satisfactory for developing psychomotor skills. However, this approach has limitations. Some educators have been exploring new ways to improve the learning outcomes of the laboratory experiences and overcome these limitations of the traditional approach. For example, Abdulwahed and Nagy (2014) investigated how the different modes of student preparation impact students' outcomes. Results indicate that pre-laboratory sessions with a teaching assistant and preparation via virtual laboratory and laboratory manual are more effective than other modes that either do not include the support of a teaching assistant or do not provide the laboratory manual. These findings may reinforce the importance of the lab preparation on students' learning. However, this approach still does not solve the problem associated with the limited ability of traditional laboratory pedagogy in developing skills such as design, modeling, and creativity (Feisel & Rosa, 2005).

2.3.2 Problem- and project-based learning

In problem-based learning, the learning occurs during students' "process of working toward the understanding or resolution of a problem." (Barrows & Tamblyn, 1980, p. 1). In project-based learning, students are challenged to work on a project that addresses a specific design challenge (Mäenpää, Tarkoma, & Vihavainen, 2015; Smith, Sheppard, Johnson, & Johnson, 2005). As described by Sheppard et al. (2008), "Unlike theory classes or cookbook laboratory exercises, open-ended or project-based laboratories do not offer a clean and clear-cut process of problem-solving. Often students must first make a diagnosis of the problem before deciding on their experimental approach" (p. 65). Smith et al. (2005) argued that problem-based and project-based approaches promote deep learning and higher levels of student engagement. Problem- and project-based pedagogies foster the development of important engineering skills. Gassert et al. (2013) used a project-based laboratory approach to support the development of modeling, design and optimization skills. Students were asked to "evaluate and design safe and efficient assistive and rehabilitative robotic systems." (p. 10) Results indicated that the students not only developed engineering skills but also increased the conceptual understanding of robotics systems. Koretsky, Amatore, Barnes, and Kimura (2008) adopted a problem-based approach to promoting learning of experimental design. These authors used task analysis to analyze the audio data recorded from students' interactions. The analysis revealed that the problem-based approach fostered higher-order cognitive activities.

2.3.3 Inquiry-based learning in engineering laboratory education

Inquiry-based learning has been successfully used in different classrooms (Blessinger & Carfora, 2014; de Jong, 2006; Psycharis, Botsari, Mantas, & Loukeris, 2014). This approach is completely different from traditional instruction. There is no cookbook or well-structured instruction. Students have to conduct investigations to explore a phenomenon. They have to formulate a hypothesis, search literature or previous work, define the purposes of the investigation, predict results, and plan and conduct the investigation (Domin, 1999). De Jong (2006) stressed that inquiry learning is not easy; to be successful, students need appropriate scaffolds. Due to its scientific-like approach, inquiry-based learning has become very popular among science educators (de Jong, 2006) and, to a lesser degree, among engineering educators (Prince & Felder, 2006). For example, Brophy, Magana, and Strachan (2013) used lectures and inquiry-based simulations to “enhance student abilities to understand the atomic process governing plastic deformation in materials” (p. 1). Buch and Wolff (2014) used an inquiry-based laboratory to educate undergraduate civil engineering students in a construction materials course.

2.3.4 Discovery learning

Discovery learning has its roots in the work of Brunner (de Jong & van Joolingen, 1998). In discovery learning, the instructor creates learning experiences that lead students to a process of discovery of the desired information, principle, or phenomenon (Alfieri et al., 2011; Domin, 1999). This process can be either minimally guided or scaffolded through feedback, worked examples, or guided instruction. Alfieri et al. (2011) found that enhanced discovery learning, using guided instruction, benefits students more than the unassisted discovery. Although discovery learning has significant popularity in the field of science education, it has not been so diffused in higher education (Prince & Felder, 2007). Indeed, very few papers were found reporting the use of discovery learning in engineering education (De Jong et al., 1998; Robson, Dalmis, & Trenev, 2012). One of the reasons for this lack of popularity of discovery learning among engineering educators is associated with the controversy regarding its educational effectiveness (Alfieri et al., 2011). Different studies reveal that discovery learning, in its traditional conception with minimal instructional guidance, has a lower impact on students learning than other inductive approaches such as inquiry- and problem-based learning (De Jong et al., 1998; Prince & Felder, 2006).

2.4 Current trend: Technology integration

The integration of laboratories into engineering education has an important space in the academic literature and community. Recent publications range from descriptive approaches where the authors aim to present an experimental apparatus (Avitabile, 2008; Ayas & Altas, 2016), to more refined educational research where the authors aim to investigate the learning effectiveness of a specific type of laboratory activity (Koretsky, Christine, & Gummer, 2011; Uribe, Magana, Bahk, & Shakouri, 2016). There are also articles exploring pedagogical approaches to laboratory education (de Jong, 2006; de Jong & van Joolingen, 1998). Finally, another common trend in the literature is related to studies that aim to investigate characteristics, affordances and differences between different types of laboratory including remote, virtual and physical labs (Corter et al., 2007; Heradio et al., 2016; Ma & Nickerson, 2006). These studies reveal huge transformations in laboratory education due to the advancements in technology. Physical labs are now competing with remote and virtual labs (Ma & Nickerson, 2006).

2.5 Current critique about laboratory education

This literature review suggests that laboratory education has faced significant progress regarding the development of new pedagogical methodologies. In addition, laboratory education is being transformed by the integration of virtual and remote technologies that seem to create unlimited opportunities for students' learning. However, despite this progress, a significant body of research indicates that there is a lack of diffusion of such innovations in engineering education, and a significant part of the progress of the laboratory education is not being incorporated into everyday laboratory learning activities (Duderstadt, 2008; Seymour, DeWelde, & Fry, 2011; Sheppard, Macatangay, Colby, & Sullivan, 2008). Indeed, today's claims regarding engineering education seem to echo the words of the Mann Report written almost a hundred years ago.

Sheppard and her colleagues (2008), in a study involving more than a hundred universities in the U.S., revealed that most laboratory activities focused on complementing lectures instead of developing essential engineering skills. They wrote: "Although laboratories provide an important practical dimension to student learning, they serve chiefly as a supplement to lectures, a place to validate the theories taught in the classroom." (p. 58)

Duderstadt (2008) criticized not only the ways laboratories are used, but also the way engineering is taught in general. He wrote,

> Despite the profound changes occurring today in engineering practice and engineering science and technology, we continue to educate and train engineers much as we have for the past several decades. In the curricula of our engineering schools, we still stress analytical skills involving scientific and mathematical analysis to solve well-defined

> problems rather than the broader skills of engineering design, systems integration, and innovation. (p. 63)

2.6 The views of scholars regarding the lack of innovations in laboratory education

To investigate the potential causes of the apparent lack of innovations in laboratory education, I delved into the literature about the integration of laboratories into engineering education, and also explored studies on the diffusion of innovations in engineering education. The results indicate a plethora of factors that directly or indirectly influence the learning outcomes of the laboratory activities. The first and most common argument in the literature relies on the logistical constraints associated with the use of laboratories (e.g., Aydin & Cagiltay, 2012; Bhargava, Antonakakis, Cunningham, & Zehnder, 2006; Melkonyan, Gampe, Pontual, Huang, & Akopian, 2014; Milo et al., 2011; Shyr, 2010; Tanyildizi & Orhan, 2009). For example, Aydin and Cagiltay (2012) argued that laboratory courses usually require a large number of educators and staff personnel. Bhargawa et al. (2006) stressed the time constraints, cost, and space. Melkonyan and colleagues (2014) highlighted the lack of human resources for laboratory maintenance and the shortage of equipment. Finally, Gustavsson et al. (2009) criticized the increasing number of students. In summary, laboratory education seems to be affected by a series of factors that may impact the efficiency of the learning activities.

Another common issue in the integration of laboratories into engineering education is associated with the use of instructional designs that do not promote deep learning of engineering skills (e.g., Abdulwahed & Nagy, 2014; Feisel & Rosa, 2005; Muoka, Haque, Gargoom, & Negnetvitsky, 2015; Omar, Zulkifli, & Hassan, 2009). For example, Abdulwahed and Nagy (2014) associated students' poor learning outcomes with the use of the "classical pedagogy of hands-on laboratories" (p. 110) Muoka et al. (2015) criticized the traditional curriculum of many Electrical Engineering programs and proposed the adoption of new pedagogies such as problem-based, project-based, and hands-on learning. Finally, Feisel and Rosa (2005) indicated the lack of clear learning outcomes for laboratory education. Feisel and Rosa (2005) also stressed that the complexity and cost of laboratory equipment and the changing motivation of faculty members "worked against a quality laboratory experience" (p. 123).

The literature on the diffusion of innovations in engineering education revealed another facet of the issues that may affect the ways laboratories are used in engineering programs. First, the literature is almost unanimous in stressing the need for a change in engineering education (e.g., Borrego, Froyd, & Hall, 2010; Jamieson & Lohmann, 2012b; Lattuca, Terenzini, & Volkwein, 2006; Seymour et al., 2011; Siddiqui & Adams, 2014). While this call for change seems to be supported by a series of national-level reports (e.g., NAE, 2004, 2008, The National Academies Press, 2007, 2010), there is no agreement about the causes of this need for change. In other words, research is still trying to understand why educational innovations are not becoming more common among engineering educators.

Froyd (2011) asserted that a change in engineering education could be seen through the lens of the diffusion of innovations model. He argued that while there is a richness in educational innovations, little research is conducted to investigate how these innovations propagate. Building on the Rogers' (2003) model of diffusion of innovations , Froyd (2011) identified three factors that influence the propagation of educational innovations: a) faculty perceptions of the innovations; b) the context in which faculty learn and make decisions regarding to innovations; and c) the role of change agents in promoting the innovations. The first two of these factors are directly related to the role of faculty in the adoption of the innovations.

Borrego et al. (2010) surveyed U.S. engineering department chairs regarding their awareness and use of educational innovations. Findings indicate a gap between the level of awareness about the importance of the educational innovations and the level of adoption of such innovations in engineering programs. While the awareness rate was 82 percent, the adoption rate was 30 percent. In addition, department chairs stressed faculty time and attitudes as highly influential for the future adoption of educational innovations. For future work, Borrego and colleagues suggested investigating the perceptions of engineering faculty members regarding the adoption of instructional innovations.

Jamieson and Lohman (2012), and Besterfield-Sacre et al. (2014) reported findings from an ASEE project aimed to support a change in engineering education. The project was conducted in two phases. In the first phase, a group of volunteers explored the critical issues and proposed actions to advance U.S. engineering education. In the second phase, engineering faculty, chairs and deans were surveyed to provide feedback regarding their impressions of the phase one report. Both Jamieson and Lohman, and Besterfield-Sacre et al. reinforced the need for ways to disseminate new instructional approaches, support faculty adoption of innovations, and foster new policies that reward teaching innovation.

Siddiqui and Adams (2014) took a different perspective on the problem. They recognized the importance of the diffusion of innovations model but argued that diffusion per se is not able to promote change alone. To these authors, sustainable change in engineering education requires a transformation of faculty beliefs and values. These authors also proposed the use of transformative learning theory as a framework for change in educational settings. They argued that in order to transform engineering education, it is necessary to transform the faculty. This current of thought seems to align with the literature on faculty beliefs regarding the adoption of teaching practices. Indeed, a significant body of research associates faculty beliefs with teaching approaches (Kember, 1997; Menges & Rando, 1989; Mertz & McNeely, 1990; Norton et al., 2005; Samuelowicz & Bain, 2001).

As discussed above, it seems that faculty is one key element in the adoption of educational innovations in engineering education. In addition, a series of factors may influence engineering faculty decisions about educational practices in the laboratories. These factors include logistical constraints, the sociocultural context, and faculty values and beliefs, among others.

CHAPTER 3. THEORETICAL FRAMEWORKS

3.1 Overview

I concluded chapter two by arguing that faculty is one of the critical elements in the adoption of educational innovations in engineering education. In addition, I identified that, despite the myriad of factors that affect faculty decisions regarding educational practices, beliefs seem to play a significant role in their final decisions. Furthermore, I showed that numerous scholars have argued that to change instructional practices in engineering education it is fundamental to change faculty beliefs. Thus, an essential step towards the adoption of innovations in engineering education would be to better understand the engineering faculty beliefs about the educational process and how those beliefs might be related to their instructional practices. However, few studies have explored engineering faculty beliefs, and to the best of my knowledge, no study has been published regarding faculty beliefs about laboratory education in engineering or engineering technology. Since laboratory education plays a fundamental role in the education of engineers, it is essential to understand the beliefs of laboratory instructors better and investigate how these beliefs relate to the laboratory instructional practices.

In this chapter, I will provide an overview of the main theories about faculty beliefs and their relation to instructional practices. As there is not a large body of literature on this topic, I will bring some discussions from K-12 education, and also discussions about how beliefs have been conceived and studied in higher education. Finally, I will introduce and discuss the theoretical framework proposed by Samuelowicz & Bain (1992, 2001). The framework associates patterns of faculty educational beliefs to orientations to teaching. These orientations describe the different ways faculty conceive the teaching and learning processes and possibly act accordingly.

3.2 On the Nature of Beliefs

I will start my discussion by presenting some dictionary definitions associated with the term belief. The Merriam-Webster dictionary mainly defines belief as “a state or habit of mind in which trust or confidence is placed in some person or thing” (Belief, n.d.-a). Similarly, the Oxford dictionary defines belief as “something one accepts as true or real; a firmly held opinion” (Belief, n.d.-b).

Finally, to the Cambridge dictionary belief is a "the feeling of being certain that something exists or is true" (Belief, n.d.-c). It is noteworthy to say that small controversy may arise when one looks at the secondary definitions discussed in those dictionaries. Indeed, in one of their definitions, the Merriam-Webster says belief is a "conviction of the truth of some statement or the reality of some being or phenomenon especially when based on examination of evidence" [emphasis added]. Conversely, the Oxford dictionary says belief is "an acceptance that something exists or is true, especially one without proof" [emphasis added]. This controversy has a low impact on the definition I am adopting in this work and will be further explored in the upcoming sections.

In this dissertation, belief is defined as an internal state or habit of mind in which a person accepts something as true and real. It can be either an idealistic belief or a belief mediated by external factors. The importance of the study of beliefs resides on the fact that beliefs play a central role on humans' attitudes, behavior and agency (Bandura, 1989a; Calderhead, 1996; Dewey, 1910; Nisbett & Ross, 1980; Rokeach, 1972). This central role of beliefs on peoples' attitudes, behavior, values, and agency have been explored by philosophers, scholars, and scientist in different disciplines, including philosophy, sociology, psychology and education.

The philosopher, John Dewey (1910) associated beliefs with two of his four senses of thought. To Dewey, the first two senses of thought referred to "everything that comes to mind" or that "goes through our heads," and matters that are not perceived through the four human senses of sight, hearing, smell, or touch. The third and four senses of thought are directly related to the notion of beliefs. Dewey associated the third sense to beliefs grounded on some real or supposed knowledge. These beliefs are "marked by acceptance or rejection of something as reasonable or improbable." (p. 4) Dewey also differentiated between two types of beliefs. The first type included beliefs that are accepted without any consideration of their grounds. In the second type, Dewey included beliefs whose acceptance depends on the examination of their basis. Regarding beliefs accepted without taking into account its real basis, Dewey wrote:

> Such thoughts grow up unconsciously and without reference to the attainment of correct belief. They are picked up we know not how. From obscure sources and by unnoticed channels they insinuate themselves into acceptance and become unconsciously a part of

> our mental furniture. Tradition, instruction, imitation - all of which depend upon authority in some form, or appeal to our own advantage, or fall in with a strong passion - are responsible for them. (p.4)

Finally, Dewey associated the fourth sense of thought with beliefs whose basis and consequences are examined in a process called “reflective thought.” To Dewey, “active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends, constitutes reflective thought.” (p. 6) Dewey considered this reflective thought as the best way of thinking and discussed the importance of developing such reflective practice among students and teachers.

The social psychologist, Milton Rokeach (1972), theorized that human’s beliefs are organized in a system of views that follows a central-peripheral arrange. Five types of beliefs are defined as follow. Type “A” beliefs, also called primitive beliefs, - 100 percent consensus - , are the most central, and are acquired or learned through direct contact with the object of belief. Rokeach argued that these beliefs are reinforced by social acceptance. Moreover, as these primitive beliefs can be associated with the person’s fundamental truths about their own reality (physical, social, and the self), any disturbance or disruption on them may cause serious reflections on the person’s system of beliefs with implications to the self-identity, self-efficacy, and self-existence. Type “B” beliefs, or primitive beliefs, - zero consensus -, are also formed through direct encounter with the object of belief, but do not require social acceptance or consensus. Rokeach argued that, as these types of beliefs derive from personal experiences, they prescind of external references and may persist even when subject to controversy. Examples of this kind of belief include phobias, faith, and hallucinations. Type “C” beliefs, or authority beliefs, are non-primitive beliefs. It means that these beliefs are not a result of a direct encounter with the object of belief. These beliefs refer to the authorities people trust or distrust while expanding their belief system. According to Rokeach, cultural and social structures affect the way people define whom they would rely on for information. Type “D”, or derived beliefs, result from the acceptance of a particular authority as a source of truth. As a consequence of such acceptance, the beliefs that seem to emanate from such authority are also accepted as true and real. The final type, or type “E” and also called inconsequential beliefs, “represents more or less arbitrary matters of taste.” (p.11). These beliefs are considered inconsequential because they have few or no connections to the entire system of beliefs, and an eventual change is such beliefs has minimal or no impact on other beliefs.

The sociologist Robert Wuthnow (2004), based on the works of Max Weber, Emile Durkheim, and Neil Smelser (1962), explored the roles of norms, values, and beliefs on social structures and human behavior. According to Wuthnow, values and beliefs serve as a source of legitimation to support people's behavior within a social context. He argued that beliefs might provide the reasons a person needs to behave in a particular way. In addition, Wuthnow presented a current of thought that views social structures as consisting of the patterned behavior that results from people conforming to the rules and expectations (norms) within a social context. These norms are "bundled" with the definitions of the different roles a person may play in a social structure. Son, mother, father, faculty, student are examples of roles a person may play. Each role has its governing rules and expectations that help to maintain the normality within a social structure. For example, a person that occupies the role of the teacher is expected to behave like many other teachers in that context, and conflicts may occur when a person starts to act or think differently. Reward systems, including salaries and prizes, are also described as mechanisms that reinforce the patterns of behaviors expected in a social context. While the norms and roles serve to establish such patterns of behaviors, beliefs and values provide stability to the social structures.

According to the psychologist Albert Bandura(1989), people's self-efficacy beliefs are a central mechanism of human agency. To Bandura, "among the mechanisms of personal agency, none is more central or pervasive that people's beliefs about their capabilities to exercise control over events that affect their lives." (p. 1175). These beliefs affect human behavior in different ways. First, self-efficacy beliefs affect the quality of people's analytic thinking and performance. Indeed, to cope with the ambiguities and uncertainties of their everyday lives, people need to make decisions that require cognitive effort to analyze information and make judgments and predictions. The quality of these cognitive processes is influenced by people's beliefs about their own ability to deal with such situations. Those people who believe in their capabilities are more prone to engage in higher levels of thinking towards a solution than those who are not so confident (Bandura & Wood, 1989). Second, self-efficacy beliefs determine people's motivation to engage in, persevere in, and conclude a task (Bandura, 1989b, 1990). Indeed, as supported by several other studies, people usually avoid, or refuse, to engage in activities they believe are beyond their coping capabilities (e.g., Arslan, 2012; Chemers, Hu, & Garcia, 2001; Landino & Owen, 1988). Conversely, people usually adhere to or participate in activities they believe to be able to handle.

3.3 Beliefs and educational decisions

While the studies mentioned above explore different perspectives on the nature of beliefs and its relevance in different disciplines, all of them point to the fundamental role of beliefs in people's behaviors and attitudes. Beliefs are at the core of human thoughts (Dewey, 1910). They seem to be organized in a hierarchical system where the most primitive ones prevail over the derived ones and are more resistant to change (Rokeach, 1972). Beliefs are also responsible for the stability of the patterned behaviors in a social structure and may play a significant role in educational practices (Wuthnow, 2004). Indeed, a significant body of research has explored the relations between educational beliefs and teaching practices in different educational levels (see reviews in Fang, 1996; Pajares, 1992; Samuelowicz & Bain, 2001).

In K-12 research, Richardson and colleagues (1991) conducted a qualitative study to investigate how teachers' beliefs about reading comprehension related to their classroom practices. Through interviews and classroom observations of 39 teachers from grades 4, 5 and 6, these authors found strong evidence of the relationships between beliefs and practices of teaching reading comprehension. Their findings indicated that teachers who believed that "knowledge is transferred from the text or teacher directly to the students" (p. 567) usually did not take into account students' background knowledge, or consider it tangentially in education. Those teachers who believed that precise pronunciation is paramount to understanding word meaning tended to interrupt students to improve their pronunciations. In general, Richardson and colleagues pointed out that teachers who believed that the subskills of reading must be learned before the meaning of the text would adopt an approach that emphasizes skills and word meaning. On the other hand, teachers who believed that learning to read is accomplished by reading, engaged students in reading literary works.

Different scholars have explored faculty pedagogical beliefs about teaching and learning in higher education settings (e.g., Hativa & Goodyear, 2002; Kember, 1997; Samuelowicz & Bain, 2001). For example, Martin and her colleagues (Martin, Prosser, Trigwell, Ramsden, & Benjamin, 2002) investigated teaching practices of 26 faculty members in four discipline areas: social sciences and humanities, business and law, science and technology, and health sciences. The findings indicated a clear relationship between the faculty conceptions of the object of study and their respective approaches to teaching. Those faculty who conceived the object of study in terms of knowledge transmission tended to adopt teacher-centered approaches. On the other hand, faculty who conceived the object of study as a knowledge construction process tended to rely on student-centered approaches. Taking a different perspective, Hativa (2000) presented two case studies exploring the pedagogical knowledge and beliefs of two faculty with poor students' rating. The findings indicated that faculty beliefs played a significant role in their classroom behaviors. For example, both faculty members believed that effective instruction was based on strict lecturing and material coverage. As a result, they tried to teach the maximum content possible, and used lectures as the only approach, avoiding discussions and questions.

Middleton and colleagues (Middleton et al., 2015) presented one of the few studies exploring the relationship between faculty beliefs and teaching practices in engineering courses. The participants were twenty-one instructors who taught STEM courses for engineering students at a large Southwestern university in the U.S. The data collection included interviews, the Approaches to Teaching Inventory (ATI) survey, and classroom observations. Using cluster analysis techniques, Middleton and colleagues identified three groups of faculty with different sets of beliefs. The first cluster consisted of faculty who demonstrated beliefs towards conceptual change and the use of student-centered strategies. The second cluster consisted of faculty who espoused beliefs towards information transmission and the use of teacher-centered strategies. Finally, the third cluster included faculty who espoused beliefs not clearly aligned with either conceptual change or information transmission. Although the findings indicate some alignment between beliefs and teaching practices, for example, student-centered faculty tended to adopt more innovations in classroom, these relationships were contextualized and mediated by department culture and norms. These findings align with other studies that indicate the role of beliefs on teaching practices, but also stressed the importance of contextual factors including institutional and department values, culture, and discipline (Coutinho et al., 2017; Hora, 2014).

Although the studies mentioned above indicates a relationship between educational beliefs and teaching practices, they lack in providing an overarching theoretical and methodological framework to explain neither how beliefs and practices relate to each other, nor how the different educational beliefs form the basis for educational decisions. This limitation is addressed in the Orientations to Teaching and Learning framework proposed by Samulowicz and Bain (2001).

3.4 The Orientations to Teaching and Learning Framework

The Orientations to Teaching and Learning Framework was conceived to investigate conceptions of teaching held by academics in two different fields: science and social science. Grounded on theoretical and empirical studies, including the works conducted by Fox (1983), Dall'Alba (1991), and Martin and Balla (1991), Samuelowicz and Bain (1992) proposed a framework that identifies and organizes the beliefs in terms of dimensions and orientations to teaching. Each dimension represents a category of belief and is arranged along a continuum in which the belief may vary from a teacher-centered to a student-centered perspective. The orientations are unique patterns of beliefs that intend to portray the specific ways academics perceive the teaching and learning processes in connection with their teaching practices. The original framework identified five orientations to teaching and five dimensions of beliefs. In a further study, Samuelowicz and Bain (2001) extended the original framework and identified seven orientations to teaching and nine belief dimensions. In this extended study, Samuelowicz and Bain interviewed academics from different fields, including engineering, architecture, and chemistry, among others.

The seven orientations, arranged along a continuum ranging from a teacher-centered to a student-centered perspective were: a) Imparting information; b) Transmitting structured knowledge; c) Providing and facilitating understanding; d) Helping students develop expertise; e) Preventing misunderstandings; f) Negotiating understanding; and g) Encourage knowledge creation. These orientations reflect different patterns of beliefs and predict the practices espoused by the academics who share the same orientation. Table 3.1 presents the seven orientations, the nine belief dimensions, and the beliefs associated with each dimension. The letters in the table resulted from a coding scheme used to identify and analyze the patterns of beliefs espoused by the academics. A indicates a belief that is closely related to a teacher-centered perspective. B indicates a belief that reflects a student-centered perspective.

Three of the seven orientations indicate patterns of beliefs called as teacher-centered. These beliefs indicate an instructional emphasis either on the teacher or on the subject-matter of the course. The other four orientations, the right-most ones, indicate patterns of beliefs that reflect a major or minor emphasis on the learners as agents of learning. According to this framework, each orientation and its constituents' beliefs define the way a teacher perceives the teaching and learning processes. Thus, the practices of such teachers will be in accordance with such orientations. For example, a teacher who espouses an orientation towards imparting information tends to emphasize the subject-matter of a course. The focus is on imparting as much information as possible through lectures. The teacher is seen as the vehicle of knowledge transmission and the main responsible for controlling the content students see. Thus the communication follows a one-way direction from the teachers to the students. In summary, to the teachers who espouse the imparting information orientation, they are the main actors in the teaching and learning processes. On the other hand, a teacher who espouses an orientation towards helping students develop expertise believes that students are the responsible for their own learning, and the teacher has the role in supporting the students. Learning is seen as a lifelong process that goes beyond just accumulating information. Teachers and students interact through a two-way communication process aiming to change the way students think and interpret the reality. In this case, the students are seen as the main actors in the teaching and learning process.

This framework provides a concrete and structured way to analyze educational beliefs and its relationships with teaching practices. The orientations and beliefs dimensions find correspondence with other studies conducted by Dall'Alba (1991), Kember (1997), Martin and Balla (1991), Prosser, Trigwell, and Taylor (1994), and Pratt (1992), among others. However, it was developed based on interviews with faculty from different domains, including social sciences, STEM, and health sciences. In addition, no information regarding laboratory education was provided. Thus, a study aiming to investigate engineering faculty beliefs about laboratory education and its relationships to the faculty teaching practices will add to the orientations to teaching and learning framework and also bring a significant contribution to a deeper understanding of the faculty decisions regarding laboratory education.

3.5 Summary

In this chapter, I presented a theoretical background about beliefs and its relationship with teaching practices. The Orientations to Teaching and Learning Framework (Samuelowicz & Bain, 2001) was presented and discussed. This framework serves as a basis for the analysis of faculty beliefs and their corresponding teaching practices. However, it was shown that, although grounded on theoretical and empirical evidence, this framework did not take into account faculty educational beliefs about the teaching and learning processes in the engineering education laboratories. Thus, investigating such beliefs and practices will shed light on an important component not well explored by engineering education research: the faculty in the labs.

Table 3.1 Orientations to teaching and learning (Samuelowicz & Bain, 2001, p.306)

Orientation / Dimensions	Teaching-centered orientations			Learning-centered orientations			
	Imparting information	Transmitting structured knowledge	Providing and facilitating understan-ding	Helping students develop expertise	Preventing misunderstan-dings	Negotiating understanding	Encouraging knowledge creation
Desired learning outcomes	recall of atomized information A	reproductive understanding A/b	Reproductive understanding A/b	Change in ways of thinking B	Change in ways of thinking B	Change in ways of thinking B	Change in ways of thinking B
Expected use of knowledge	within subject A	within-subject for future use A/b	within-subject for future use A/b	interpretation of reality B	interpretation of reality B	interpretation of reality B	interpretation of reality B
Responsibility for organizing or transforming knowledge	Teacher A	Teacher A	teacher shows how knowledge can be used A/b	Students & teacher B/a	Students B	Students B	Students B
Nature of knowledge	Externally constructed A	Externally constructed A	Externally constructed A	Personalized B	Personalized B	Personalized B	Personalized B
Students' existing conceptions	Not taken into account A	Not taken into account A	Not taken into account A	Not taken into account A	used to prevent common mistakes B/a	Used as basis for conceptual change B	Used as basis for conceptual change B
Teacher-students interaction	One-way; Teacher > students A	Two-way to maintain students' attention A/b	Two-way to ensure/clarify understanding B/a	Two-way to negotiate meaning B	Two-way to negotiate meaning B	Two-way to negotiate meaning B	Two-way to negotiate meaning B
Control of the content	Teacher A	Teacher A	Teacher A	Teacher A	Teacher A	Teacher A	Students B
Professional development	Not stressed A	Not stressed A	Not stressed A	Stressed B	Stressed B	Stressed B	Stressed B
Interest and motivation	Teachers' A	Teachers' A	Teachers' A	Students B	Students B	Students B	Students B

CHAPTER 4. RESEARCH DESIGN AND METHODS

4.1 Overview

This chapter outlines the research design that informs the present study. It begins by restating the research questions followed by a description of the rationale for the selection of the research methodology, the context, selection criteria, and methods. After this overall contextualization of the study, this chapter outlines the data collection and data analysis methods used to answer the proposed research questions. The chapter ends with a discussion of trustworthiness and researcher positionality.

4.2 Research Questions

1. What are the faculty beliefs about the integration of laboratories into engineering education?
2. How do faculty beliefs relate to their current teaching practices in laboratory education?

4.3 Research Design

A multiple case study design was used for this investigation. This multiple case study investigated beliefs and teaching practices in engineering education laboratories. The study had two phases. In the first phase, an exploratory approach was used to identify faculty beliefs regarding laboratory education. In the second phase, the results from phase one were triangulated with other sources of data to investigate the relationship between beliefs and practices.

Case study is a research design aligned with the qualitative paradigm. According to Creswell (2014), a qualitative study aims at "exploring a problem and developing a detailed understanding of a central phenomenon" (p. 16). Furthermore, case study is a research methodology which allows the investigation of "a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident" (Yin, 2016, p. 16). Thus, a case study approach was especially appropriate for the present study because the goal was to investigate a contemporary phenomenon—engineering faculty beliefs and teaching practices related to laboratory education—for which contextual conditions were paramount. For example, elements such as participants' background, type of institution, and departmental contexts could pose additional difficulties to understand the phenomenon.

In addition, Yin (2014) detailed how to identify a "niche" to use case study methodology. To Yin, a case study is a niche when the research questions ask "how" and "why" about a "contemporary set of events over which a researcher has little or no control" (p. 14). Schramm (1971) concluded that "the essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result" (p.6). The present study investigated how educational beliefs influenced faculty decisions about laboratory instructional designs. Thus, a case study design was appropriate.

Case study has been successfully used in different domains such as education (Yin, 2006), nursing and public health (Baxter, Susan Jack, & Jack, 2008), and business (Vissak, 2010). Case & Light (2011) listed case study as one of the seven emerging methodologies in engineering education research. Indeed, case study has informed the research design of several studies in engineering education settings. For example, Magana and colleagues (2016) used case study methodology to investigate the effect of prior programming experiences on engineering students' performance and self-beliefs. They used surveys to gather student information. Results indicate the importance of developing students' programming skills from the very early stages of the curriculum. Oleson and Hora (Oleson & Hora, 2014) took a qualitative case study approach to investigate the sources of knowledge and teaching practices of STEM faculty at three research institutions. Using semi-structured interviews and observations, Oleson and Hora found a myriad of influences on faculty teaching practices. These authors did not mention any faculty experience regarding laboratory education, however.

A multiple case study approach is appropriate when the characteristics of a phenomenon may vary across contexts and individuals (Yin, 2014). In this study, there was evidence that beliefs and practices could vary as a consequence of participants' background, and socio-cultural contexts such as college and department. Thus, a multiple case study approach provided a better sense of those variations than a single case approach. In addition, as this study aimed to answer two related but qualitative different research questions, a two-phase approach was necessary. First, an exploratory study investigated the faculty beliefs about laboratory education. Second, these beliefs were contrasted with the espoused and reported practices to identify how beliefs and practices are related.

4.4 Overview of Data Collection and Data Analysis Methods

This multiple case study was conducted in two different phases. In Table 4.1, I present the main characteristics of each phase. These phases can be conceived as two subsequent studies that answer different research questions (see Figure 4.1). In phase one, I conducted an exploratory study aimed at exploring faculty beliefs regarding the integration of labs into engineering and engineering technology education. In phase two, I triangulated the findings from the phase one with the data from questionnaires, interviews, and documents to analyze how faculty beliefs related to their teaching practices.

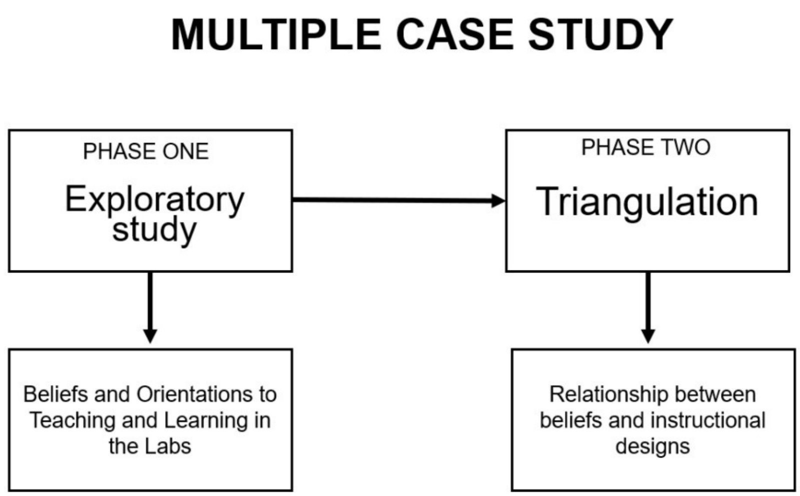

Figure 4.1Depiction of the research design

Table 4.1 Summary of the Research Design: Multiple Case Study

	PHASE ONE **Exploratory study**	**PHASE TWO** **Triangulation**
Research Questions	1. What are the faculty beliefs about the integration of laboratories into engineering education?	2. How do faculty beliefs relate to their current teaching practices in laboratory education?
Chapter	Five	Six
Methodology	Two-phase multiple case study	
Participants	8 engineering and 5 engineering technology faculty	
Sampling	Purposeful: Participants were invited to participate in this study based on their work as faculty/instructor with direct relation to laboratory activities. They preferably must be teaching a lab course, or be involved in any process regarding the instructional design of lab activities.	
Data collection	Semi-structured interviews, exploring topics such as the importance of engineering knowledge and skills, the role of labs in engineering/technology education, teaching and learning in the labs, the role of instructors and students, and lab instructional designs.	Document analysis of faculty's instructional documents used in lab activities. Syllabi, lab manual, lesson plan, and assignments are examples of these instructional documents. The interviews and findings from the phase one served as sources of data for this second phase too.
Data analysis	The audio recordings from interviews were transcribed and analyzed using the constant comparative method to identify and categorize the beliefs. A qualitative analysis was used to group participants according to their patterns of beliefs.	The documents (syllabus, lab manuals, and assignments) were analyzed through content analysis. The questionnaires were summarized to provide a big picture of each participant's background. The data from the different sources were combined through a process of triangulation.

Figure 4.2 illustrates the characteristics of the study conducted on phase one. After a recruitment process, participants were interviewed. The interviews were transcribed and analyzed using a constant comparative method (Glaser, 1965). The results of this analysis were organized into nine

categories of beliefs. The participants' beliefs were then classified according with their position in a continuum ranging from a content-centered to a learner-centered perspective, and resulted in five different orientations to teaching and learning in the labs. The beliefs and orientations were analyzed, and comparisons between participants of the Colleges of Engineering and Engineering Technology were made in order to answer the first research question. A report was generated to be used in phase two.

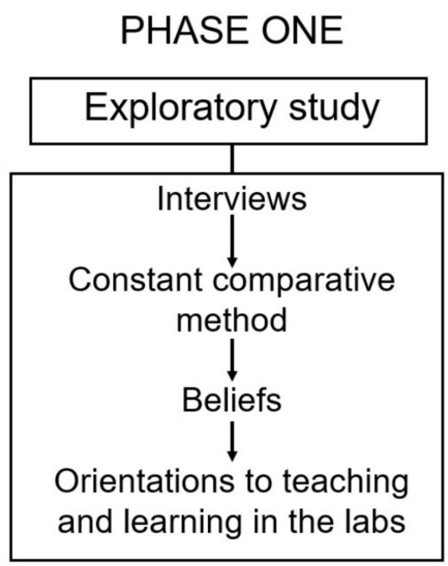

Figure 4.2 Characteristics of the phase one

Figure 4.3 depicts the characteristics of phase two. In this phase, the interviews and the reports from phase one describing the participants' beliefs and orientations to teaching and learning in the labs were triangulated with the additional data collected from each participant. The additional data included a questionnaire and documents such as syllabi, lab manuals, and students' assignments. Individual case reports were generated to illustrate the relationships between beliefs and practices of each participant. These reports were then compared and contrasted to identify similarities and differences among the participants.

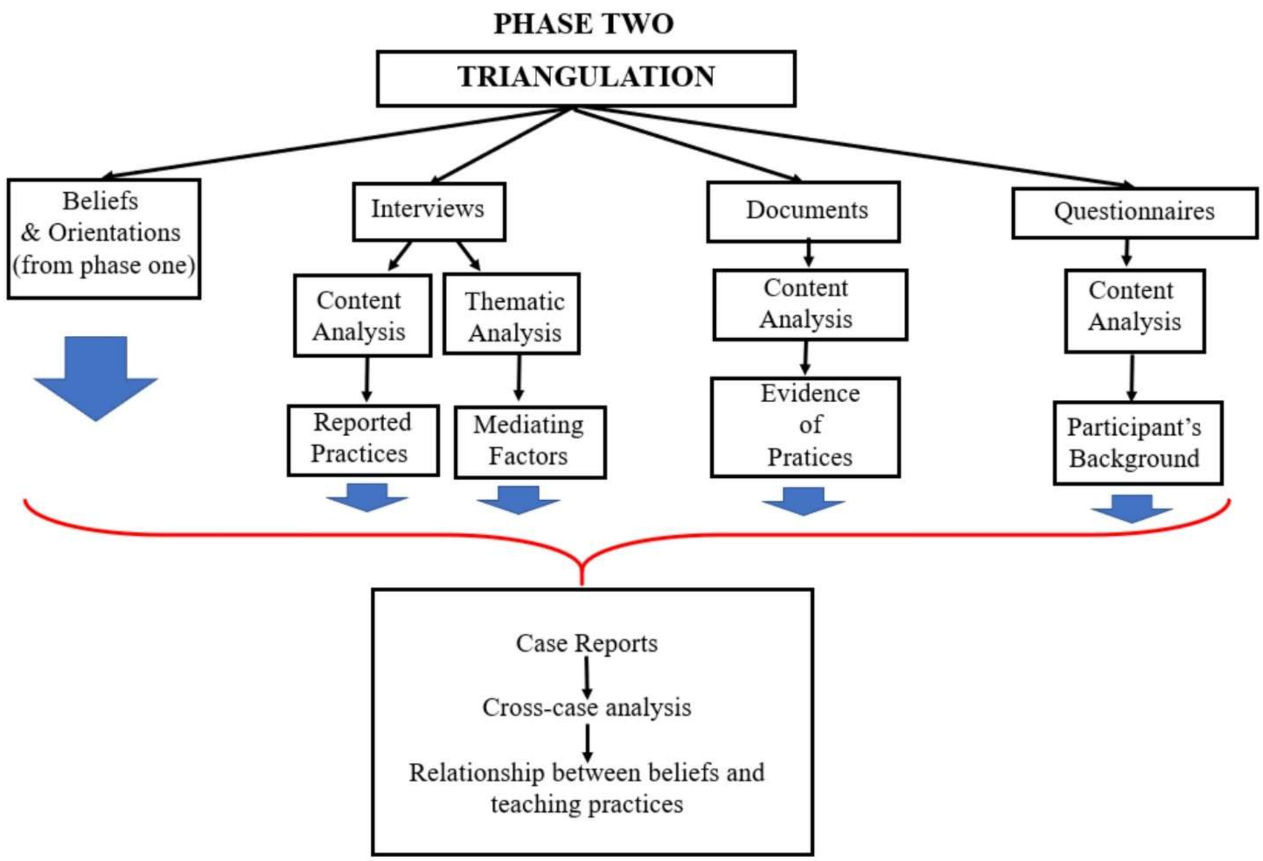

Figure 4.3 Characteristics of phase two

4.4.1 Selection criteria and Setting

The study was conducted at a large Midwestern university. As this study focused on exploring faculty beliefs about laboratory education and investigated the relationship between such beliefs and their corresponding teaching practices in the labs, all participants had to meet the following criteria. The participants must be a professor at the colleges of engineering or engineering technology at the same university; be responsible for a lab course either at the current or at a past semester; have autonomy to create and/or change the instructional designs adopted for the lab activities. In addition, given the existence of situations where one faculty member taught the lecture, and another faculty taught the lab, I chose those faculty members who were teaching the labs or who were responsible for the lab activities.

4.5 Phase one – Exploratory Study

This phase draws on the data from the interviews with all the participants. The goal of this phase was to answer the following research question:

1. What are the faculty beliefs about the integration of laboratories into engineering education?

4.5.1 Recruitment Process and Participants

To recruit the participants of this study, I first searched all the lab courses offered during the fall semester of 2018 in the two colleges. During this search, I also identified the faculty responsible for the courses and the eventual instructors associated with the lab components. The search resulted in a list of more than forty faculty and instructors who met the selection criteria described above. An invitation email was sent to these members by my advisor, Dr. Alejandra Magana. She also invited colleagues from her personal network of collaborators. The invitation described the main characteristics of the research and the data collection process and asked the readers to participate in the study. Ten faculty members agreed to participate in this phase of the study. To increase the number of participants, I asked some faculty members and graduate students at the School of Engineering Education to indicate colleagues who would be willing to participate. Two more participants accepted to participate in the interviews. Finally, I visited two lab supervisors from the college of engineering and asked them to indicate professors who were engaged in promoting laboratory activities. One more faculty member was added to the list of participants.

Thirteen engineering and engineering technology faculty members working in four-year engineering programs at two different colleges: the College of Engineering (N=8) and the College of Engineering Technology (N=5) participated in this study. Participants were chosen based on their involvement in teaching laboratory courses or courses mixing lectures and labs.. All participants were asked about their levels of autonomy. I included only those participants who had the autonomy to make changes in one of the components of the instructional design, such as the content, the assessments, or the pedagogy.

4.5.2 Data Collection Methods

Interviews. Semi-structured interviews were used to gather faculty information. A semi-structured interview is a research method of "questioning individuals in which, while there is a broad thrust to the direction of the questions, issues that arise from responses may give rise to new questions and directions of inquiry" (Duignan, 2016). According to Baškarada (2014), semi-structured interviews are more flexible than standardized protocols and allow the researchers to probe the interviewees in order to achieve a deeper understanding of the interviewee's perspective. In addition, interviews are one of the most important sources of evidence in case study research (Yin, 2014). This importance reflects on the increasing use of interviews in case study articles (Magana, Brophy, & Bodner, 2012; Matusovich, Streveler, & Miller, 2010; Oleson & Hora, 2014).

To support the interviews, I developed an interview protocol following the guidelines adopted by Samuelowicz (1999). In such a study, Samuelowicz aimed to explain the relationships between faculty beliefs and their corresponding orientations to teaching and learning in higher education settings. The interview protocol used in that study was composed of ten broad questions exploring four dimensions of the educational process: knowledge, teaching, learning, and the link between teaching and learning. I adapted that interview protocol and included some new questions to take into account the specificities of laboratory education. The final interview protocol had eighteen main questions and a series of probe questions that helped to clarify the participants' views of a particular topic. Table 4.2 presents the central questions of the original and the modified protocol.

The complete interview protocol, including all the probe questions, is presented in Appendix A.

4.5.3 Data Analysis Method

Constant Comparative Method. A constant comparative method (Glaser & Strauss, 1967) was used to analyze the interviews and code the beliefs under the different categories. A constant comparative method (CCM) is a research method used in qualitative research to analyze data from interviews, observations, and documents. It allows a deeper understanding of a phenomenon than other traditional methods and provides a systematic way to generate theory from the qualitative data. The method has four main steps: "(1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory"

Table 4.2 Interview protocol

	Samuelowicz Protocol	**This study protocol**
		1. Tell me your path to …(the current university)
Questions related to knowledge	Q6. What is knowledge in your discipline? Q7. What is learning?	2. What are the most important knowledge and skills engineers must have to be good professionals in the field? 3. How do you think they learn best such knowledge and skills?
Questions related to the role of labs		4. What role do labs play in the current state of engineering education? (actual) 5. What do you think should be the main role of labs in engineering/technology education?
Questions related to teaching and learning	Q9. What aspects of a course are difficult for students to learn? Q2. What is teaching? Q3. Do you see as your role and students' role in the teaching and learning process? Q4. What do students bring to the learning process Q5. What makes somebody a good teacher?	6. How do think labs must be taught to prepare engineers better? 7. What aspects of a course are difficult for students to learn in the labs? 8. What are the main differences between teaching in the lab and teaching a lecture section only? 9. What do you see as your role in the teaching and learning process in the lab? 10. What do you see as students' role in the learning process within a lab context? 11. What are the characteristics of a good lab instructor/faculty? 12. What are the main barriers to good teaching in the labs?

Table 4.2 continued

Questions related to the instructional design	Q1. What do you aim to achieve through your teaching? . Q10. We have talked about teaching and learning, does your teaching influence student learning? How? Q8. How do you know that your students have learned something?	13. What do you want your students to know or be able to do at the end of the lab course? 13.1 Do you think you usually achieve your aims? 14. How do you know that your students have learned something? 15. Tell me about your pedagogical approaches 16. What is your level of autonomy to make changes in the lab course? 17. If you have the power to make the changes you wanted, what would you change in your lab?
Question to identify any implicit conflict between beliefs and practices.		18. Suppose that you are a faculty in a college/university where students do not have access to laboratory education, do you believe these students will be as prepared as a student who had laboratory instruction? Why?
Final question		19. Based on what we talked about today, are there any ideas or recommendations you would have for the design of better lab activities?

(Glaser & Strauss, 1967, p. 105). In the first step, the researcher needs to read the interviews and code the individual items, or incidents, in “as many categories of analysis as possible” (Glaser, 1965, p. 439). While coding the incidents, the researcher has to continually compare each new incident with the previous ones placed in the same category. To resolve conflicts in coding the incidents, the researcher must stop coding and reflect on the conflict in order to define a logic about the data. This process results in a memo describing the properties of each category of incidents. In the second step, the incidents start to be sorted according to the properties of each category. Also, as the properties of each category become well-defined, constant

Comparisons can also be made between properties and categories leading to a more profound sense of the categories and their relationships. In the third step, the analysis focus on integrating the overlapping categories and reduction of the final categories. This process results in a final description of all categories, the corresponding properties, and an eventual theory emerges from the data. In the final step, the researcher focuses on writing the theory.

In the present study, each interview was considered a single unit of analysis. Eight categories of beliefs were defined at the outset based on the theoretical framework proposed. The theoretical categories aim to reveal the participants' beliefs regarding 1) The nature of knowledge in engineering; 2) The role of labs; 3) Teaching in the labs; 4) Learning in the labs; 5) The agent responsible for transforming the knowledge in the labs; 6) The desired learning outcomes; 7) The role of faculty; and 8) The role of students. The method also allowed space for new categories that could emerge from the data. To conduct the CCM, I started coding the interviews and identifying the participants' beliefs associated with each of the eight categories. This sorting process took several hours since sorting the interviews within each category required attention and reflection to identify differences and similarities between the participants. While analyzing, memos were generated to resolve conflicts in the sorting process. In the end, a codebook was generated (see Appendix D). The interviews were re-coded according to the codebook and small adjustments were done to fit the data. While conducting the CCM, I was also looking for new categories of beliefs not described by the theoretical framework.

The analysis of the beliefs and its corresponding properties made possible the generation of a coding scheme that revealed patterns of beliefs among participants. These patterns of beliefs were grouped and analyzed qualitatively by looking for similarities and differences among the participants' patterns of beliefs. A report was generated describing the different orientations to teaching and learning in the labs, and the corresponding faculty beliefs.

4.6 Phase Two – Triangulation

In phase two, I analyzed different sources of data to answer the research question two, as follow:

> 2. How do faculty beliefs relate to their current teaching practices in laboratory education?

4.6.1 Data Collection

The data collection included the report from the phase one, interviews, questionnaires, and instructional documents. The use of different sources of data is a characteristic of the case study approach. It helps to increase the trustworthiness of the results using a triangulation process that leads to a “stronger substantiation of constructs and hypothesis” (Eisenhardt & Eisenhardt, 1989, p. 538). Specifics of the data sources used in this phase two are:

The report from the phase one. The report from phase was used to characterize the participants regarding their beliefs and orientations to teaching and learning in the labs.
Interviews. The same semi-structured interviews collected in phase one were used in this second phase. This time the goal was to capture the participants’ reported practices, and also identify inevitable conflicts between beliefs and practices.

Questionnaire. A questionnaire was used to gather participants’ demographic and background information, including their level of education, the field of study, type of institution, and professional development needs (see Appendix B). Also, participants indicated their familiarity with the different instructional approaches used in laboratory education. This questionnaire was presented in a paper-and-pencil format to the participant at the time of the interview. Some participants preferred to answer it immediately, and others asked me to pick it up later.

Documents. At the end of the interviews, participants were asked to provide the following artifacts:

(a) Syllabi. A syllabus is a written document that communicates information about a course, its goals, structure, sequence of class activities, assignments, and attendance policies, among other things (Fink, 2013). The syllabi allowed the analysis of essential characteristics of the laboratory courses such as instructors’ intended learning outcomes, assessment instruments, content, and pedagogical choices.

(b) Laboratory manuals. Laboratory manuals or worksheets are important sources of evidence about the instructional designs adopted by the instructors. Laboratory manuals are used to inform students about how to conduct the learning activities. Laboratory manuals used are closely linked with the pedagogical approaches adopted in the lab. For example, a manual that asks students to follow a rigid and well-structured set of activities may be associated with a traditional design approach.

(c) Students' assignments and examinations. These documents provide evidence of how the instructors assess students' learning. Assignments were homework, lab reports, and project solutions, among others. Examinations included knowledge tests, course exams, or presentations. Thus, pedagogy and assessment may be identified by analyzing these documents.

4.6.2 Data Analysis

Following a case study approach (Yin, 2014), I first conducted the within cases analysis. That means, I analyzed each participant's set of data and generated individual reports describing, at the case level, how beliefs and practices were related. Second, I conducted a cross-case analysis to identify a pattern of similarities and dissimilarities between the cases. A report of this cross-case analysis was also generated.

I used the following three methods to analyze the several sources of data to generate the individual reports.

Content Analysis. Content analysis is a research method used to make replicable and valid inferences from the content of text data (Krippendorff, 2004). Hsieh and Shanon (2005) described three different approaches to content analysis: conventional, directed, or summative. In the conventional approach, themes and codings arise naturally from the text data. In the directed approach the initial codes are defined at the outset based on some theory or prior research. The last approach, summative content analysis, takes a more quantitative orientation and involves counting and comparisons of textual references. In the present study, I adopted a directed approach to investigate how the documents elicited evidence of faculty beliefs, influences, and instructional designs. According to Hsieh and Shanon (2005), the first step in the directed content analysis is to identify key concepts or variables as initial categories.. The next step involves reading each document to identify and code all the passages associated with the coding categories. In the end, after reading and coding all documents, a final report can be used to summarize all the findings.

In the present study, content analysis was used to analyze the written artifacts (syllabus, lab manuals, and assignments). Content analysis was also used in this study to analyze the interviews and identify the participants' reported practices related to the three main components of instructional design, as follows: content, assessment, and pedagogy.

Triangulation. Triangulation is a technique used to combine multiple methods and data sources in qualitative research (Patton, 2015). Triangulation can also be used to enhance the credibility of research by reducing the bias that comes from the use of single methods or data sources (Denzin, 1989; Patton, 2015). Denzin (1989) argues that no single method can provide a broad perspective of the empirical reality, and multiple methods of data collection must be used to overcome this issue.

In the present study, questionnaires, interviews, and written documents revealed different perspectives and contextual information of the participants. Thus, to integrate them and thereby construct a more enhanced perception of the engineering faculty beliefs and their actual practices in laboratories, I used triangulation strategies. These strategies occurred at two different levels: within the case and across the cases. At the within case level, the information of each participant was analyzed as a single unit. I tried to identify eventual alignment between the different sources, but also identify eventual differences between participants' self-reports (questionnaire and interview) and the written documents. At the cross-cases level, the results from the within case analysis were compared to identify similarities and differences between the participants. In addition, the results were triangulated with the literature on faculty beliefs to relate the present findings to other studies in the area.

4.7 Researcher Positionality and Trustworthiness

I am a faculty member who has been working with laboratory education for more than 20 years. In addition, I have designed and built several types of laboratory equipment for educational purposes. This background is a possible source of bias and may compromise the trustworthiness of the study. Several measures were taken to overcome this potential limitation and increase trustworthiness. First, the researcher is aware of the situation at the outset, and this awareness allows him to bracket (Ashworth & Lucas, 2000; Dowling, 2007) eventual biases from his experience. Second, a peer examination approach was conducted (Anney, 2014). The research design, questionnaires, and interview protocol were presented to my research group. Their feedback and suggestions were taken into account to improve the data collection instruments and the research design. Third, a pilot study was conducted. Four graduate students, three of them with significant experience in teaching labs courses were interviewed and provided insights on how to improve the interview protocol. The fourth participant focused on the wording and tried to explain the meaning he was making from each question. This process was rich and also helped to improve the interview protocol. Fourth, six interviews were coded by two researchers with significant experience in conducting a qualitative analysis. These researchers used the codebook generated through the constant comparative method phase. A follow-up discussion served to identify eventual differences and helped to reduce eventual bias. The rate of agreement between this researcher codes and the other two coders was above 85%. Finally, a thick description (Patton, 2015) of the whole study has been provided. Triangulation with other studies also increased the trustworthiness of this study.

4.8 Summary

In this chapter, I detailed the research design of this study. I first provided a general overview of the chapter and restated the research questions. Then, I described the essential characteristics of the research design, including the methodology, the setting, the cases, the participants, as well as the data collection and data analysis methods. Finally, I discussed some issues regarding my positionality and trustworthiness.

CHAPTER 5. FACULTY BELIEFS ABOUT LABS

This chapter addresses the following research question:

RQ 1: What are the faculty beliefs about the integration of laboratories into engineering education?

5.1 Introduction

In this chapter, I present the findings from phase one of this multiple case study. This phase aimed to identify how faculty members conceived the teaching and learning processes in the engineering education laboratories. Similarly to the study conducted by Samuelowicz (1999), I emphasized the faculty views of the engineering knowledge, the processes of teaching and learning in the labs, the roles of students and faculty, the role of laboratories, and the intended learning outcomes for laboratory activities. In addition, I compared the College of Engineering with the College of Engineering Technology at a large Midwestern University to identify qualitative similarities and differences in their faculty members' beliefs about teaching and learning in the labs.

5.2 Participants

Thirteen faculty members from the Colleges of Engineering and Engineering Technology participated in this study. Eight participants were from the College of Engineering, and five from the College of Engineering Technology. All participants had a background in engineering. Twelve of them had Ph.D. in the field of engineering, and one had a master's degree also in engineering. The faculty members occupied different positions, including Visiting Professor, Professor of Practice, Assistant Professor, Professor, and Associate Professor. In addition, participants were from the aeronautics and astronautics, electrical, mechanical, civil, chemical, and nuclear engineering programs at the College of Engineering, and electrical, mechanical and manufacturing engineering technology programs at the College of Engineering Technology.

5.3 Data Collection

Semi-structured interviews were used to gather participants' information. The interviews followed a protocol described in Appendix A. The questions explored different dimensions of the teaching and learning process in the labs, including knowledge, the role of labs, teaching and learning, and instructional design for lab activities, among others. Twelve interviews were conducted at the participants' office. One interview was conducted via Skype to accommodate the time limitations of the participant. Each interview lasted between 40 and 75 min, with an average time of 50 min. The interviews were recorded and transcribed by a third party. A questionnaire was used to gather participants' demographic and background information including their educational degrees, rank at the institution, time dedicated to teaching in the labs.

5.4 Data Analysis

A first step to analyze the data was to review all the transcribed interviews. In this step, while listening to the recordings, I reviewed each of the transcribed interviews to make corrections, add observations, and refresh the participant's voices in my mind. In a further step, I started to analyze the data. The interviews were analyzed carefully aiming to identify the participants' beliefs. Each interview was considered a single unit of analysis. The constant comparative method was used, and the similarities and differences between the participants' beliefs were identified according to eight broader categories defined at the outset, based on the theoretical framework proposed. The theoretical categories aimed to reveal the participants' beliefs regarding 1) The nature of knowledge in engineering; 2) The role of labs; 3) Teaching in the labs; 4) Learning in the labs; 5) The agent responsible for transforming the knowledge in the labs; 6) The desired learning outcomes; 7) The role of faculty; and 8) The role of students. The method also allowed space for new categories that could emerge from the data.

During the analysis, I identified a series of tensions contrasting what the participants espoused as their ideal beliefs with their actual practices. For example, one participant said, "trial and error is the only way students can learn," however, s/he said "but that is not possible" given some real institutional constraints such as large enrollment and lack of resources. To deal with these tensions, I decided to report in this chapter the beliefs participants espoused as their ideal beliefs within ideal scenarios. In the next chapter, I explore what participants described as their actual practices.

The use of the constant comparative method allowed in-depth comparisons between and within the different categories of beliefs espoused by the participants. This in-depth analysis revealed two broader perspectives on such beliefs. On the one hand, some participants expressed beliefs that emphasized the content-side of the instructional design. On the other hand, there were beliefs that emphasized the learners as agents of transformation. This dual perspective indicated that it would be possible to arrange certain beliefs along with a continuum ranging from a content-centered to a learner-centered perspective. Thus, I reviewed each of the nine categories of beliefs to identify those who could be arranged according to this dimensional view. Six categories were immediately identified and arranged as dimensions of beliefs. A seventh category was added to include the faculty beliefs regarding the role of instructors. I noticed that all participants indicated the central role of instructors as either mentors or consultants. Mentors challenged students and helped them to transform the knowledge by themselves. Consultants also helped students, but they also gave a lot of answers to students and sometimes these answers prevents students from transforming the knowledge by themselves. Two categories, the role of faculty and the view of students' abilities to deal with abstract concepts did not result in a dimensional perspective.

Following a similar approach proposed by Samuelowicz (2001), I coded the beliefs as A (content-centered), A/b (content-centered but with flavors of learner emphasis), B/a (learner-centered but with flavors of content emphasis), and B(learner-centered). Table 5.1 below describes each dimension of beliefs and the corresponding coding.

I reviewed all participants' beliefs and coded them following the coding scheme proposed in Table 5.1. Table 5.2 below, presents a summary of each participant's set of beliefs. As the coding scheme used was essentially qualitative and categorical, I used a qualitative approach to group the participants according to the different patterns found in Table 5.2. In the first step, I analyzed the patterns of beliefs presented in Table 5.2. The analysis indicated the existence of nine different patterns of beliefs, characterized by different sequences of letters. These letters indicated where each participant's belief was positioned in a continuum ranging from a content-centered to a learner-centered perspective. A summary of the different patterns of beliefs and the respective participants is presented in Table 5.3.

Table 5.1 Beliefs dimension and the coding scheme

Dimension	Content-centered	Intermediate categories		Learner-centered
Belief	A	A/b	B/a	B
Nature of knowledge	Externally constructed			Internally constructed
Role of labs	Connection theory and practice		Develop professional ways of being	Develop complex thinking
Teaching in the labs	Transmission of knowledge	Co-construction with focus on the content	Co-construction with focus on the ways of thinking	Construction of knowledge through open-ended activities
Learning in the labs	Through hands-on experiences			Through trial and error
The agent responsible for transforming knowledge	External	Faculty with students		Students
Desired learning outcomes	Students will know more			Students will learn differently
Role of instructors	Consultant			Mentor

According to Samuelowicz (2001), the nine different patterns of beliefs summarized in Table 5.3 would indicate the existence of nine different orientations to teaching and learning, since each pattern indicates a different and particular way to conceive the teaching and learning process in the labs. However, the tensions expressed by the participants and the reduced sample size of this study created difficulties to differentiate all these nine categories clearly. Also, the coding scheme proposed was a way to discretize the continuum describing the content-centred / student-centred perspective. This discretization, while allows a broad view of the different patterns of beliefs, also pose some difficulties since shadow zones might exist between two close but different beliefs. Thus, I adopted the following approach to identify the resulting orientations to teaching and learning in the labs. First, I identified in table 5.3 those participants who shared the same pattern of beliefs. This first analysis indicated the existence of three different groups of participants, each of them sharing a singular pattern. These three groups were: (a) Group A, composed by Eng_2 and Eng_6 who shared the pattern A A A B A A B; (b) Group B, composed by Eng_1 and Tech_1, who shared the pattern B B/a B/a A A/b B B, and; (c) Group C, composed by Eng_5, Eng_7 and Tech_4, who shared the pattern B B B B B B B. By analyzing the beliefs espoused the participants of these first three groups, I identified the first three orientations to teaching and learning in the labs. They were, Reinforce Lectures, Developing Professional Ways of Thinking, and Facilitating Expertise Development. However, there were six other patterns of beliefs which were different from each other, although with many overlapping characteristics.

Table 5.2 Resulting patterns of beliefs

Pattern	**Sequence of letters**							**Participants**
1	A	A	A	B	A	A	B	Eng_2 & Eng_6
2	A	A	A	B	A	A	A	Eng_4
3	A	A	A/b	A	A	A	A	Eng_3
4	B	A	A	A	A	A	A	Tech_3
5	A	A	B	A	A/b	A	A	Tech_5
6	B	B/a	B/a	A	A/b	B	B	Eng_1 & Tech_1
7	B	B	B	B	B	B	A	Eng_8
8	B	B	B	A	B	B	A	Tech_2
9	B	B	B	B	B	B	B	Eng_5, Eng_7 & Tech_4

Table 5.3 Summary of participants' beliefs

Dimension	Nature of knowledge	Role of labs	Teaching in the labs	Learning in the labs	Agent responsible for transforming knowledge	Desired learning outcomes	Role of instructors
Eng_1	B	B/a	B/a	A	A/b	B	B
Eng_2	A	A	A	B	A	A	B
Eng_3	A	A	A/b	A	A	A	A
Eng_4	A	A	A	B	A	A	A
Eng_5	B	B	B	B	B	B	B
Eng_6	A	A	A	B	A	A	B
Eng_7	B	B	B	B	B	B	B
Eng_8	B	B	B	B	B	B	A
Tech_1	B	B/a	B/a	A	A/b	B	B
Tech_2	B	B	B	A	B	B	A
Tech_3	B	A	A	A	A	A	A
Tech_4	B	B	B	B	B	B	B
Tech_5	A	A	B	A	A/b	A	A

To identify the orientations to teaching and learning in the labs reflected in the six different patterns, I reviewed all the six participants' interviews, comparing and contrasting their espoused beliefs with the ones reflected in the orientations found previously. This analysis indicated that Eng_4 shared the same orientation as the participants of group A above mentioned. In addition, Eng_3, Tech_3, and Tech_5, although espousing slightly different patterns of beliefs shared a common orientation towards Connecting Theory into Practice. Finally, Eng_8 and Tech_2 shared a pattern of beliefs oriented towards Supporting Students' Professional Development. The comparisons made and the resulting orientations were further explored in the following section.

5.5 Results

The results are organized in the following manner. First, I describe participants' beliefs in the eight categories defined at the outset, and in an emerging category that represents the participants' view of students' ability to deal with abstract concepts. Second, I organize each of the first seven different categories of beliefs according to a continuum ranging from a content-centered towards a learner-centered perspective. Finally, to better understand the role of the beliefs on teaching practices, I grouped the participants based on the differences and similarities of their espoused patterns of beliefs. The results of this process indicate the participants' idealized orientations to teaching and learning in the labs. Five main orientations were found. Finally, I compare the beliefs and orientations between the participants of the Colleges of Engineering and Engineering Technology.

5.5.1 Faculty Beliefs

In this section, I will report the idealized views of the participants regarding the teaching and learning processes in the labs. For each category of belief, I will present the different conceptions, supporting such conceptions with quotes from participants' voices.

5.5.1.1 The nature of knowledge

This dimension reveals how each participant described the knowledge and skills in their disciplines. Some participants described the knowledge and skills regarding the subject matter plus some technical and non-technical skill such as programming, teamwork, communication, and safety.

Other participants described the knowledge in terms of the expertise, or ability to deal with and solve engineering situations.

- Externally constructed (Eng_2, Eng_3, Eng_4 & Eng_6 / Tech_5)

A faculty member who espoused this belief saw the engineering knowledge as an external and well-defined body of concepts and principles, grouped by subject-matter or stated in the curriculum. A participant was explicit and described the engineering knowledge in her/his field as,

> every single course that is in the curriculum is a knowledge base; it's a knowledge component, that obviously is important. Otherwise, it wouldn't be in the curriculum. So the short answer to your question is every single course in the curriculum. (Eng_6)

- Internally constructed (Eng_1, Eng_5, Eng_7, & Eng_8 / Tech_1, Tech_2, Tech_3, Tech_4)

A faculty who espoused this belief saw the engineering knowledge as an internal ability to deal with the complexities of the profession. It may be characterized by the ability to use different concepts, principles, and skills when dealing with real-world engineering situations. These faculty members acknowledged the importance of learning concepts, principles, and skills but argued that engineering goes beyond just having such knowledge. One participant argued, after describing several specialties in her/his field and its related subject-matters,

> But, to me a more, I do not know if it is an abstract category, is the ability to use that knowledge. So the first category tends to be in a realm where students can memorize and regurgitate and practice, and I mean they need that, but by itself, if that is all they can do with it, they cannot do much. But, then taking that to a stage where they can apply that to problems. So look at a problem and say, "Well, okay, here's the problem we are trying to solve. Here's what we are trying to do. But, which of those tools and principles apply to this problem?" They have to have practice in doing that, or they just have no idea how to use the knowledge they have collected. (Eng_8)

A participant from the College of Engineering Technology expressed her/his belief in the following way,

> … I think it is really important for them to have an understanding of the basic ideas of mechanical engineering. Even more than a grasp of the facts. I mean, a grasp of the facts is important but more than that they need to understand the way of thinking that places ... An understanding of physics and a willingness to calculate and do experiments when they do not know what they are ... When they have got a problem, they have never seen before. (Tech_2)

5.5.1.2 Role of labs

This dimension reveals how each participant described the main role of labs. Three main roles were identified. They ranged from the simple view of labs as a way to help students to see in practice the concepts discussed in the classroom, to a more sophisticated view were labs help students to develop critical thinking and expertise in the field.

- Connection between theory and practice (Eng_2, Eng_3, Eng_4 & Eng_6 / Tech_3 & Tech_5)

Faculty espousing this belief saw the labs as a place where students reinforce the theory learned in the classroom by watching demonstrations, conducting well-structured experiments, or just playing with tools and concepts. These activities allowed students to go beyond abstractions and learn through experience by seeing, touching, feeling, measuring and other embodied processes. Six participants reported this belief. Two typical quotes from them are,

> Well currently, labs play a very important role of allowing the students to practice the knowledge they are receiving in the classroom, and that they read in textbooks to apply it in an actual atmosphere, get their hands dirty, and find, actually measure what they are taught. ... The labs are very important in that respect because the students can actually see in reality practice what they are learning and reinforce concepts. (Eng_3)

Similarly,

> For the lab, the lab is good to prepare the students to connect, basically what they have learned in theory to what is practice, right? Not everything goes a hundred percent perfect, right? Even though you analyze on the computers, yes you have this answer, but in real life, you have lots of this problem about preparing the lab, preparing how tight is the screws and all this stuff, all add up and make life or things not perfect. So, the lab is preparing the students to be aware that not everything is perfect if that makes sense. (Tech_3)

- Develop professional ways of being (Eng_1 / Tech_1)

Two faculty members espoused the belief that laboratories aim to allow students to get in touch with real-world practical applications that foster the development of new professional ways of being. To these faculty, the labs were not the place to develop a theory but a place where students deal with examples from the common situations in the field to develop practical expertise. One participant said,

> Answering your question, I think a laboratory is essential for ... If you have an engineering course, you must have laboratory practice, because this is how we show the students in the real world… Because, remember that in engineering school, 80-90% are going to go into the industry and going to start working right away, so they must have the practicality in hand. Some students, they want to stay in the university. They are going to become ... researchers, so they have a more fundamental neck, and they strive to have more theory and things like that. However,But in both cases, we must know how things work. HoweverBut, it is much more important for that 80% that goes to the industry you must know exactly how to put together parts. So, the laboratory has an essential contribution to that formation I think. (Eng_1)

A participant from the College of Technology presented a similar view,

> I actually have my own opinion of what we are doing with our labs. I feel like we have created labs that are focused on demonstrating what the theory says. Labs that are very

> focused on the textbook and demonstrating this theory but not very well demonstrating what's out there in the industry. Our students are not really very well fitted or trained to make abstractions from what the theory says into what the actual practice is. I feel that we should move away from this very highly theoretical labs and move to a more practical type of lab where the student needs to develop more of their own thinking and make abstractions on how to apply this knowledge into an actual situation that could be useful in the industry. (Tech_1)

- Develop complex thinking (Eng_5, Eng_7 & Eng_8 / Tech_2 & Tech_4)

Faculty espousing this belief saw labs as playing different roles in students' developmental processes. They argued that labs must progress from very basic activities, focusing on developing students' conceptual understanding, to more advanced and complex practices where students learn to deal with open-ended situations and decision-making processes.

> I think one of the things I would say is that labs need to be ... As a student progresses through the program, as they go from sophomores to juniors to seniors, I do think students need to be in more open-ended labs. Labs that don't have explicit instructions on, "Do A, do B, do C," as you might get in a freshman chemistry lab or something. I think we have to move towards more open-ended labs as a student progresses through the program. They cannot be cookie cutter. We have labs right now in our program that are very open-ended, and everyone might get a different answer, and there may be ambiguity in how it is written on purpose. (Eng_7)

5.5.1.3 Teaching in the labs

This category describes the participants' beliefs regarding the ways laboratories must be taught. Although all participants stressed the importance of laboratory activities in engineering education, there were few agreements regarding the ways the teaching process must occur. Similarly, as the beliefs about learning in the labs, some participants revealed a tension between their views on how labs must be taught and the ways they actually teach. These tensions will also be explored in chapter six.

- Transmission of knowledge by demonstrating the phenomenon, theory, or tool, and then engaging students in the hands-on activities. (Eng_2, Eng_4 & Eng_6 / Tech_3)

A faculty who espoused this belief believed that teaching labs involve showing the students the phenomenon, a theory or a tool, and after that, trying to engage students in hands-on activities aiming that students could be able to understanding and reproduce such knowledge.

One participant expressed this belief in the following way,

> In the lab, and that is why it is very important to design the experiment very, very carefully, you have to actually, you start from their end. You say, okay, here is a physical situation. Usually, physical situations are very messy. In the lab, you try to make them not messy so that you can then identify one thing. And then you work, and everybody then sees it, everybody understands that, and that is very, very, I guess, natural for people then to say, "Okay, yes, this happens this way," so you do that. And then, how do you then say, get the theory in there. It is the last thing you do. (Eng_2)

A participant from the College of Technology explains her/his approach in the following way, “so whatever they learn as the formula in the class, they kind of learn it hands-on, they kind of see it how that translated into a hands-on. (Tech_3)

According to this view, the instructor must first transmit his knowledge to the students and then engage these students in hands-on activities hoping these activities help students to internalize the transmitted knowledge. All participants described certain uncertainty regarding the effectiveness of this approach. Regarding this effectiveness, one participant said,

> I do not actually know to what extent it does. I guess it is a lot of wishful thinking. You just make them (students) play with it and see what comes up. And probably different students get different things out of it depending on their own experience with it. (Eng_4)

- Co-construction of knowledge by mentoring students during the hands-on activities. (Eng 3)

A faculty member who espoused this belief believed that teaching labs involved being in continual interaction with students while they are performing the experiments. The idea is to be mentoring the students, asking questions that would support the students' process of knowledge construction. Indeed, the faculty knows that the knowledge is already transformed in the experiment handouts, but believes that the mentoring process can lead students to more advanced knowledge. However, despite bringing a co-construction perspective, this belief is still grounded on a transmission of knowledge perspective where the knowledge from books and lectures must be transmitted to students. The lab activities facilitate the transmission process.

One participant expressed this belief in the following way,

> Well, the way I think this should be done is the instructor can ask questions but challenge the students because of the knowledge and experience he has, or she has. Come into the lab where students are running experiments, measuring variables, writing down data, sitting on tables, making plots. So come in, and I asked them, "Okay, what are you measuring right now?" We are measuring flow rate, we are measuring temperature, pressure, and composition for this reaction." So how do you think you're going to use that data, for what purpose? And once you fulfill that purpose, what else do you think you can do with what you produce? You produce a model, where are you going to use that model? Can you relate it to what you're learning in class? This being applied in industry, things like that. I come in and ask questions, and I challenge them to think beyond what is written in the handout." (Eng_3)

- Co-construction of knowledge by exploring ways of thinking in the profession and mentoring the students during hands-on activities. (Eng 1/Tech_1)

A faculty who espoused this belief believed that teaching labs involved first engaging students in a co-constructive process where the faculty not only introduced the topic and made connections with the profession, but also involved students in a reflective process that connected the demands of the profession with the experiment related activities. The idea was to help students to create interrelations between the theory, the experiments, and the professional ways of using such knowledge. To reach this goal, the instructors had to engage students in the hands-on activities and then provided some kind of guidance. This perspective was also heavily grounded on the transmission of knowledge approach, but this time the knowledge came mainly from the instructor.

Describing her/his approach, one participant said,

> Well, it is the goal for explain the experiment, giving examples what those are, and then asking, giving practical problems for them, not problems they have to solve by equations or anything, but saying ... Let's say that I have a problem. So, they (the students) can start thinking of that, and they came up with very... So, I ask ... Let's say we would have to do that, how are we going to do? Then at the end, we end up to have to make or measure something related to the experiment we are going to do. So, you ask them how they think they are going to do that. Then, for their own conclusions, we end up with, "Okay, so we have to measure this. So, let's learn how to measure that," and then you go back to the experiment. I do that even in class when I'm doing theory is the same thing like that. (Eng_1)

- Knowledge construction through open-ended activities (Eng_5, Eng_7, & Eng_8 / Tech_2, Tech_4 & Tech_5)

A faculty who espoused this belief believed that teaching labs involved designing open-ended situations where students needed to go through a solution process that goes "beyond just following a formula or following steps." Six participants espoused this belief, and they stressed the importance of open-ended situations in creating opportunities for students to construct their own knowledge through planning, trial and error, decision-making, and synthesis. The perspectives of these three participants are represented by the following quote,

> I think one of the things I would say is that labs need to be ... As a student progresses through the program, as they go from sophomores to juniors to seniors, I do think students need to be in more open-ended labs. Labs that don't have explicit instructions on, "Do A, do B, do C," like you might get in a freshman chemistry lab or something. I think we have to move towards more open-ended labs as a student progresses through the program. They cannot be cookie cutter. We have labs right now in our program that are very open-ended, and everyone might get a different answer, and there may be ambiguity in how it is written

> on purpose. Things that cause a student to think as opposed just to follow. Our labs, as we get to our junior year, and then into our senior year, it is not like following a recipe to make a cake or a pie or something. They get more open-ended, but that I think it ultimately makes the students better because it is not following a recipe. It is following, here's the big idea, what we want to do here. Let's see how you think about it. Let's see if you can make decisions that are intuitive, and they are good. (Eng_8)

Comparing the current state of laboratory education with an ideal situation, Tech_2 argued,

> The state right now is that not all classes have lab components. Many do. The way it works right now is, typically, there are lecture sections, and there are lab sections, and they're coordinated. The same ideas are present in both, so the students can go back and forth between concept and practice and do it every week and that works well, that works very well. Ideally, they would spend undirected time in the lab, where, rather than going through planned activities, they were just given an open- ended request. They had to explore what ideas were needed and what equipment was needed and figure it out. There'd need to be a lab supervisor, a technician or something, in there to make sure they do not break too much stuff or make sure nobody gets hurt. But, beyond that, that is how I would do it. I learned that way, although I did it by accident.

5.5.1.4 Learning in the labs

This category describes the participants' beliefs regarding the ways students learn in the labs. Overall, all participants stressed the educational importance of hands-on experiences where students can see, touch, build, apply, analyze and/or synthesize knowledge. All participants but two stressed the importance of fostering teamworking. In addition, most of the participants expressed the belief that learning in the labs occurs through a trial and error process. However, as there were questions that prompted participants to provide their idealistic view of the educational process, some participants revealed a tension between their views on how students best learn in the labs and the limitations of the actual laboratory approaches. These tensions will be further explored when I present some additional findings from this study, in chapter Six.

- Students learn in the labs through hands-on experiences (Eng_1 & Eng_3 / Tech_1, Tech_2, Tech_3 & Tech_5)

Six faculty members espoused the belief that students learn in the lab because they have the opportunity to see, touch, and work with real-life equipment. These faculty members believe that the experiments help students to see the relation between the theory and the practice in the field, and also develop different skills such as teamworking, measurement, and communication. One participant expressed her/his view on how student learning in the lab, in the following way,

> By seeing, like for example ... That is the reason I like laboratories is that you really go there you have to put things together and make things work. It is a practical work of some theory that you have walked before sometimes, but it makes things work, and through examples, through real life, real-world examples. (Eng_1)

Similarly, a participant from the CT said: “so our students, they are very much driven by hands on. They want to see things. That is how they learn most.” (Tech_5)

It is interesting to note that, although these faculty stressed the importance of the hands-on activities on students’ learning, they did not place any emphasis on eventual trial and error processes that occur during the experimentation.

- Students learn by trial and error (Eng_2, Eng_4, Eng_5, Eng_6, Eng_7 & Eng_8 / Tech_4)

Seven faculty members emphasized the role of trial and error approaches on students’ learning. Although this emphasis on trial and error was common among all of these faculty, the approaches seemed to be considerably different. While two faculty, Eng_4 & Eng_6, expressed the idea of experimenting within an experiment or trying different possibilities within the scope of an already defined experiment, the other five faculty members expressed the idea that students learn best by trying and failing while having to operate within a broader scope of an open-ended problem. To these later faculty, students learn best in the lab when they have the opportunity to design an experiment or go through a decision-making process where failure is more than welcomed. For example, expressing why s/he believed students learn best through open-ended activities and trial and error, one faculty said,

> They would have to think much deeper because they would have to go ... They would not get something that has already been laid out for them or anything. They would have to start from zero. They would have to go through the whole trial and error experience; the process of actually designing the experiment is already challenging. How do I design the experiment? I extract only the information that I need and not all other kinds of stuff. You have to think hard to do that. It is very, very challenging and it is kind of open-ended. (Eng_2)

A typical quote from one of the former two faculty members is,

> So the labs need to be done in such a way that the student is free to truly experiment and play and get this direct experience of the physics, or the system that they are analyzing. So ... And they can try different things and fail, and learn through that process of trial and error. And to do that, again, you need, first of all, time. Actually, that is probably the biggest resource that is lacking because with large enrollments you just don't have enough time to get the students through the lab and give them enough time individually to try things. (Eng_6)

Although seven faculty members expressed their belief in the importance of trial and error processes, five of them expressed some non-conformity with the current approaches in the labs. They argued that limitations such as large enrollment, time, lack of TAs and resources prevented students from truly engaging in trial and error activities. (Eng_2, Eng_4, Eng_5, Eng_6, Tech_4)

5.5.1.5 The agent responsible for transforming knowledge

This dimension reveals participants' beliefs regarding who was responsible for organizing/transforming knowledge in the labs. The analysis indicated three different beliefs. They are,

- External agent (Eng_2, Eng_3, Eng_4 & Eng_6 / Tech_3)

Faculty who espoused this belief believed that students have a minimal effort in constructing/transforming the knowledge in the labs. They argue that it is important to align everything from books and manuals to facilitate students' activities. In this case, the knowledge is transferred to students through well-structured lab manuals and handouts, or directly from instructors during the activities. For example, Eng_3 describing her/his lab activities said,

> Really I think there's not much there because the way those are set up and designed for different experiments that they run, different concepts that are covered in course. They are given very precise instructions in the handout, what they have to do and what the objectives are. And the activities are just come in, read your handouts before, come prepared with your personal protection equipment, and start running the experiment, okay? There are not really many activities beyond that. They need to use different instruments, but then everything is very well spelled out. (Eng_3)

Similarly, Tech_3 describes her/his teaching approach in the following way,

> Giving them hints or clue or always referring to them what they are doing is this is what we were learning in class a couple of days ago. So, helping them make the connections. So, for example, … whatever you wanna call it, so we do that experiments, and then telling them that, what we learn in class, this is the formula for calculating that bend. So, keep referring to the students what they are doing in the lab that this is what the theory behind it. So, kind like of put that in their head. So making the connections.

- Faculty/Instructors with students (Eng_1 / Tech_1 & Tech_5)

Three participants espoused the belief that students must be actively engaged in building their own knowledge with different instructional support from the faculty and instructors. The first participant (Eng_1) believed that students must be involved in understanding and being able to define and plan different experiments depending on their needs. As pre-lab activities, s/he used real-life problems associated with the ongoing experiments and engaged students in exploring how an expert would do to solve such problems. Everything was under the control of the faculty member, but at least students had the opportunity to think about the experiment and discover how it was connected with their profession.

One participant from the College of Technology adopted different approaches depending on the level of the course. For the low-level courses, s/he provided a lot of guidance but still leaving room for students to think for themselves, and provided the necessary support. In the higher level courses, s/he adopted project-based learning and supervised students along the semester. Describing students' typical activities at low-level courses, s/he said,

> They look into what's going on. They make a drawing or take a picture and point to different things. Then, the next level is connecting things so how do you put parts into the system, what's going to happen if you connect here or there. Then I come and look at their connections or their diagram. I tell them what's right or what's wrong and then once that is done, then I'll let them turn it on, and I explain what's going on. (Tech_1)

- Students (Eng_5, Eng_7 & Eng_8 / Tech_2 & Tech_4)

To five participants, students should be responsible for creating, transforming or organizing the knowledge while developing the lab activities. In this case, the faculty or instructor was responsible for creating and maintaining the learning environment where students felt safe to explore different ideas. One participant expressed her/his view in the following way,

> I cannot force them to learn, but to give them and create an environment, both in terms of the personality and the ... What's the word I'm looking for? The atmosphere? There's another word. Climate? I don't know. I forgot what the word is, but I try to prepare and create an environment or a climate where students feel comfortable failing, and learning, and being engaged. I want to create an environment where they can ask me questions and not be scared to say, " [Eng_7] is going to yell at me because I'm supposed to know the answer to that." (Eng_7)

Tech_2 stressed the importance of patience when working with open-ended labs and students have to tackle the situations by themselves. Regarding this topic, s/he said,

> Patience, lots and lots of patience. Patience and understanding that it is not about you; it is about the students. That you're willing to let them struggle a little bit and even if they get frustrated, don't lose your temper. Let them struggle helpfully, you're not trying to be cruel, but when they start to get too frustrated, that is when you give them a nudge to keep them moving.

5.5.1.6 Desired Learning Outcomes

This category describes faculty members’ desired learning outcomes from laboratory education. I adopted the approach proposed by Samuleowicz & Bain (1992), and identified two main perspectives,

- Students will know more (Eng_2, Eng_3, Eng_4 & Eng_6 / Tech_3 & Tech_5)

To participants holding this belief, the desired learning outcomes of laboratory activities could be expressed in quantitative terms. The idea was that at the end of the lab courses, students would have learned concepts, principles, and skills according to a series of learning objectives expressed in a syllabus.

- Students will know differently (Eng_1, Eng_5, Eng_7 & Eng_8 / Tech_1, Tech_2 & Tech_4)

According to this view, at the end of a lab course, students must be able to think differently. Participants still expressed the importance of knowing more, but the focus is in on changing students’ way of thinking towards the profession.

> Let's say that we have all those topics, so the students how to be able to do that, but if you ask me from the professional development point of view, I think that at the end of my class, the student should be able to actually think twice about how to solve a problem, read very well and understand the problem that is being posted there, how to understand the tools for me, understand all the tools that are available to solve that problem. For example, if you have four unknowns, you need four equations, thing like that, and then be systematic in a way to solve problems. You could be systematic, and there is one side of solving a problem

> that is the systematic way, and the other one is the most stochastic way, that requires you to actually think out of the box. There is no recipe for that. (Eng_5)

5.5.1.7 Role of Faculty

This category describes the participants' beliefs regarding the role of instructors in the labs. The participants of this study revealed a dual perspective regarding their roles as a faculty and the roles of instructors in the lab. First, all participants from the College of Engineering mentioned that they do not teach or lead the labs. Their role is oriented towards lecturing, instructional designing, and management. Second, participants from the College of Engineering said that the teaching assistants were responsible for running the lab activities. Thus, I will discriminate below what the faculty saw as their roles and what they saw as the lab instructors' role in the lab. Participants also revealed certain tensions between their idealistic view and the reality in the labs. These tensions arose because most faculty did not teach the labs and also due to others constraints such as time and large enrollments. First, I will present what the faculty saw as the main role of instructors, and then what they see as their role.

Instructors' roles

- Mentor (Eng_1, Eng_2, Eng_5, Eng_6 & Eng_7 / Tech_1 & Tech_4).

Seven participants revealed the importance of being together with students, asking questions, challenging them and also coaching them during experiments. In general, they argued that the instructors must not provide immediate answers to students but, instead ask questions that would foster a reflective process on students' minds. A typical quote from one participant was,

> … and you become more of a coach, and you purposely do not provide as much information, and you purposely watch them stumble, and you let them know when they stumble, and then you help build them back up. But you do not give them the solutions, and once again, it comes more the facilitator/coach role, and less of the I guess a salesman. (Eng_7)

Despite this belief, three participants also revealed that although mentoring is an ideal situation, it cannot be achieved due to several constraints such as lack of time, TAs, resources, among others.

To these participants, instructors should give answers to the students to help them to finish the experiments. One participant said,

> In an ideal world, if we lived in Athens 2000 years ago, then the instructor would only pose the questions and then let the students do all the process. The instructor should only ask questions. He should not give answers, but unfortunately, we have to give them some answers so that they can move on to the next part. (Eng_2)

Similarly, another participant revealed his vision in the following way,

> Like in a dreamland, you would work in the lab while the students are doing an experiment, and you can sit down with them, and spend 15 minutes or something, and play with the experiment with them, and say "Why do you think this is happening? And what if we do this? Can you guess what's gonna happen here?" This is not gonna happen, ever, under the current system. (Eng_6)

In addition to the three above mentioned participants, two other expressed a contradictory vision. At the same time, they believed their role was to be mentoring the students in the lab; they also admitted that they would not be present during the lab experiments. In other words, they use expressions such as “I will be mentoring” or “I will be guiding” but when asked if they would present in the labs, a common answer was,

> No, I mean I already know that for the next semester, I will not be able to be present all the time in the lab. That is the reason I'm asking for a lecture when I'm going to tell them what they are going to do. (Eng_1)

- Consultant (Eng_3, Eng_4, Eng_8 / Tech_2, Tech_3 & Tech_5)

The word consulting serves to express different ways faculty conceived the instructors’ role in the labs; all of them were related to the amount of support students must receive during the lab activities. In general, I am using the word consulting to express a process by which the instructor provides the answers to students while they are in the labs. It is the inverse of mentoring. Three participants revealed the need to provide high levels of support to students which mean almost answering everything, and sometimes doing the work for the students. Two participants used almost very similar ideas to describe their visions,

> Ideally, the instructor in the lab should ... He should just like teach the students, "Okay, here is this instrument. This is what it does. This is how you use it. This is what you do." Make them familiar with the equipment and the apparatus so that they can run the experiment and all that. Ideally, you should then pull back and let the students try things on their own and eventually make the connection with the theory, but that is not possible. Then the instructor needs to intervene a little more, and he needs to give them, tell them what to look for. This is already a problem. They should discover that on their own, but there is no time for that, so the instructor... And then, at that point, again, the instructor should not say anything, and he should let the student discover the connection with the theory, but this is not possible. (Eng_2)

And,

> The issue is that the students have very limited time and opportunity to actually experiment within the experiment, and do something. So pretty much they go in, a TA holds their hand to do something in 15-20 minutes, and that is about it. (Eng_6)

Two participants expressed a dilemma in controlling how much help instructors should provide to students. The following quote gives an example of this tension,

> And there is a dilemma relative to how much you require the student to figure that out (the solution), versus how much you do that for them. Because when they are first learning it, it may be too big a leap to figure that out. But over time, the objective is that they get better and better at figuring that out for themselves. So it does depend on how far along they are in their development, as to how much you do that for them. (Eng_8)

- Lecturer (Eng_2, Eng_5, Eng_6, Eng_7)

Beyond the lecture component in a course that has both lecture and labs, participants also stressed the importance of having lectures on the labs. In general, these lectures aim to introduce some theory and explain lab procedures. Here is how one participant described her/his approach,

> The lab is more structured in the sense that it is always the same. The TA will talk about the experiment, so there is a blackboard, and there is a screen with PowerPoint slides. There are some iClicker questions. (Eng_5)

- Grader (Eng_1, Eng_5 & Eng_6). Three participants have graders to evaluate the lab reports. That means, these faculty members did not assess the lab reports by themselves. They have teaching assistants who read and grade the reports.

Faculty Roles

- Lecturer.

All participants mentioned their role as lecturers, indicating that they were responsible for the theoretical part of the courses. However, while all participants from the College of Engineering informed that the TAs were responsible for running the lab activities, only one participant from the College of Engineering Technology mentioned that TAs ran her/his labs. S/he stressed, although, that s/he taught at least one lab section per semester. Another professor, who was teaching a lab course only, reported the importance of lecturing to students about the relationship between the experiments and the profession. Thus, s/he added one hour every other week to provide such background to students. S/he said,

> Then, I think all the labs must have a special lecture before the lab. That is also what I'm asking for. Every week before the lab I'm going to put all these students together, not only each section, and then I'm going to explain what's that lab for and how it links with the real world. (Eng_1)

- Instructional designer

All participants described some level of involvement with instructional designing activities. This involvement, in general, was less related to changing the contents of lab activities, and more towards improving the pedagogy in the labs and the development of assessment strategies. The limitation on the content side may be associated with the original curriculum, ABET objectives, and need to submit any change to the curriculum committee. One participant described her/his level of autonomy to make curriculum changes in the following way,

> I will say 70%. Like this is a core course. I cannot just go there and teach nuclear engineering, but the topics are part of what is given. How I teach that or how I reconfigure the labs, I have autonomy. I can actually make changes….The topics are kind of fixed. I mean, this is what we have in the curriculum. I cannot re-change things. (Eng_5)

Two participants expressed the role of inheritance in their lab activities. They said that their labs were designed some time ago, and they still followed such experiments and structures. One participant said,

> The course existed before I came along, even though that course, although I have had a connection to it for a very long time because I was a TA for it when I was working on my PhD in the mid-90's. So, I have to say partly the objectives are inherited, but I try to look at them and think about whether the objectives make sense. (Eng_8)

Two participants from the College of Engineering made changes in the content of their labs. The first one just added one new experiment and designed the whole instructional approach for that experiment. The second one substituted one software tool for another and had to make adjustments in the content. In the College of Engineering Technology, two participants created the lab courses “from scratch.” If making changes in the content part is somewhat difficult, adapting the pedagogy to assist better the students is very common among participants.

Eleven participants reported concerns regarding improving the way they present the content to students. Eng_1, for example, completely revamped a lab course. Due to the limitations associated with the curriculum committee and ABET, s/he made few changes in the content part of the course.

However, significant changes were made to the pedagogical approaches. S/he created pre-lab activities, added a one hour lecture every other week to explain the importance of such labs and start to incorporate virtual labs as a way to scaffold students towards the procedural knowledge and also conceptual knowledge. These virtual labs will be used as a pre-lab component.

Four participants from the College of Engineering stressed their role in developing new ways to assess students' learning. In general, they stressed the importance of developing very well detailed rubrics for the lab reports, especially to guide TAs while grading the student's reports. One participant suggested more interaction between the engineering faculty and engineering education researchers develop new assessment instruments.

- Management (Eng_1, Eng_4, Eng_5, Eng_6, Eng_7 & Eng_8 / Tech_1, Tech_2 & Tech_4)

The second most cited instructors' role was associated with management activities. From the thirteen participants, nine mentioned this role, and four considered management as their main role (Eng_4, Eng_5, Eng_6 & Eng_7). Indeed, these nine participants used different words to describe their managing activities, including management, coordination, supervision, organization, and monitoring.

In general, participants from the College of Engineering argued that, as they do not teach the laboratories activities, their main role involved making everything working well. This means, preparing the Teaching Assistants (TAs), stating the assessment procedures, providing the supplies, among others. One participant explained his role in the following way,

> Well, the practical element recognizes my role as primarily a manager's role. Because, as I said, it is a management exercise. So I need to be essentially thinking and putting the procedures in place, so that all of these things happen, happen properly, on time and consistently, whether it's the setup of the lab, and prepping the TAs for the labs, or the grading calibration, all these things I'm managing on the week to week progression. So, as a lab instructor, your number one job is a management job. It is not a teaching job. (Eng_6)

Another participant described her/his role as, “I am like the CEO of the course, right? I do not even go there, but I manage it in that way.” (Eng_5)

Two participants (Eng_1 & Eng_8), although acknowledging that they did not teach labs directly, described the importance of monitoring the lab activities. One of these participants expressed her/his role in the following way,

> I deal with a lot of labs, and I try to poke my head in them occasionally, but I don't really get to observe that much in the labs, but I try to do what I can to connect with students to find out what's happening as well and see if there's anything that needs attention that way. So, yeah, I have the duty of teaching it in the lecture, but I do have a responsibility for knowing what's going on in the lab and trying to make sure things are dealt with if there's ... something needs attention. (Eng_8)

On the other hand, three participants from the College of Engineering Technology also expressed activities of coordination and management, but rather than concerns with TAs they emphasized logistics to guarantee that everything was in place in the labs, that equipment is working well and the students are safe.

- Motivator (Eng_1, Eng_7, & Eng_8 / Tech_1 & Tech_4)

Five participants believed they were the main responsible for motivating students. Two participants believed that what motivates students in the labs is the awareness about the importance of the labs, and the link with the real world and profession (Eng_1 & Eng_8). A typical quote from them is,

> So, part of my job is to keep them motivated and make sure that they understand all the procedures, and they understand the importance of the results they are getting and what's the theory behind that, but it's more important what that result they're getting in the lab how this is important for their application later. I must give them this link to the real world. (Eng_1)

One participant believed s/he was responsible for motivating students by creating a safe environment for students. S/he said,

> I cannot force them to learn, but to give them and create an environment, both in terms of the personality and the ... What's the word I'm looking for? The atmosphere? There's another word. Climate? I do not know. I forgot what the word is, but I try to prepare and create an environment or a climate where students feel comfortable failing, and learning, and being engaged. I want to create an environment where they can ask me questions and not be scared to say, "Professor is going to yell at me because I'm supposed to know the answer to that. (Eng_7)

- Provider of feedback (Eng_3, Eng_6 & Eng_7 / Tech_5)

Four participants stressed the importance of providing formative feedback to students. They saw this feedback as an important element to help students to improve their performance, especially in writing reports. Talking about the characteristics of a good instructor, one participant said,

> The other part of this is one of the other things that could be challenging where I have seen some lab instructors fail is they do not get feedback to the students promptly. This is also important to about to say, "Okay, you wrote a lab report. Before you write the next lab report, I'm going to give you some feedback on this lab report." (Eng_7)

Similarly, Tech_5 said, a good instructor is,

> Somebody who is able to provide the right feedback, and personalized feedback. Somebody who can understand the special needs, particular needs of students. Somebody who has the technical knowledge and the professor must know the material of course. Knowledgeable, being able to provide good feedback, being able to think very quickly, I think, on their feet.

- Grader (Eng_2, Eng_3 & Eng_7)

The role of grading reports was expressed by three faculty members. Two of them expressly assumed this role. One faculty mentioned grading in a generic sense and did not define who was responsible for the grading process.

5.5.1.8 Role of students

This category describes the participants' beliefs regarding the role of students in the labs. The participants in this study described students' roles mostly in four main themes: preparation, participation, group work, and reports. Participants also revealed certain tensions between their idealistic view and the reality in the labs. These tensions will be detailed in Chapter 6. The resulting beliefs are,

- Preparation (Eng_1, Eng_3, Eng_4, Eng_5, Eng_7 & Eng_8 / Tech_1, Tech_3 & Tech_5)

Nine participants stressed the importance of students' prior preparation before the lab activities. Among the preparatory activities, they cited reading the theory, being familiar with the lab procedure, and running pre-labs.

- Participation (Eng_1, Eng_3, Eng_4, Eng_5, Eng_7 & Eng_8 / Tech_1, Tech_2, Tech_3, Tech_4, Tech_5)

Eleven participants placed special attention on the importance of being actively engaged during the lab activities. This engagement, however, had different perspectives. First, some participants reported the importance of respecting safety rules, following instructions, showing up on time and collaborate with other members of the group. Other faculty stressed the importance of more intellectual engagement, including trying different approaches and asking questions.

- Teamwork (Eng_1, Eng_3, Eng_5, Eng_6, Eng_7 & Eng_8 / Tech_1, Tech_2, Tech_3, Tech_4, Tech_5)

Eleven participants stressed that group work is part of their lab activities. It was almost taken for granted that students must work in groups when doing labs. Four faculty members stressed the importance of students learning how to work in teams. However, only two of them reinforced the idea of working in teams to collectively construct knowledge. In other words, only two faculty members stressed that students should learn from each other. Thus, it was not clear from the interviews if teamwork is a way to foster the social construction of knowledge, a way to deal with the large enrollments, or a taken for a granted approach based on tradition. Also, one participant positioned himself as contrary to group work in labs (Eng_2). S/he argued that students learn best individually or in a group of two, and when they work in groups, there are always students that do not collaborate with the others. A second participant (Eng_5) expressed the opposite view as Eng_2 and argued that the best way to learn is from peers. However, s/he said s/he did not know if that approach happened in the labs s/he was responsible for since the labs were led by teaching assistants. Only one participant did not mention group work anytime. Finally, two participants mentioned the use of peer evaluations tools to assess students' teamwork.

- Reports (All Engineering participants / Tech_3 & Tech_5)

Students must write reports at the end of the lab activities. This belief was unanimous among all participants at the College of Engineering. Two participants from the College of Engineering Technology mentioned the use of reports. The reports were generally used to grade the students. Four participants mentioned the importance of developing communication skills among students, and used reports as a way to foster such skills (Eng_1, Eng_3, Eng_6, Eng_7). These faculty also mentioned the importance of providing feedback to students on how to write the reports.

5.5.1.9 View of students' abilities to deal with abstract concepts

This category of beliefs describes how participants viewed their student's cognitive abilities to deal with the concepts, principles, and skills in the classroom and in the labs. Not all participants expressed beliefs regarding this category. Eleven participants, six from the College of Engineering and five from the College of Engineering Technology, described four different but sometimes complementary perspectives. The perspectives are,

- Students have difficulties with abstract concepts (Eng_2, Eng_4, Eng_6)

Three participants from the College of Engineering believed their students were not prepared, and sometimes not able to deal with the abstractions necessary to connect theory into practice. The three of them believed that students did not have such abilities. Two of these participants associated this lack of abstract skills with the educational system that does not prepare students to make abstractions. An example of such belief was expressed by Eng_6,

> And, the majority of the students actually lack almost entirely the ability of abstract thinking. So if they see a mathematical equation with terms like pressure and temperature and velocity, these are just symbols to them. They have no idea what they mean. So the equation does not allow them to develop intuition. Other educational systems, and other places, they build that earlier on, so the students actually can relate math to physics in an abstract sense. This is not the system in the United States. (Eng_6)

One participant associated this lack of abstract skills to the intrinsic nature of human beings and to the inherent complexity of the abstract concepts. S/he said,

> Because it is abstract. Theory's abstract and the students are trying to learn how to think. For them to work with abstract ideas is practically impossible. They can use formula but to actually make the abstraction and say, this mathematics is really this and not an idea that's formed in your brain, completely outside of experience, is actually exactly what's happening, in reality, is a miracle. And we are not born with that notion that our mind can abstract itself and describe the universe. Even when we go to class, we do not get it. It is just, "Oh yeah. We have to do this. This is a formula so that, so I can do this one for now" and all that, but they do not get it. (Eng_2)

- The learning styles of engineering technology students are different (all engineering technology participants)

All participants from the College of Engineering Technology also saw students' difficulties in dealing with abstractions, but all of them associate these difficulties to a particular learning style that is highly grounded on concrete experiences, instead of abstractions. A typical example of this belief is,

> Our students are very special and different. We attract students that are very hands on. They want to touch things; they want to see things. The theory is fine with them, math, they can take the math, but if you just stay at the math level, there's a bunch of questions, they will disengage. (Tech_5)

- Developmental view (Eng_7 & Eng_8 / Tech_2 & Tech_4)

Four participants presented a perspective that acknowledges that students begin college with a basic set of skills and competencies, and eventually face difficulties in grasping the knowledge. However, they argued that the engineering knowledge must be built through a developmental process, starting from well-defined experiences but, as soon as possible, engaging students in open-ended approaches that help students to build their own knowledge. In sum, these participants see the students moving from novices who need to learn the basics, to a more advanced level of expertise where knowledge is built by themselves.

- Students are highly capable (Eng_1)

One participant viewed her/his students as highly competent, able to learn whatever necessary, as longs as these students had the right motivation.

> Well, I think motivation is the main one that we have discussed before, because if you really want to learn something you're going to learn it, because the students here are top, they are top students. If they are correctly motivated, they are going to learn. The problem is when you do not get them, and they are not interested in your lecture, or in your lab, that is the case. So, I think motivation is the main part.

5.6 Discussion

5.6.1 Derived Faculty Orientations

The qualitative analysis of the different pattern of beliefs resulted in five different groups, which were translated into orientations. Each group represented patterns of beliefs that were representative of a particular way a faculty conceived the teaching and learning processes in the labs. These conceptions are what scholars call orientations to teaching and learning. To better interpret these orientations associated with each set of beliefs, I arranged the five resulting orientations following the same approach used to code the beliefs. This time, the orientations were arranged from left-to-right according to the number of beliefs coded as A’s and B’s. The final arrangement, depicted in figure 5.2, illustrates the five orientations as progressive stages of conceptions that emphasize the content towards conceptions that emphasize the learners.

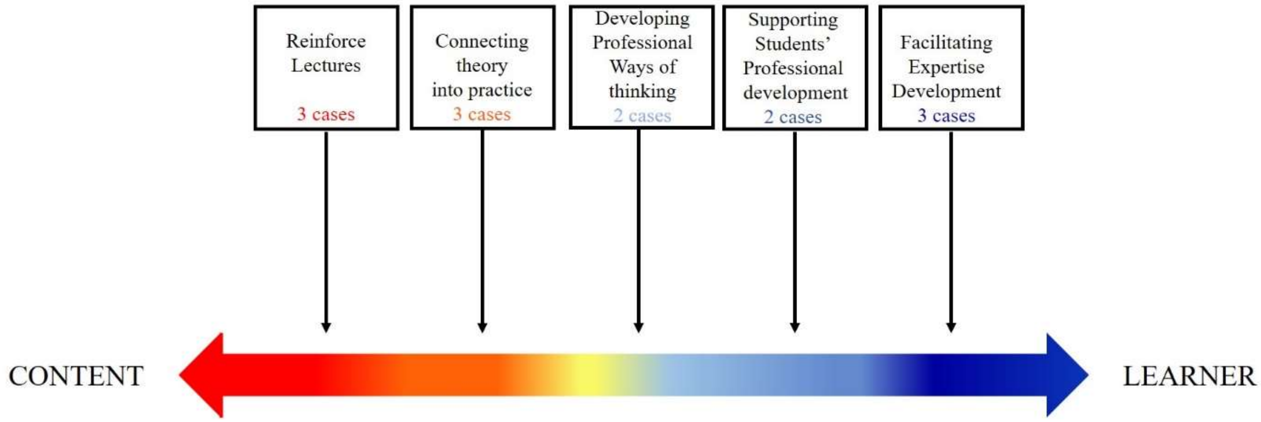

Figure 5.1 Five orientations to teaching in the labs

In the following sections, I will discuss each orientation according to the specific patterns of beliefs presented in each associated group.

5.6.1.1 Orientation 1: Reinforce Lectures

Table 5.4 Patterns of beliefs in Group 1

Dimension	**Nature of knowledge**	**Role of labs**	**Teaching in the labs**	**Learning in the labs**	**The agent responsible for transforming knowledge**	**Desired learning outcomes**	**Role of instructors**
Eng_2	A	A	A	B	A	A	B
Eng_4	A	A	A	B	A	A	A
Eng_6	A	A	A	B	A	A	B

The patterns of beliefs expressed by the participants in this group suggest an orientation to teaching that places a strong emphasis on content rather than the learner. To these faculty, the main goal of the lab activities was to reinforce the lectures. Thus, I called this orientation, Reinforce Lectures.

This group brings together three participants who expressed beliefs highly content-centered. Eng_2 and Eng_6 revealed the same pattern of beliefs and Eng_4 diverged from the other two only regarding her/his view of the role of instructors. While Eng_4 saw instructors as guides who control the amount of support to students, the Eng_2 and Eng_6 expressed a more idealistic view where instructors are mentors who challenge the students while they are conducting the experiments. In general, participants in this group conceived the knowledge in the profession as externally constructed. Labs were seen as places that serve to reinforce the lectures. According to these participants, in the labs, students could see the connection between theory and practice and make sense of abstract concepts. Teaching in the labs involved the transmission of the knowledge from the instructor or from the manuals to students. To these participants, students learn best through trial and error processes. However, they revealed the importance of giving precise instructions to students. Thus, the agent responsible for transforming the knowledge in the labs was external. It could be whether a book, a manual, a handout, or the instructor.

5.6.1.2 Orientation 2: Connecting theory into practice

Table 5.5 Patterns of beliefs in Group 2

Dimension	Nature of knowledge	Role of labs	Teaching in the labs	Learning in the labs	The agent responsible for transforming knowledge	Desired learning outcomes	Role of instructors
Eng_3	A	A	A/b	A	A	A	A
Tech_5	A	A	B	A	A/b	A	A
Tech_3	B	A	A	A	A	A	A

The patterns of beliefs expressed by the participants in this group were highly similar to the previous one with a small difference: a strong emphasis on the benefits of the hands-on approaches that help students to connect the theory from the classroom with the real world. Thus, I called this orientation Connecting Theory into Practice.

Faculty in this group also placed a strong emphasis on content rather than the learner. The idea of using the labs to reinforce the lectures was also the same as the orientation one. However, reviewing the interviews from each participant in this group I noticed a slight difference. While participants in group one focused just on supplementing the lectures as a way to overcome students’ limitations with abstract skills, participants in group two (this group) aimed not only to supplement their lectures but also to develop some practical skills such as measurement, programming, and equipment operation, among others. This group brings together three participants who expressed beliefs heavily content-centered. The three participants had slightly different patterns of beliefs. While Tech_3 conceived knowledge as internally constructed, characterized by the ability to self-learn, the other two agreed with each other and described knowledge as externally constructed. The three participants completely disagreed regarding teaching in the labs. Eng_3 conceived teaching as a co-constructive process, Tech_5 stressed the importance of knowledge construction through open-ended activities, and Tech_3 was heavily focused on transmitting knowledge. As a final divergence, while to Tech_5 faculty and students must share the knowledge construction in the labs, to Tech_3 and Eng_3 everything must be spelled out to students.

5.6.1.3 Orientation 3: Developing professional ways of thinking

Table 5.6 Patterns of beliefs Group 3

Dimension	Nature of knowledge	Role of labs	Teaching in the labs	Learning in the labs	The agent responsible for transforming knowledge	Desired learning outcomes	Role of instructors
Eng_1	B	B/a	B/a	A	A/b	B	B
Tech_1	B	B/a	B/a	A	A/b	B	B

This group brings together participants who expressed beliefs midway in the continuous content-centered/learner-centered. The two participants in this group have a very similar view that acknowledged the importance of theory on the education of engineers but believed that labs are not the places to reinforce such a theory. To these participants, lab activities must aim the development of professional skills associated with the applications of the engineering knowledge to solve engineering problems. Thus, I called this orientation Developing Professional Ways of Thinking.

Participants in this group saw the knowledge in the profession as internally constructed. Labs were seen as places where students have contact with real-world problems and get familiar with the ways of think and act in the profession. Teaching in the labs was described as a co-constructive process. Learning occurs through hands-on activities where students can see, touch and build things. Instructors should act as mentors and guides challenging the students continually while they conduct the experiments. Students were seen as the co-responsible for transforming the knowledge in the labs. According to these participants, the instructors and the students should be continually interacting in such a way that fosters the transmission of the knowledge from one to another. Finally, the participants in this group expected the lab courses helped students to transform their way of thinking towards the profession. Comparing this group with the two previous ones, I noticed that there was a shift towards the learner side of the continuous. However, these participants, at the same time that emphasized the role of the learners, and the importance of changing their ways of thinking toward the profession, still espoused beliefs where content prevail over the learners' transformation. These beliefs were associated to the participants' view on how students learn best in the labs which stresses the importance of hands-on activities but with no emphasis on trial and errors processes, and their view of the agents responsible for transforming the knowledge in the labs. According to this view, students and instructors had to be interacting all the time, but the main driver of such interactions were the activities previously defined in the lab manuals and handouts.

5.6.1.4 Orientation 4: Supporting students' professional development

Table 5.7 Patterns of beliefs Group 4

Dimension	Nature of knowledge	Role of labs	Teaching in the labs	Learning in the labs	The agent responsible for transforming knowledge	Desired learning outcomes	Role of instructors
Eng_8	B	B	B	B	B	B	A
Tech_2	B	B	B	A	B	B	A

The patterns of beliefs expressed in this group reveal an emphasis on the learners rather than the content. Despite this emphasis on the learners and on the learners' transformation, the two participants of this group stressed their role as guides who controllled the amount of support to students. The idea expressed by these participants was to challenge the students to engage in the lab activities in a way that fostered the students' own thinking but, to guarantee the students' success, answers had to be given along the way. The amount of support would vary according to the students' level. As the overall idea was to support students' professional development, I called this orientation, Supporting Students' Professional Development.

This group brings together participants who expressed beliefs mostly situated on the right side of the continuous content-centered/learner-centered. Participants have agreed on all the beliefs but one. The divergence regards the way these participants conceived learning in the labs. While Eng_8 stressed the importance of trial and error processes, Tech_2 focused more on the importance of hands-on activities where students can see, touch and build things. As for similarities, participants in this group saw the knowledge in the profession as internally constructed. Labs were seen as places where students develop complex thinking. Teaching in the labs involved creating an environment that facilitated learning through the use of open-ended activities. Instructors must act as guides who scaffold students in the labs and control the amount of support based on the level of difficult students face. Students were seen as the main responsible for transforming the knowledge in the labs rather than just following instructions. Finally, the participants in this group expected that their lab courses helped students to transform their way of thinking towards the profession. Comparing this group with group 3 above, I noticed that the main difference between them is the role of instructors in the labs. Indeed, the two participants in this group stressed the role of instructors as providers of support. The idea was that students, at the beginning of the programs, needed a lot of support and the instructors must be there to give them the answers, but as the students advance towards the higher levels, the amount of support must be reduced.

5.6.1.5 Orientation 5: Facilitating Expertise Development

Table 5.8 Patterns of beliefs Group 5

Dimension	Nature of knowledge	Role of labs	Teaching in the labs	Learning in the labs	The agent responsible for transforming knowledge	Desired learning outcomes	Role of instructors
Eng_5	B	B	B	B	B	B	B
Eng_7	B	B	B	B	B	B	B
Tech_4	B	B	B	B	B	B	B

The patterns of beliefs expressed by the participants in this group suggest an orientation to teaching that places a strong emphasis on learners rather than the content. To the faculty in this group, the main goal of the lab activities was to transform students towards becoming experts. Thus, I called this orientation, Facilitating Expertise Development.

This group brings together participants who expressed beliefs that were totally situated on the right side of the continuous content-centered/learner-centered. This fact indicated an emphasis on the learners as agents of transformation. The knowledge in the profession was conceived as internally constructed focusing more on the engineers' ability to deal with the demands of the profession than the subject-matter of the disciplines. Labs were seen as places where students developed complex thinking rather than reinforced the theory from the classroom. Teaching in the labs involved creating an environment that facilitated learning through the use of open-ended activities. Instructors had to act as mentors who challenged students instead of giving answers. In addition, the students were seen as the main responsible for transforming the knowledge in the labs rather than just following instructions. Finally, the participants in this group expected that the lab courses helped students to transform their way of thinking towards the profession.

5.6.2 Comparison between the two colleges

To illustrate the similarities and differences between these two different colleges, I created two tables that contrast faculty orientations and beliefs. Table 5.8 contrasts faculty beliefs. It presents only the number of cases who espoused such beliefs. Table 5.9 presents a comparison between the faculty orientations to teaching in the labs. The table describes the participants' orientations, the number of participants holding such orientations, and also a typical quote from one participant holding such orientation.

Regarding the beliefs, finding qualitative differences were difficult. Indeed, in almost all the categories and sub-categories of beliefs, I found examples of participants from the two different colleges. That means, in general, the qualitative differences regarding beliefs were very few between the two colleges. However, differences regarding the perception of students' capabilities to deal with abstract concepts and students' learning styles became prominent in the interviews. First, three participants from the College of Engineering mentioned the lack of abstract skills among their students. According to these faculty, these cognitive limitations could prevent better outcomes from the laboratory experiences. Indeed, these faculty members believed that the use of labs actually helped students to learn the abstract concepts discussed in the classroom. To these faculty, students learned abstract concepts when they saw a phenomenon. This kind of perception was reported in a slightly different way by the faculty members at the College of Engineering

Technology. To the faculty members at the Collge of Engineering Technology, their students may face difficulties regarding learning abstract concepts. However, instead of arguing that students' did not have the necessary skills, the participants argued that the eventual difficulties might be a result of students' learning styles.

The comparisons between the faculty orientations to teaching in labs at the College of Engineering and at the College of Engineering Technology did not reveal any qualitative difference. That means, the orientations identified by this study can be held by any faculty at the two schools. It is important to notice, however, that no participant from the College of Technology espoused an orientation towards reinforcing lectures. The reason for that may be a consequence of the belief that students at the College of Technology are very concrete learners that require hands-on activities not only to reinforce the theory but also to connect the theory into the practice. Furthermore, as this is a qualitative study, and the goal is to capture and understand the phenomenon without aiming any kind of quantitative analysis, I cannot make any further statement regarding the popularity of any orientation at the two colleges.

Table 5.9 Belief categories by college

Belief	**College of Engineering** **N=8**	**College of Engineering Technology** **N= 5**
1. Nature of knowledge		
Externally constructed	4	1
Internally constructed	4	4
2. Role of labs		
The connection between theory and practice	4	2
Develop professional ways of being	1	1
Develop complex thinking	3	2

Table 5.10 continued

3. Teaching in the labs		
Transmission of knowledge	3	1
Co-construction of knowledge by mentoring	1	0
Co-construction of knowledge by exploring ways of thinking	1	1
Knowledge construction through open-ended activities	3	3
4. Learning in the labs		
Trough hands-on experiences	2	4
By trial and failure	6	1
5. The agent responsible for transforming knowledge		
External agent	4	1
Faculty/Instructors with students	1	2
Students	3	2
6. Desired learning outcomes		
Students will know more	4	2
Students will learn differently	4	3
7.1 Role of faculty		
Management	6	3
Lecturer	8	5
Instructional designer	8	5
Motivator	3	2
Provide feedback	3	1
Grading	3	0
7.2 Role of instructor		
Mentor	5	2

Table 5.11 continued

Consultant	3	3
Lecturer	4	0
Grader	3	0
8. Role of students		
Preparation	6	3
Participation	6	5
Teamwork	6	5
Reports	8	2
9. View of Students		
Students have difficulties with abstract concepts	3	0
The learning styles are different	0	5
Developmental view	2	2
Students are highly capable	1	0

Table 5.12 Orientations to Teaching in the Labs

Orientation	College of Engineering	College of Engineering Technology
1. Labs for reinforcing lectures	Cases: 3 “The lab is important. And especially when ... Even when it ha's not done right, it still adds to the whole experience and to the lecture.”	Cases: 0
2. Labs for connecting theory into practice	Cases: 1 “The post-lab should be a good tool to bring a stronger connection between the theory and the facts that they have actually measured in the lab, and how to use those to go to the next level, which is now applying.”	Cases: 2 “For the lab, the lab is good to prepare the students to connect, basically what they have learned in theory to what is practice, right? Not everything goes a hundred percent got a perfect, right? Even though you analyze on the computers, yes you have this answer, but in real life, you have lots of this problem about preparing the lab, preparing how tight is the screws and all this stuff, all add up and make life or things not perfect. So, the lab is preparing the students to be aware that not everything is perfect, if that makes sense.”
3. Labs for developing professional ways of thinking	Cases: 1 “So, part of my job is to keep them motivated and make sure that they understand all the procedures and they understand the importance of the results they are getting and what's the theory behind that, but it's more important what that result they're getting in the lab how this is important for their application later. I must give them this link to the real world.”	Cases: 1 “I would like our students to use the lab space to practice a little bit more in the context of the industry. I feel like it would be preferable if the students came prepared to the lab and this is something that I myself have not implemented. If I could do some prework before they come to the lab, excuse me, I think it would benefit them better because then they could use the lab time to work on a project or some sort of task that is oriented towards achieving a goal, so to speak rather than just demonstrating a physical concept or something like that. Don't get me wrong; I do not think that the theory is not important. The theory is very important, but I do not think they need to demonstrate the theory if it is already being demonstrated. There are lots of YouTube videos doing that already.”
4. Labs for supporting students' professional development	Cases: 1 “A lot of the stuff they do in the lab is pretty much directly demonstrating what I want them to be able to do and it's just my hope that when they get out of the lab, that without the benefit of the TA present and without somebody giving you the lab manual that he or she will still be able to repeat that process. And, in fact, in the X course that follows, that builds on this, it is much more open-ended. The spec is actually pretty tight, but their process, how they deal with it is pretty open-ended. They eventually have to show that they can do that themselves unless somebody is doing it for them.”	Cases: 1 “The lab activities are important in two ways. The least important of the two ways is, the obvious skills they learn in how to run a specific test or how to use a specific piece of equipment. That is important, but that is not the most important. The most important is when they learn the broader skill of when a test is helpful, how to set one up, how to make results that mean something, how to close the loop and bring those results back to their analysis, to either correct the analysis or use the analysis to correct the test, 'cause that happens too. Then they think in that more broad way that makes them better engineers. Better employees.”
5. Labs for facilitating expertise development	Cases: 2 “In terms of some practical things, we want them to be able to write lab reports using a critical eye, being able to specifically assert things that they can assert, know where there's ambiguity in the experiments, so to be able to think critically is ultimately ... That is probably the ultimate goal, is to be able to do a lab, to think about the results, to be able to write them up in a way that communicates, and then to be able to say what's important and what isn't in your lab.”	Cases: 1 “I want them to be able to conceive of when they have a problem that can be solved with a measurement. I want them to be able to, number one, recognize that a measurement will help. Be able to figure out, conceptually, how they could make the measurement and then, finally, how to set it up and actually conduct it properly so that their results are meaningful. It is harder than it sounds.”

5.7 Summary of Findings

In this chapter, I explored faculty educational beliefs associated with the use of laboratories in engineering education. I investigated and answered the following research question:

> RQ 1: What are the faculty beliefs about the integration of laboratories into engineering education?

To answer the research question one, nine different categories of beliefs were identified and explored. These beliefs presented the views of engineering faculty regarding several elements of the teaching and learning processes in the labs. The analysis of the participants' beliefs revealed that most of the espoused beliefs could be arranged along a continuum ranging from a participants' emphasis on the content, or a skill, towards an emphasis on the learner's transformation. After classifying the participants' beliefs according to a coding scheme that took into account their emphasis on the content or on the learner, I conducted a qualitative analysis and identified five orientations to teaching and learning in the labs. These orientations reflected the different ways faculty conceived the teaching and learning processes in the labs. However, as the faculty in this study revealed a series of tensions regarding their ideal views of labs in contrast with their actual practices, I decided to explore first what faculty espoused as their ideal view of the lab education. Thus, the orientations presented in this chapter can be conceived as the faculty idealistic conceptions about the teaching and learning processes in the labs. In chapter six, I investigated the actual teaching practices as espoused by the faculty, and as their instructional materials indicated.

Five main idealistic orientations to teaching and learning were found. These orientations were organized along a continuum ranging from a content-centered to a student-centered perspective. The following orientations were found,

Orientation one: Reinforcing lectures
Orientation two: Connecting theory into practice
Orientation three: Developing professional ways of thinking
Orientation four: Supporting students' professional development

Orientation five: Facilitating expertise development

The orientation one, Reinforcing Lectures, is located at the extreme left of the continuum. Orientation five, Facilitating Expertise Development is located at the extreme right. The orientation two, Connecting Theory into Practice is very close to the reinforcing lectures one but adds the idea of giving the students the opportunity to develop some practical skills such as measurement and data analysis. Participants following the third orientation, Developing Professional Ways of Thinking, wanted to give students the opportunity to learn practical skills inherent to the profession. Among those skills, they cited the ability to design new experiments to solve an engineering problem. In the fourth orientation, Supporting Students' Professional Development, the goal was to support the development of students while they progressed from novices to experts in the field.

Finally, the comparisons between the orientations and beliefs of the faculty at the Colleges of Engineering and Engineering Technology revealed minimal qualitative differences. The only evident qualitative difference related to the views of the faculty at the College of Engineering Technology regarding their students learning styles. To these faculty, students at the College of Technology have a learning style that values concrete experiences instead of abstractions.

CHAPTER 6. RELATIONSHIP BETWEEN BELIEFS AND TEACHING APPROACHES

This chapter addresses the following research question:

RQ 2: How do faculty beliefs relate to their current teaching practices in laboratory education?

6.1 Introduction

In the previous chapter, I identified five main orientations to teaching in the labs and nine different categories of educational beliefs regarding the use of labs in engineering education. The results are an important contribution to the current discussions regarding the adoption of educational innovations in engineering education settings. However, this knowledge alone does not provide information on how the beliefs and orientations to teaching are related to the current teaching practices in the labs. To advance our understanding in this regards, in the second part of this multiple case study, I investigated how do faculty beliefs relate to their current teaching practices in the labs. I wanted to see, for example, if the faculty members' espoused beliefs are translated into their instructional practices. The results indicate the influence of a series of external and internal factors that may impair the successful alignment between beliefs and practices.

6.2 Sample and Data Collection

The participants of this second phase of the study were the same thirteen faculty members described in the previous sections. In this phase, I collected the following data: (a) interviews, (b) questionnaires and (c) instructional documents such as course syllabi, lab manuals, and students' assignments. The same semi-structured interviews described in the previous chapter were used as the main source of information. The questionnaires were used to gather participants' information such as educational background, courses taught, rank, time spent on academic duties, and professional development needs. Finally, the document analysis provided evidence of the instructional design used in the labs.

For each participant, I created a data set containing all the data provided. The Table 6.1 below illustrates the sources of data provided by each of the thirteen participants. It is important to notice that not all participants provided a complete set of data.

Table 6.1 Data collection sources

Participant	**Questionnaire**	**Interview**	**Documents**
Eng_1	☑	☑	☑
Eng_2	☑	☑	
Eng_3	☑	☑	☑
Eng_4	☑	☑	☑
Eng_5		☑	☑
Eng_6		☑	
Eng_7	☑	☑	
Eng_8	☑	☑	☑
Tech_1	☑	☑	☑
Tech_2	☑	☑	
Tech_3	☑	☑	☑
Tech_4	☑	☑	
Tech_5	☑	☑	☑

6.3 Data analysis

Following a case study approach, I considered each participant as a single case and conducted a within case approach aiming to capture how each participant's beliefs related to their teaching practices. The data from the interviews were triangulated with the data from the questionnaires and instructional documents, to support the within case analysis. In a final step, I compared the thirteen cases to identify similarities and differences among them.

A seven-step approach was adopted. First, the data from the questionnaires were used to generate an initial profile, describing the participant's teaching experiences, main academic duties, number of courses taught per semester, professional development needs, and familiarity with different pedagogical approaches used in lab education. Second, a summary describing each participant's set of beliefs and her/his corresponding idealistic orientation to teaching in the labs was generated. Third, the written documents, including the syllabus, manuals, handouts, and/or course slides were analyzed using content analysis. Each set of documents was analyzed, and evidence of the adopted instructional designs was coded. The main goal of this analysis was to identify evidence of the lab learning outcomes, assessment practices, and pedagogical approaches. A summary of each participant's instructional designs was generated.

Fourth, evidence from each participant's instructional design was also gathered from the interviews. This evidence was coded according to their relationship to content, assessment or pedagogy. In addition, as reported in the previous chapter, I identified several tensions in the participants' voices. These tensions were also coded to illustrate how each participant perceived and dealt with the constraints of the educational environment. For each participant, I created a summary of the evidence of instructional designs and tensions. Fifth, I merged the summaries from the four previous steps and created a unique profile of each participant. This profile reported the participants' background information, their beliefs, and orientations to teaching in the labs, evidence from their lab practices, and also evidence of participants' tensions regarding the educational processes. Each profile is presented in Section 6.3 below. Finally, in the sixth step, I triangulated the evidence from the different sources of information to make sense of the relationship between each participant' set of beliefs and teaching practices. A further step was to compare the different cases to identify similarities and differences.

6.4 Results

The results are organized in the following manner. First, I will present the results of the within case analysis. The profile of each case is presented, and the relationships between beliefs and practices are analyzed. Second, I will present the findings from the cross-cases analysis. Finally, I summarize the findings.

6.4.1 Case one: Eng_1

Background. Eng_1 had a solid experience teaching in higher education settings with also experience in teaching labs. Her/his main responsibility was teaching. S/he reported to dedicate 90% time to teaching and 10% to research. Although Eng_1was responsible for the lab course, s/he did not teach any lab section. Eng_1 primarily taught undergraduate courses, having an average number of three courses per semester. S/he reported a moderate level for professional development on instructional practices and Information and Communication Technologies (ICT). S/he mentioned the use of computational experiments, and also the use of problem and project-based approaches besides of traditional laboratory activities. S/he used lab reports and peer evaluations to assess her/his students.

Beliefs and orientation. The findings from the phase one, described in the previous chapter, revealed that this participant was oriented towards using the labs to help students to develop professional ways of thinking in the field. S/he saw knowledge as internally constructed by the students characterized by the "knack for engineering." S/he described teaching in the labs as a co-constructive process where the faculty explores new ways of thinking in the profession and mentors students during the hands-on activities. Thus, to this participant, faculty and students were responsible for transforming the knowledge in the labs.

Furthermore, this participant saw the labs as places where students have the opportunity to apply knowledge through real-world examples from the field. Regarding learning in the labs, s/he believed that students learn best through hands-on, structured activities. As her/his main role, Eng_1 mentioned the role of a mentor who challenges the students by asking questions, and serve as a role model during the experiments. S/he also believed that the best way to assess students in the labs is through personal interactions during the hands-on activities. Eng_1 wanted her/his students to think differently after taking her/his lab course.

Reported teaching practices. This participant reported practices that fitted with the use of traditional lab education. Eng_1 provided basic details of her/his teaching practices. First, s/he aimed her/his students to be able to understand the principles associated with the course, and to design and conduct an experiment anytime they wanted to "measure something." The focus would be less on the theory and more on practical applications associated with the profession. Second, the formal assessment involved the use of reports where students had to show and analyze the results. The pedagogical approaches involved the use of pre-labs aiming to scaffold students towards the lab activities. The idea was to create a prior knowledge associated with safety, equipment operation and procedures. Before the pre-lab, and every other week, this participant reported being lecturing to students to provide the "contextualization" and increase students' motivation. No details were presented about the lab practices per se, but the participant reported to be "completely against" providing instructions such as "go there, turn on the machine, press button number one, press button number two, read what's written in the visor number one." Instead, her/his practices in the lab tried to follow the procedural recommendations from standard norms in the profession. These recommendations provided high-level orientations instead of step-by-step instructions.

Evidence from documents. This participant adopted a traditional lab education approach. Eng_1 provided the course syllabus, lab manual and course slides. The analysis of the syllabus indicated that the main goal of the lab course was to reinforce the concepts learned in the theoretical classes. In addition to this reinforcement, the course aimed to develop other engineering skills such as instrumentation, data analysis, and teamwork. The course was structured as a series of experiments that covered concepts and principles already studied in previous courses. Before every lab experiment, Eng_1 gave a one hour lecture to connect the experiment with practical situations of the profession. The assessment component of the design included participation, pre-labs assignments, peer evaluations, and reports. The lab reports were comprised 50% of the total grade. In the prelab assignments, students answered questions regarding the experiment, the theoretical assumptions, and mathematical formulations. These pre-labs were due before every experiment and were responsible for 20% of the grade. The lab manual included a summary of the related theory and provided high-level instructions on how to perform the experiments. These high-level instructions described the steps to be performed without giving step-by-step orientations, such as " press button 1," "open valve 2." The manual also provided high-level instructions on how to write the lab reports. No evidence of project- and problem-based approaches were found.

Tensions. Upon initial examination, there was a good alignment in the participants' beliefs and her/his teaching practices, and also between the reported and actual practices. Although using traditional lab education, this participant believed that s/he could instill professional ways of thinking by lecturing to students before every lab activity. During such lectures, Eng_1 provided an overview of the importance of the lab activity and engaged students in a co-constructive process aiming to show students the reasons to conduct the experiments and devising some procedural steps. As the participant believed her/his students were highly capable, the hands-on activities just added to what they learned during the lectures. However, despite this apparent alignment between beliefs and practices, Eng_1 implicitly expressed a tension that contradicts an espoused belief and a teaching practice.

The tension in this participant's voice was a consequence of her/his absence during the lab activities. Indeed, TAs led the labs, and the participant had many other duties that prevented her/him from attending the labs. Thus, mentoring and assessing students during the hands-on activities were not possible at its full potential. To alleviate this tension, the participant said,

> No, I mean I already know that for the next semester, I will not be able to be present all the time in the lab. That is the reason I am asking for a lecture when I am going to tell them what they are going to do. Why is that? Because we have so many sections, and I will be teaching another course, that I am not going to be able to be there. However, I am going to monitor everything, and I will have the first lecture with the students before. I am going to put all the students together. I am going to have the lecture. I am going to motivate them about the lab. So, I am going to have TAs that is going to run the experiment, but if possible, I will be there. I am not going to be able to be there in all the sections. I already know because I will be teaching another course. It is too many sections.

In addition, although the participant mentioned the use of project- and problem-based approaches, no evidence of its use was found. A possible explanation can be associated to the fact that this participant also taught higher level courses not explored in this study. Thus, s/he might have used those approaches in such courses.

Summary. Considering the relationships between beliefs and teaching practices of this participant, the tensions and eventual contradictions seemed to have the minimal influence of her/his orientations to teaching in the labs. It seems that s/he did not perceive any problem in not attending the lab sections, as long as s/he was lecturing to students every other week. Thus, beliefs and practices seem to be aligned.

6.4.2 Case two: Eng_2

Background. Eng_2 had prior experience teaching in higher education settings and in labs. Her/his main responsibility was teaching. S/he reported to dedicate 50% of her/his time to teaching, 30% to research and 20% to service. Eng_2 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate to a higher level of need for professional development on all the areas presented in the questionnaire. As instructional approaches, s/he mentioned the use of traditional lab experiments, computational experiments, and demonstrations. S/he used lab reports and exams to assess her/his students. This participant was not teaching any lab course at the time of the interview. For this reason, s/he did not provide any instructional material related to lab courses.

Beliefs and orientation. According to the analysis described in chapter five, this participant was oriented towards reinforcing lectures. S/he saw knowledge as externally constructed based on a set of concepts and disciplines. S/he described teaching in the labs as a transmission of knowledge process where the faculty member demonstrates a phenomenon, theory or tool, and then engages students in the lab activities. Furthermore, according to this participant, the labs must be aligned with the lectures, and follow books and lab manuals. Thus, labs aimed at supplementing the lectures. Regarding learning in the labs, this participant believed students learn best by trial and error processes, having the opportunity to explore the different theories through a discovery learning approach. S/he mentioned as an instructor's ideal role, the role of a mentor who mentors students during the lab activities.

Reported teaching practices. Eng_2 reported practices that fitted with the use of traditional lab education. Although s/he was not teaching any lab course at the time of the interview, s/he described her/his practices when teaching labs in the following way. First, s/he aimed her/his students to be able to understand principles associated to her/his discipline and to learn some practical skills such as measurement and safety. Second, the only formal assessment mentioned were the reports. The pedagogical approaches involved a preliminary lecture before every lab. The goal of such lectures was to tell students what they were going to do and teach fundamental principles. These preliminary lectures were different from the lectures given in the classroom. According to him/her, labs and classroom lectures had to be aligned and use the same textbooks. In the lab, students received orientation on the experimental apparatus, and have to follow a handout with precise instructions on "what they need to do to write the report." During the lab activities, TAs helped students to run the experiments and take data.

Evidence from documents. This participant did not provide any written documents.

Tensions. This participant explicitly expressed a series of tensions regarding her/his beliefs and the corresponding teaching practices. A first tension this participant expressed contrasted her/his belief about how students learn and the way the current labs are. S/he believed students learn better by trial and error but pointed out that the lack of resources and time prevents the use of such approaches in the labs. As a consequence, according to her/his view, instructors must give the students "a very well-outlined procedure and then write a report, hopefully between doing the lab and writing the report, they started making the connections." As s/he said,

> And, then you would like to have an open-ended amount of time so that the students could try everything and learn by themselves, but that would take so long that you have to tell them, well, do this, do that, do the other. That is the procedure. You do not have time to let them make many mistakes, because then they would never learn, but the best way to learn is by making mistakes. Ideally, it would be, if you have infinite time and infinite resources, let them learn on their own, but we cannot do that, so we have to tell them, "Well, this is the procedure. Open this valve, close this valve, push this button."

A similar tension regards her/his ideal view of the role of instructors and the actual role. According to him/her, instructors must act as a mentor, challenging and guiding the students while they are performing the experiments. However, s/he argued that because of the lack of time, resources, and the students' difficulties in learning abstract concepts, instructors should tell students almost everything they needed to do, instead of asking questions. This tension was present in several passages. In one those passages, s/he said,

> Ideally, the instructor in the lab should... He should just like teach the students, "Okay, here is this instrument. This is what it does. This is how you use it. This is what you do." Make them familiar with the equipment and the apparatus so that they can run the experiment and all that. Ideally, you should then pull back and let the students try things on their own and eventually make the connection with the theory, but that is not possible. Then the instructor needs to intervene a little more, and he needs to give them, tell them what to look for. This is already a problem. They should discover that on their own, but there is no time for that, so the instructor... And then, at that point, again, the instructor should not say anything, and he should let the student discover the connection with the theory, but this is not possible.

S/he also believed that instructors must be present all the time during the lab activities, but argued that it is not possible given the actual institutional constraints,

> Because then the instructor is there all the time and there might be TAs or anything, but he is always available. He is always there, so if you could have then very, very small groups and the instructor could then give an introduction to each one of the small group of students, or you can have a lecture. And then while the students are doing the lab and in particular, if you want to break up it so that, say, the best thing would be if you could use the lab 40 hours a week, 50 weeks a year. And the professor should be there 40 hours a week. Maybe he is doing something else, but he should be available, so the student can come and say, "Hey, professor, what's happening over here?"

Summary. The analysis of this participant's interview revealed that her/his practices were mediated not only by the espoused beliefs but also by external factors such as time, resources and students. In this case, the mediating factors instilled patterns of behaviors that contradicted some of the beliefs espoused by the participant. First, instead of creating a learning environment where students could learn by trial and error, s/he adopted practices that minimized students' efforts and guided every step of the students' actions. Second, instead of acting as a mentor who challenges the students "on-the-fly," s/he used to give the right answer to students as a way to keep students' progress towards the end of the experiments.

6.4.3 Case three: Eng_3

Background. Eng_3 has prior experience teaching in higher education settings and also in labs. Her/his main responsibility was teaching. S/he reported to dedicate 60% of her/his time to teaching, 30% to research and 10% to other duties. Although Eng_3 was responsible for a lab course, s/he did not teach any lab section. Eng_3 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate to a higher level of need for professional development on all the areas presented in the questionnaire. S/he mentioned the use of computational experiments, and also the use of problem and project-based approaches besides of traditional laboratory activities. S/he used lab reports, face-to-face meetings, and peer evaluations to assess her/his students.

Beliefs and orientation. According to the analysis described in Chapter 5, this participant was oriented towards using labs to connect theory into practice. S/he saw knowledge as externally constructed based on a set of concepts and principles. S/he used her/his labs to engage students in activities that not only foster the learning of the subject matter but also provide a view of potential applications in the profession. Also, s/he described teaching in the labs as a co-construction of knowledge process where the instructor mentors the students during the lab activities.

Furthermore, this participant had a dual view regarding the agent transforming the knowledge in the labs. According to this dual view, while in capstone courses students must be responsible for constructing the knowledge, in the regular courses, everything must be spelled-out to students in order to facilitate their activities. Thus, in regular courses, the lab activities must be aligned with the lectures, and follow books and lab manuals. Regarding learning in the labs, this participant believed students learn better through hands-on, structured activities. S/he described as an instructor's ideal role, the role of a mentor who mentors students during the lab activities.

Reported teaching practices. This participant reported practices that fitted with the use of two different approaches to lab education. In low-level courses, s/he reported practices associated with traditional lab education. In the capstone course, s/he adopted practices associated with project-based learning. For methodological reasons espoused in Chapter Four, I will not describe any finding regarding capstone courses. This participant provided basic details of her/his teaching practices. First, s/he was not explicit regarding the course learning outcomes. S/he just mentioned that there was a list of outcomes. However, s/he mentioned an emphasis on measurement, equipment operation, communication, and teamwork. Second, the formal assessment basically involved the use of reports. S/he used to provide feedback to students after analyzing each report. The pedagogical approaches involved the use of recitation sessions where the TAs discuss the experiments with the students. The students are asked to conduct the experiments following the "very precise instructions" from the handout. According to Eng_3, "there's not many activities beyond that. They (the students) need to use different instruments, but then everything is well spelled out."

Evidence from documents. This participant adopted a traditional lab education approach. Eng_3 provided the course syllabus and lab manual. Lectures and lab experiments composed the course. The analysis of the syllabus indicated that the main goal of the course was to apply theoretical concepts to analyze different phenomena in the discipline. In addition to this applied component, the course aimed to develop experimental and designing skills. The course was structured as a series of lectures that cover numerous concepts and principles. There was a small number of labs to supplement such lectures. The assessment component of the instructional design included homework, reports, exams, and a team design project. While the lab reports were responsible for 20% of the total grade, the exams were responsible for 60% and the project 10%. It is important to notice that, the exams, homework, and design project are not associated with the lab experiments. The lab manual included a summary of the related theory and provided step-by-step instructions on how to perform the experiments. The level of details prevented students from "figuring out" any step. Everything wass detailed at the level of which should be connected, turned-on, or turned off. Figures were provided to illustrate each step of the experiment. Although this participant adopted a small team project in the course, this project was not related to the labs and had a theoretical component only.

Tensions. This participant also revealed a series of tensions that challenged her/his role as faculty and instructor. First, s/he contrasted her/his view of an ideal instructor and the actual role played by him. According to her/his view, an ideal instructor must act as a mentor by challenging and guiding the students while they conduct the experiments, but as TAs led the labs, s/he believed that approach was not possible in labs other than the capstone courses. To alleviate this tension, s/he tried to be present even in the regular labs,

> Well, the way I think what should be done is the instructor can ask questions but challenge the students because of the knowledge and experience he has, or she has. Come into the lab where students are running experiments, measuring variables, writing down data, sitting on tables, making plots. So come in, and I asked them, "Okay, what are you measuring right now? "We are measuring flow rate; we are measuring temperature, pressure, and properties." So how do you think you are going to use that data, for what purpose? And once you fulfill that purpose, what else do you think you can do with what you produce? You produce a model, where are you going to use that model? Can you relate it to what you are learning in class? this being applied in industry, things like that. I come in and ask questions, and I challenge them to think beyond what is written in the handout.

But, as the TAs led the labs, s/he concluded,

> Okay, one thing I can tell you right now, most of the labs are run by teaching assistants, *subject1* labs, the *subject2* engineering, *subject3*. The teaching assistants are the ones that are right there all the time. In the capstone lab, we also have the teaching assistants to be full-time in the lab, but the instructor also spends a large amount of time in the lab. I think the best thing to do is to always have instructors not just teaching assistants. Teaching assistants are good. The graduate students, they are being educated, but the experience of an instructor that has several or many years of experience already is much more valuable to better run the lab sessions, that is my feeling. And so what I do in these courses where I have a lab, the *subject1* engineering lab, I spend a lot of time in the lab sessions. I do not just leave to the teaching assistants.

Finally, Eng_3 stressed the lack of specific training for TAs and instructors running the labs,

> If we want them (*the TAs*) to run all the experiments in the lab, that is a lot of time. Also, from the teaching methodology point of view, none of us get any training whatsoever, and I think that will be very useful. Find out what are the best practices and have a quick training session for everybody that is coming for the first time to teach a lab. And in the case of the grad students, there is some course that they take on good teaching practices. I think that is a good thing to do, but for instance, for the labs, they do not get any particular training on how to conduct the session.

Summary. The triangulation between the data from the interview, questionnaire, and written documents indicates a good alignment between beliefs and practices, and also between the reported and actual practices. However, the tensions revealed her/his concern with the outcomes of the laboratory activities due to the absence of an instructor all the time in the labs, and the lack of experience of the TAs who lead the labs. The only belief that seems to be challenged was associated with the role of instructors, but that seems to be mitigated by the participant who tried to attend the lab sections.

6.4.4 Case four: Eng_4

Background. Eng_4 had prior experience teaching in higher education settings and also in labs. Her/his main responsibility was research. S/he reported to dedicate 25% of her/his time to teaching, 50% to research and 25% to other duties. Although Eng_4 was responsible for a lab course, s/he did not teach any lab section. Eng_4 primarily taught undergraduate courses, having an average number of one course per semester. S/he reported a moderate to a higher level of need for professional development on content and performance standards, assessment practices, and classroom management. S/he mentioned the use of computational experiments, and also the use of demonstrations and problem-based approaches. S/he used lab reports to assess her/his students.

Beliefs and orientation. According to the analysis described in chapter five, this participant was oriented towards using labs to reinforce the lectures. S/he did not present a big picture of the profession, but see the knowledge in the field as externally constructed based on a set of concepts and principles. Also, s/he described teaching in the labs as a transmission of knowledge process where the faculty demonstrates a tool and then asks students to reproduce such knowledge "wishing" the students would learn something from those processes. Regarding learning in the labs, this participant believed students learn better by trial and error processes, having the opportunity to explore different tools. S/he saw as the main faculty role, the role of a coordinator, responsible for managing the TAs and with minimal relation to the lab activities. Instructors, in her/his view, must control the amount of support, but sometimes they should "feed the answers" to the students.

Reported teaching practices. This participant reported practices that fitted with the use of traditional lab education. S/he was responsible for a lecture and lab course. S/he taught the lecture component, and the TAs led the labs. Regarding the lab, s/he described the main components of the instructional design in the following way. First, s/he aimed her/his students to apply the techniques "they have seen in class." Second, the only formal assessment reported were reports graded by TAs. The pedagogical approaches involved giving students a series of tasks that they need to write a report. Then the TAs checked the answers. According to this participant, her/his lab activities are "very structured." Eng_4 informed that the main components of the instructional design were inherited. Thus, content and pedagogy were inherited, and the assessments were the only component that seemed to be changed by Eng_4.

Evidence from documents. This participant adopted a traditional lab education approach. Eng_4 provided the course syllabus and the lab manual. The course was composed of lectures and lab experiments. The analysis of the syllabus indicated that the main goal of the lab component was to implement the concepts learned in the classroom using a software tool. The course was structured as a series of lectures that covered numerous concepts and principles. The lab activities had to build upon the "material covered in the lecture." The assessment component of the instructional design includes homework, reports, and exams. While the lab reports were responsible for 20% of the total grade, the exams were responsible for 70% and homework 10%. The lab manual reviewed the related theory and provided step-by-step instructions on how to perform the experiments. Everything was spelled out in details. Each concept seen in the classroom had a corresponding practice in the labs. Basic coding instructions were also presented.

Tensions. This participant expressed a series of different tensions. First, s/he demonstrated certain dissatisfaction with the current assessment instruments used to evaluate students. Second, s/he felt the lab activities were outdated but did not envision any strategy to fix the problem. Third, s/he demonstrated concerns regarding controlling what TAs do in the labs. Fourth, s/he revealed the influence of inheritance on her/his current practices in the lab. Finally, it is highly worth to mention that, in several passages, this participant stressed the strong influence of the institutional reward system on her/his practices.

As a first tension, Eng_4 complained about the assessment instruments in use which did not assess very well the students learning gains. In addition, s/he believed the lab learning objectives were not clear, and s/he was unsure if the actual teaching practices develop the knowledge and skills students needed. In her/his view, a better alignment between the learning goals and the assessment instruments would be an ideal situation, but s/he argued that aligning these components of the instructional design would require time and dedication, and stressed that there were no incentives for that. Regarding this tension, s/he argued,

> It would be good, if, in addition, we had some clear idea of what we are trying to make them accomplish and make sure they reach these objectives, but that is a lot more work to assess. That would require, probably your lab redesigned, and the curriculum is really all intertwined, and this lab is set and changing anything requires a lot of work. So, what would the benefit be? Well, potentially we could have better-trained students, but we do not have any data that says that it would actually be better. Could it be better? Yes. But at what cost? I am being cynical, I mean, practical here.

Eng_4 also stressed that the lab activities were outdated. S/he said, “I think that if we can give them problems that are really real problems with real data ... Problems that are relevant today, instead of 20 years ago, I think this would be a good way.” However, despite being aware of this problem, s/he argued that the current institutional structures did not foster change in the labs. S/he argued,

> We need to have a consistent curriculum, and we have a structure in place to get approvals to make a change. There's ABET accreditation. There's a whole administrative structure

> that is very heavy, and there is no incentive, really, for faculty to do the work to change the lab, because, at the end of the day, the only thing you get is potentially better-educated students. You're not going to get more papers, in fact, you are going to get fewer papers. So, since there is no reward for teaching well, it is not actually evaluated either. We get a teaching evaluation score, but that probably wouldn't change if we had a better lab. And this teaching evaluation, of course, reflects probably other things. There would be no measurable impact. So no reward. Why would people do that, right? You have to be self-driven.

A third tension related to the difficulties in controlling what the TAs do in the labs. S/he revealed this tension in the following way,

> Well, it is really difficult to control what the teaching assistants do. There's a disconnect in it because I do not know exactly what's going on in the lab. I am not teaching the lab. So I am just looking at certain high-level things, and they implement everything, so I rely on them communicating with me what's happening. So it is very indirect, and I really don't have much control.

This participant also revealed the influence of inheritance on her/his practices. S/he argued that, as other professors designed the labs, s/he had no control of the instructional designs adopted in the course. This tension was expressed in the following way,

> Just like I do not have much control over the lab content, because it was designed before me and it is part of the curriculum. So I'm just one little piece in the puzzle, and I do not have much control either on the teaching design.

Summary. The analysis of this participant did not reveal any specific conflict between the beliefs explored in chapter five and her/his teaching practices. However, it is important to notice that despite the certain dissatisfaction with assessment instruments, lack of control of TAs, and inheritance of curriculum, s/he did not take any measure to alleviate some of her/his tensions. The reason for that conformity, s/he said, may be a consequence of the institutional structures that make difficult any change, associated with the lack of rewards to those who focus on teaching instead of conducting research. In other words, according to this participant, the lack of rewards does prevent him/her from committing time to improve teaching practices in the labs.

6.4.5 Case five: Eng_5

Background. Eng_5 did not return the background questionnaire.

Beliefs and orientation. According to the analysis described in chapter five, this participant was oriented towards facilitating expertise development. S/he conceived the knowledge in the field as externally constructed based on a set of concepts, principles, and disciplines, but also stressed the importance of problem-solving skills as an internally constructed knowledge. S/he described teaching in the labs as a knowledge construction process where students engage in open-ended activities that foster creative thinking, decision-making, and problem-solving. Regarding learning in the labs, this participant believed students learn better by trial and error processes, having the opportunity to use different tools, and developing their experimental strategies. S/he conceived as an instructor's main role, the role of a mentor responsible for being challenging students during the lab activities. However, s/he stressed s/he did not teach the lab sections, and thus, her/his main role was of a coordinator (or "CEO"), responsible for managing the TAs, and taking care of all the lab-related duties, except teaching.

Reported teaching practices. This participant reported practices that fit with the use of traditional lab education. In the interview, Eng_3 provided few details of her/his teaching practices. First, s/he aimed her/his students to be able to understand and apply the concepts and principles associated with the course. Second, the formal assessments involved the use of reports and exams. The pedagogical approaches involved the use of recitation sessions where the TAs discuss the experiments with the students and ask questions using iClickers. The students are asked to conduct the experiments following the "well-designed instructions" from the handout. Indeed, as explained by Eng_3, students just observe TAs operating the equipment, record data, take notes and follow instructions to write the report. According to Eng_5, it was fundamental that lectures and labs were totally aligned.

Evidence from documents. Eng_5 provided the course syllabus, slides, and two lab handouts. Lectures and lab experiments composed the course. The analysis of the syllabus indicated that the main goal of the course was to develop students' conceptual understanding of concepts and principles related to the participant's discipline. In addition to this theoretical component, the lab course aimed to develop students' experimental skills. The course was structured as a series of lectures that covered numerous concepts and principles. There was a significant number of labs to supplement such lectures. The assessment component of the instructional design included homework, reports, exams, and quizzes. While the lab reports were responsible for 30% of the total grade, the exams were responsible for 50% and the other assessments 20%. It is important to notice that, the exams included questions associated with the lab experiments. The handouts presented a solid review of the related theory and provided step-by-step instructions on how to perform the experiments. The procedures were richly detailed and contained figures to illustrate each step. The handouts included tables and datasheets to facilitate the data collection. They also described every component of information that needed to be in the lab reports.

Tensions. This participant expressed a series of tensions that challenged her/his espoused beliefs. First, s/he believed that students learn best by trial and error, and by going through decision-making processes, but argued that, given the high number of students, it was impossible to follow such approach. S/he said, "I cannot do that here because I have 150 students. We split that into 24, 25 student groups. I have six labs right now. When they go to the lab, they actually see the TA operating the machine." This participant stressed the time of the lab activities as a limiting factor,

> For me, the ideal lab will require a little bit more time than what we do now. We need to let them play more than now. For me, the labs as they are right now, which is just going to these sections and see how the material deforms, and all this, this, it is good, but not ideal. For me, the ideal is "I give you all this in the table, just figure out how to do it." That is for me the lab. For me, they learn if you give them the possibility of making decisions. They have to be making decision points, not just the doing the experiments.

Eng_5 stressed the importance of the interaction between the instructors and the students. However, s/he also did not teach in the labs, and thus this interaction between him/her and the students was different. Regarding this tension, s/he said, “I do not get to teach the lab, so I do not have that interaction at all, just when they come to my office and ...”

A third tension related to the alignment between the lectures and the lab activities. S/he deals with this tension in the following way,

> Again, my big concern with the labs right now and that it is not perfect and it needs a lot of work, is the connection with the lectures. It is always a big, big concern of ... There is two type of connections that I see. One is the topics, how we are teaching this topic and how I make the connections. I try to actually put that effort in what I can control in the lectures, trying to every time, we see these things, you guys are going to see these in the lab. That is the easy part, but the most difficult one is to coordinate the logistic that I need to finish such topic before we get into this lab. I have a big safety factor. Now the labs get a little bit later compared with what I finish.

A fourth tension related to the difficulties in controlling what the TAs do in the labs. Although s/he believed in the importance of peer interactions during the classes and argued that s/he used such approach in the lectures, but s/he had no control of what happened in the labs,

> My approach, I do not know if I am maximizing that, but my approach will be talking with your neighbors. Discuss things. Discuss. That will be my real approach. Two groups, I mean, try to solve it and feel free to ask somebody who is sitting by you, to actually ask him how to do things. Discuss and if you do not agree, try to understand why. That will be my approach. I do not know if we are actually doing that way right now in the labs. Although we have groups and we have discussions.

A final tension regarded to an apparent conflict between what this participant believed to be the ideal lab and the current labs. Her/his view of the ideal labs seems to be highly influenced by the way s/he learned during her/his undergraduate time. Contrasting her/his learning experience with the current “well-designed” and well-structured labs, s/he said,

> Like I said before, it is not ideal in the sense that when I was undergraduate, I was just given a room and say, "you are there, you have cables there," and I need to go and actually figure out what I needed. Here, it is not like that. The expectations are lower, much lower. I expect them to actually recognize what they did, what the TA did, that they observed that they understand what to do with the data and that they actually have a connection with the theory that we see in the lectures. That is my expectation.

Summary. This participants' patterns of beliefs seem to be in opposition to her/his actual practices. Indeed, given the tensions stressed by Eng_5, most of her/his espoused beliefs were contradicted by her/his reported practices and by the evidence of the instructional documents. Indeed, Eng_5 believed the role of labs was to develop complex thinking. Also, s/he believed that teaching in the labs must involve knowledge construction through open-ended activities, and s/he also believed students learn best through trial and error processes. However, her/his lab activities did not use any open-ended approach, and students did not have to go through trial and error processes. Everything was spelled out to students, and even the equipment had to be operated by TAs. Thus, no development of complex thinking, no open-ended activities, and no learning through trial and error occurred.

Furthermore, according to him/her, an ideal instructor is like a mentor, but the TAs led the labs and had no experience to mentor the students. Finally, the expected learning goals were much less than s/he wanted because of the limitations of the lab activities. To Eng_5, time and large enrollments were the limiting factors that prevented the adoption of her/his ideal practices. In summary, given the reported constraints of time and enrollment, Eng_5 adopted practices that fitted to an orientation towards supplementing lectures or connecting theory into practice.

6.4.6 Case six: Eng_6

Background. Eng_6 did not return the background questionnaire.

Beliefs and orientation. This participant was oriented towards using labs to supplement lectures. S/he conceived the knowledge in the field as externally constructed based on the curriculum. S/he described teaching in the labs as a transmission of knowledge process where the faculty lectures about the theory, and then engage students in hands-on activities aiming to help them to make sense of the theory. According to this participant, the labs had to be aligned with the lectures, and follow books and lab manuals in order to minimize students' learning efforts. Regarding learning in the labs, this participant believed students learn better by trial and error processes, having the opportunity to "experiment within the experiment." S/he saw as her/his main role, the role of a manager, responsible for managing the TAs, and taking care of all the lab-related duties, except teaching. On the other hand, s/he believed that an ideal instructor should have more interactions with students while mentoring them during the experiments.

Reported teaching practices. This participant reported practices that fitted with the use of traditional lab education. In the interview, Eng_6 provided enough details of her/his teaching practices. First, s/he aimed her/his students to be able to understand and apply the concepts and principles associated with the lectures. Second, the formal assessments involved the use of reports and well-designed rubrics. The pedagogical approaches involved the use of a pre-lab lecture that covered the theory, the procedures, and equipment inspection. Then students are asked to conduct a "cookbook execution of the labs" through well-structured instruction. According to Eng_5, it was fundamental that lectures and labs were totally aligned.

Evidence from documents. This participant did not provide any written document.

Tensions. This participant revealed a series of tensions during the interview. First, s/he argued that students had limited time to do the experiments and indicated that that limitation might impair the students' learning processes. Second, s/he demonstrated concerns regarding managing and training the TAs. Third, s/he stressed the importance of aligning the lectures and the laboratory activities. Finally, s/he argued that the current system prevents instructors from having ideal interactions with students.

First, Eng_6 emphasized the gap between what would be an ideal lab and the actual labs. In her/his view, labs must foster creativity, independence, and trial and error processes. However, s/he argued that due to time limitations, large enrollments, and lack of resources, the actual lab activities did not give students the opportunity to explore the full potential of such activities.

> The big difference is... Because labs are not well resourced, either in terms of equipment, or enough TAs, or enough time in the ... Days of the week. Because of large enrollments etc. The issue is that the students have very limited time and opportunity to actually experiment within the experiment, and do something. So pretty much they go in, a TA holds their hand to do something in 15-20 minutes, and that is about it. So the reality is they have no independence, no initiative, no individual contribution or intellectual engagement of any kind on what they are doing. So I would say, actually, that between intent and execution there's a huge gap between what is being done.

S/he also provided a very concise explanation of the reasons for such approach,

> Because if you allow the students to figure out the experiment for themselves, then you need a two-hour lab instead of 15 minutes. I have, in the fall semester, anywhere between 300 and 360 students. If I put, ideally, in a team of three of four, that is a hundred plus, 120 groups. With two setups available for me to do the experiment, let's say 10 hours a week, five days a week, okay? That is 50 hours, that is a hundred groups. I can barely get them through. And actually, we cannot have that many hours. You need to have twice as many because as groups, they cannot also have the right time for the lab. So effectively you have to keep the lab down to 30 minutes and make sure it can be executed in 15 because if all you have is 30, add a little bit of time to figure out what is going on, that is it. You are in; you are out. So it is really an enrollment issue. An enrollment and resources issue. If you had 20 setups, and three times, or four times space, and twice as many TAs, then you can allow the students to spend an hour or two to do things the right way.

This participant also revealed some tensions regarding the influence of TAs. S/he stressed the different TAs' educational backgrounds and levels of experience and described how these factors might affect the grading processes. For example, describing how to address students' difficulties in developing teamwork and communication skills, s/he stressed the importance of providing students with consistent feedback but pointed for the lack of consistency among the TAs grading criteria. Thus, s/he said,

> Painfully. So... The first of all, the other thing to consider in this, is that, at least in our case, because we have many labs, and many lab sections, we also have many TAs. Now as you can imagine, the TAs, first of all, they may be doing the course for the first time, they may be coming from some other international school, not even a US school. They come in with different levels of experience, and also different backgrounds. So the TAs coming in are actually ... And the TAs are the ones that are grading the lab reports. Okay?

To address the difficulties with the TAs, ENG_6 proposed TA training, but then s/he stressed two new tensions, the lack of time to prepare the TAs, and the development of consistent rubrics,

> We do not have time, even in between, to sit down. Like we have a week, but that is not enough to get things framed. So consistent well-structured training of the TAs in terms of grading, feedback, communication and all of these things. That is one. Second, what we had to do is we had to restructure the lab reports and create detailed rubrics that are both available to the TAs, and that is how we train the TAs, but also available to the students so that it can have, and much clearer one-to-one correspondence of what is expected from them.

Another tension related to the alignment between the lectures and the lab activities. S/he expressed this tension in the following way,

> First of all, the lab has to be well-aligned with a lecture. Because the lecture is where you cover, at least in our case ... I am sure other labs are structured differently. But in our case the lab is part of the course, it is not a separate lab. It is a component of the course, so it has to be within the syllabus and within the academic semester. It has to be aligned in such a way that follows the lecture.

Finally, s/he revealed a tension regarding her/his role as a faculty (management), and what would be an ideal role of an instructor in a lab. S/he said,

> So, ideally, in a very ideal scenario, where you can have some very ideal scenario, first of all, you would have enough time to have direct interaction and engagement with the students during the lab. Like in dreamland, you would work in the lab while the students are doing an experiment, and you can sit down with them, and spend 15 minutes or something, and play with the experiment with them, and say "Why do you think this is happening? And what if we do this? Can you guess what's gonna happen here?" This is not gonna happen, ever, under the current system. Not for the instructor, not for the TAs.

As a corollary of all the tensions mentioned above, this participant, although aiming her/his students to be able to understand and apply the principles covered in the lectures, admits the inefficiency of the current labs. When questioned if the lab learning outcomes are met, this participant had a short answer: “no!”

Summary. The analysis of this participant’s interview revealed that similarly to Eng_2, teaching practices of Eng_6 were mediated not only by the espoused beliefs but also by external factors such as time, resources and students. In this case, the mediating factors also instilled patterns of behaviors that contradicted some of the beliefs espoused by the participant. For example, s/he believed students must have opportunities to experiment “within the experiment” and learn through trial and error. However, given several constraints including large enrollments, lack of resources, and limited time for time for the labs, s/he had to create very precise lab procedures and make everything fast and easy to students. In addition, this limited time for the experiments also led the participant to contradict her/his belief about the role of instructors. Instead of being mentors, the TAs who led the labs had to “hold” the students’ hands and do the labs, to speed up the experiments. The other tensions, although responsible for much additional work, seemed to be relatively under control by the participant.

6.4.7 Case seven: Eng_7

Background. Eng_7 had prior experience teaching in higher education settings with also experience in teaching labs. However, at the time of the interview, Eng_7 was teaching only lecture courses with no lab component. S/he reported to dedicate 30% of her/his time to teaching, 30% to research and 40% to other duties. Eng_7 primarily taught undergraduate courses, having an average number of one course per semester. S/he reported a moderate level of need for assessment practices. As instructional approaches, s/he mentioned the use of project-based approaches. S/he used lab reports to assess her/his students.

Beliefs and orientation. According to the analysis described in Chapter 5, this participant was oriented towards facilitating expertise development. S/he conceived knowledge as internally constructed by the students. In addition, s/he described teaching in the labs as a knowledge construction process where students engage in open-ended activities that foster critical thinking and decision-making. Thus, to this participant, students were responsible for transforming the knowledge in the labs.

Furthermore, this participant saw the labs as places where students have the opportunity to develop complex thinking. Regarding learning in the labs, this participant believes students learn better by trial and error processes, having the opportunity to use different tools, and developing their own experimental strategies. S/he saw as an instructor's main role, the role of an instructional designer, responsible for creating an atmosphere where "students feel free to fail and mess up something." Also, s/he described the role of a mentor who guides the students "through that process of making those connections…to synthesize the ideas and experiments…and come down to a principle or something new."

Reported teaching practices. This participant reported practices that fitted with the use of open-ended labs. In the interview, Eng_7 provided general ideas of how s/he proceeded when teaching labs. First, s/he aimed her/his students to be able to "critically think" about an experiment and to analyze and communicate the results effectively. S/he also wanted her/his students to learn to deal with uncertainty and ambiguity in experimental data. Second, the formal assessments involved the use of reports. The pedagogical approaches involved the use of a pre-lab lecture that covered the theory and the experimental open-ended activities. Eng_7 emphasized the importance of creating a safe learning environment that facilitates learning and encourages students to try different things without being afraid to fail. To Eng_7, the level of complexity of the engineering education labs must progress from a well-structured lab, at freshman and sophomore years, to very open-ended labs at junior and senior years.

Evidence from documents. Since this participant was not teaching any lab course at the time of the interview, s/he did not provide any written document.

Tensions. This participant revealed only two main tensions in her/his teaching practices. The first one regards to the management of the instructional process. The second referred to balancing the learning activities in the labs. Eng_7 had the main concern regarding keeping the labs functional for the student's activities. This concern included equipment, supplies, training, and organization. S/he expressed this concern with the following words,

> I think in a lab setting; practically you always worry that the experiments are going to go okay. Doing a lab requires a lot more effort than showing up and lecturing on the board. You got to make sure the supplies are there for *The Program,* in particular; we got to make sure that all the equipment is working, make sure that the supplies are there and all that. That is certainly a big concern practically about running a lab, is making sure that the TA is trained, that you are trained, that the equipment is working, that the experimental supplies are where they are supposed to be.

Another tension in regards to her/his instructional design. During all the interview, Eng_7 stressed the importance of open-ended activities, and their role in developing a series of engineering skills, including critical thinking and designing of experiments. However, s/he reveals the following tension regarding the design of lab activities: "It cannot be so open-ended that there's no structure, but it cannot be so detailed that they are not mentally engaged. It cannot be like a freshman chemistry lab, right?

Summary. This participant did not provide enough evidence of her/his teaching practices to evaluate the alignment of her/his beliefs and practices. S/he emphasized the use of open-ended activities and the idea of the progression of labs. Thus, there is a perfect alignment between the espoused beliefs and teaching practices. Also, the tensions expressed by this participant indicated how time-consuming is to manage all the complexities of a lab course.

6.4.8 Case eight: Eng_8

Background. Eng_8 has prior experience teaching in higher education settings with also experience in teaching labs. S/he reported to dedicate 30% of her/his time to teaching, 5% to research and 65% to other duties. Although Eng_8 was responsible for the lab course, s/he did not teach any lab section. Eng_8 primarily taught undergraduate courses, having an average number of one course per semester. S/he reported a moderate level of need for professional development on assessment practices and instructional practices in her/his field. S/he mentioned the use of traditional labs together with the project- and problem-based approaches and discovery learning. S/he used lab reports, exams, projects, surveys, and functional testing of students' designs to assess her/his students.

Beliefs and orientation. According to the analysis described in chapter five, this participant was oriented towards supporting students' professional development. S/he conceived knowledge as internally constructed. Also, s/he described teaching in the labs as knowledge construction process where students engage in open-ended activities that foster creative thinking, decision-making, and problem-solving. Thus, to this participant, students are responsible for transforming the knowledge in the labs.

Furthermore, this participant sees the labs as places where students have the opportunity to develop complex thinking. Regarding learning in the labs, this participant believed students learn best by trial and error processes, having the opportunity to use different tools, and developing their experimental strategies. S/he presented multiple views of her/his roles regarding lab activities. First, s/he stressed her/his role as a lecturer, with minor influence on the labs. Second, s/he reported the importance of monitoring the lab activities as the TAs are the responsible for running the activities. Finally, s/he described the ideal role of an instructor in the role of a consultant who provides answers to students.

Reported teaching practices. This participant reported practices that fitted with the use of mixed approaches using both traditional well-structured activities at the beginning, and open-ended problems and projects at the end of the labs. In the interview, Eng_8 provided general ideas of how s/he proceeded when teaching labs. First, s/he aimed her/his students to be able to understand and apply concepts and tools. S/he also wanted her/his students to develop problem-solving strategies useful in the profession. Second, the formal assessments involved exams, peer evals, and projects. This participant was teaching two lab courses at the time of the interview. The first course, for junior students, followed a more traditional approach having lecture and labs. The lectures were focused on explaining concepts and tools, and in the labs, students had to apply such knowledge. The pedagogical approach emphasized traditional well-structured activities but with a final project. The second course was a capstone course, and it was heavily based on open-ended activities. To Eng_8, the level of complexity of the engineering education labs must also progress from a well-structured lab, at freshman and sophomore years, to more open-ended labs at junior and senior years.

Evidence from documents. This participant adopted a hybrid approach combining traditional lab education with small open-ended tasks and a project. Eng_8 provided the course syllabus and two lab handouts. The course was composed of lectures and lab experiments. The analysis of the syllabus indicated that the main goal of the lab course was to implement the concepts learned in the classroom through computational simulations. The course was structured as a series of lectures that covered numerous concepts and principles. The lab activities aimed to allow students to apply the concepts learned in the lectures. The assessment component of the instructional design included quizzes, exams, pre- and post-labs, and a project. Quizzes and exams were responsible for 30% of the total grade, the pre- and post-labs assignments were responsible for 35%, and the final project responded for 35% of the grade. The lab handouts included a summary of the related theory and provided step-by-step instructions on how to perform the experiments. The first handout provided a series of well-detailed instructions and aimed to familiarize students with the system. At the end of this first handout, students were asked to solve some open-problems, and minimal guidance was given. These were what I called as small open-ended tasks. The second handout was from the fourth lab section and provided the guidelines for a first project. A problem was stated, and students were asked to solve such problem through a sequence of activities minimally detailed. The syllabus informed the students how the course would start using well-structured activities to familiarize the students with the system and tools, and progressively moving to more open-ended activities where students would have to propose solutions grounded on the knowledge gained in the classroom and previous labs.

Tensions. This participant reported a series of tensions regarding the use of open-ended activities in the labs. First, s/he pointed to the fact the students tend to "cookbook" the activities or find ways to make the activity less complicated. To explain this students' approach, s/he said, "That is, you will have a lab where we want to get them to think for themselves, but they will find ways to cookbook it." To deal with this situation, Eng_8 used to change the lab activities but stressed the difficulties in doing that.

> So the things we want them to figure out, they will just find out what the solution was. And that is hard because ... I give you the example of the *specific* lab. That is the specifications, the test cases, the whole thing is, it is a hard thing to put together for the first time. And changes to that content are difficult to make along the way. So over time, we look for ways of adjusting content, so the students cannot just look at the last design.

Eng_8 also stressed that the time required to conduct the open-ended activities might prevent him from using such approaches more often. S/he said,

> I really like open-ended projects, but they take an awful lot of time. They take a lot of time for the students, but they take an awful lot of time to manage and assess and observe what they are doing, so if I had the unlimited human bandwidth to work on this, I would do a lot more with projects.

Eng_8 also argued that differences between the theory and the experimental results might be troublesome both to students and instructors. This fact may lead instructors to organize the activities in a way that prevents students from having such difficulties. However, s/he argued that making things easy for students does not necessarily benefit the students. As s/he said,

> And, you know it would be tempting to just, well, make the lab as clean and predictable as possible so that they (the students) don't have to struggle with that problem. But to me, that is the kind thing they need to learn.

This participant used to think that labs were more interactive and created more opportunities for learning than lectures, but argued that instructors needed to be present to "coach" the students while they are facing experimental difficulties. The tensions arise because the faculty was not there, and the educational outcomes rely mainly on TAs.

> I deal with many labs, and I try to poke my head in them occasionally, but I don't really get to observe that much in the labs, but I try to do what I can to connect with students to find out what's happening as well and see if there's anything that needs attention that way. So, yeah, I have the duty of teaching it in the lecture, but I do have a responsibility for knowing what's going on in the lab and trying to make sure things are dealt with if there's ... something needs attention.

And,

> From the Teaching Assistant side, in terms of what the teaching assistants do ... Part of the lab is the teaching assistant presenting or explaining what they are going to be doing in the lab, the course deadlines, and things, and some technical content and presentations skills vary. There are some TAs who pretty much just read the slides. Though, of course, the TAs aren't the only people who do that, but there are others that have a good sense of what they really want to explain about it. So the TA presentation skills vary.

Another tension regarded the influence of inheritance on the lab courses. The participant, although acknowledging the influence of inheritance, tried to update the course learning objectives to keep the labs up to date with the industry needs. S/he said,

> The course existed before I came along, even though the Design course, although I have had a connection to it for a very long time because I was a TA for it when I was working on my PhD in the mid-90's. So, I have to say partly the objectives are inherited, but I try to

> look at them and think about whether the objectives make sense. A lot of the objectives that I write, I'm thinking in terms of, "Okay, what are they going to do with this? How do people use this when they go to work?"

Summary. The analysis of this participant's interview revealed that the teaching practices of Eng_8 were also mediated not only by the espoused beliefs but also by external factors such as time, resources and students. In this case, the mediating factors did not cause any contradictory behavior, or contradictory teaching practice, but increased the level of complexity of the instructional design and practices. For example, because students used to try to "cookbook" the execution of the labs, s/he tried to upgrade the challenges continually. However, upgrading the labs was time-consuming. Also, given the limitations in her/his time, and also the students' time, s/he limited the use of more open-ended projects. Furthermore, instead of making the labs easier to students, as a way to cope with the students' difficulties in translating the theory into practice, Eng_8 tried to progressively increase the level of complexity of the activities while controlling the amount of support provided to students. In summary, Eng_8 spent much time trying to adapt her/his teaching practices to maintain the alignment between beliefs and practices.

6.4.9 Case nine: Tech_1

Background. Tech_1 had prior experience teaching in higher education settings and also in labs. S/he reported to be dedicate 35% of her/his time to teaching, 55% to research and 10% to other duties. At the time of the interview, Tech_1 was teaching a course that had lab and lecture components. Tech_1 taught at least one lab section per semester. Tech_1 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate or high level of need for professional development on all the areas presented in the questionnaire but one, information and communication technologies (low need). S/he mentioned the use of traditional labs together with computational experiments, demonstrations, and project- and problem-based approaches. S/he used projects and surveys to assess her/his students.

Beliefs and orientation. The findings from the phase one, described in the previous chapter, revealed that this participant was oriented towards using the labs to help students to develop professional ways of thinking in the field. S/he described knowledge in the profession as internally constructed. Also, s/he described teaching in the labs as knowledge construction process where students engage in open-ended activities that foster creative thinking, decision-making, and problem-solving. To this participant, the instructor must be around to guide the students while they conduct the experiments. Furthermore, this participant saw the labs as places where students develop professional ways of thinking. Regarding learning in the labs, this participant believed students learn better through hands-on experiments. S/he presented multiple views of her/his roles regarding lab activities including lecturing, mentoring, and motivating students, among other roles. At the end of labs, Tech_1 wanted her/his students to know differently than when they started. S/he believed students at the College of Engineering Technology have a learning style that values hands-on experiences rather than abstract ones.

Reported teaching practices. This participant reported practices that fitted with the use of open-ended lab projects. Tech_1 provided evidence of her/his teaching practices. First, s/he aimed her/his students to be able to apply knowledge in real industry problems and develop critical thinking skills. The focus would be less on the theory and more on practical applications associated with the profession. Second, the formal assessment basically involved the use of exams and projects. The participant reported the use of project-based learning, "especially in higher level classes in the third year and above where instead of giving them the traditional labs, I just give them a project to work through a period of time."

Evidence from documents. This participant adopted a traditional lab education approach and a small design project. Tech_1 provided the course syllabus and the lab handouts. The analysis of the syllabus indicated that the main goal of the course was the demonstration of concepts and principles in practical situations. In addition to this demonstration component, the lab activities aimed at teaching students how to operate equipment, measure variables and analyze results. The course was a lecture and labs course. There were 23 lectures and several lab activities spread over 14 weeks. The assessment component of the design included exams (30%), reports (30%), quizzes (30%), project (5%) and homework (5%). The lab manual included a summary of the related theory and provided well-detailed instructions on how to perform the experiments. Despite the use of highly structured instructions, Tech_1 included a series of open-ended questions at the end of each lab activity. These questions should be part of the lab reports and aimed to engage students in a reflective process relating the results of the experiments with either the theory or the potential industry situations. No information was provided regarding the final project.

Tensions. Tech_1 expressed many tensions. First, s/he argued that labs are very important because they allow better interaction between himself as the instructor and the students. However, due to the number of lab sections, s/he would be present in just one section per semester. The other sections were led by TAs. To tackle this tension, s/he said,

> I have at least one section every semester that I teach myself, so I am the instructor for the lab. Then, I can see where they (the students) are struggling, and then I can coordinate with my TA, hey, this is difficult for them, this is not connecting very well, and I also get feedback from my own TA and he tells me things that he notices too, so we meet like a lot, every week.

A second tension regarded students' attitudes toward the lab activities. S/he expressed a concern when students instead of engaging in a constructive mode of learning, try to cookbook the activities,

> sometimes we do project-based learning activities but still, I mean, they (the students) can't really get out of that focus of, … this is a recipe for getting an A or a B and as soon as I'm done, then I leave. So that is something that I feel like we struggle, I struggle with that personally.

The third tension is connecting the classroom content with the lab activities.

> Connecting the class content with the lab sometimes is not easy to do and not only for me as a faculty and the course coordinator but also in the sense of like in their (students) own minds this is clicking. It is not easy, always.

A fourth tension related to time and resources. According to Tech_1, improving the existent activities or designing new ones require a lot of time. Also, the lack of resources such as equipment, space, and TAs may cause additional stress.

Summary. The triangulation between the interview, the reported practices, and evidence from the syllabus and lab manual indicated an apparent contradiction between her/his the reported versus the actual practices. S/he mentioned the use of project-based approaches and the documents made evident the use of traditional labs. However, according to Tech_1, the use of project-based learning was associated with higher level courses, and the documents were from a low-level course. Since this apparent contradiction was resolved, Tech_1 seemed not to be affected by tensions s/he reported. Indeed, s/he did not perceive any problem in not attending the lab sections, as long as s/he taught one section per semester and had regular meetings with TAs to be aware of the other sections. The role of a mentor was not possible for all the lab sections and, s/he had no guarantee that TAs would do a good job in mentoring the students. Furthermore, although Tech_1 mentioned the same mediating factors cited by other participants, s/he did not reveal any higher level of problems with such factors. That means that Tech_1 did not contradict any specific belief because of those factors.

6.4.10 Case ten: Tech_2

Background. Tech_2 had prior experience teaching in higher education settings with also experience in teaching labs. S/he dedicated 50% of her/his time to teaching, 20% to research and 30% to other duties. At the semester of the interview, Tech_2 was teaching only lecture courses with no lab components. Tech_2 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate level of need for professional development on instructional practices and laboratory equipment.

Beliefs and orientation. This participant was oriented towards using the labs to support students' professional development. S/he described knowledge in the profession as internally constructed. In addition, s/he described teaching in the labs as knowledge construction process where students engage in open-ended activities that foster creative thinking, decision-making, and problem-solving. Thus, to this participant, students are responsible for transforming the knowledge in the labs. Furthermore, this participant saw the labs as places where students have the opportunity to develop complex thinking. Regarding learning in the labs, this participant believed students learn better through hands-on experiences. At the end of her/his lab courses, Tech_2 wanted students to know differently. S/he conceived the main role of the instructors in the role of guides who support students while they are learning. S/he believed students at the College of Engineering Technology have a learning style that values hands-on experiences rather than abstract ones.

Reported teaching practices. This participant reported practices that fitted with the use of problem-based lab approaches. Tech_2 provided evidence of her/his teaching practices. First, s/he aimed her/his students to be able to identify a problem and design a solution using the knowledge and tools learned in the course. The participant reported the intention to use problem-based learning approaches but acknowledged that using such approaches was not always possible given time limitations. According to Tech_2, if an instructor wants to run too many experiments, then it is necessary to give precise instructions since "you have to move kids through." S/he agreed with the use of traditional labs in low-level courses, but argued that the amount of details in the instructions must be controlled. To Tech_2, as students progress toward the graduation, the labs must become less structured, with "guidance, but not direction." Given this belief, Tech_2 reported having reduced the number of experiments to allow students to go over less-structured labs. "I think it worked. It is not the only way to do it, but it seemed to work."

Evidence from documents. Since this participant was not teaching any lab course at the time of the interview, s/he did not provide any written document.

Tensions. Tech_2 expressed many tensions. First, s/he argued the keeping a seamless blend between classroom and lab activities is becoming difficult and resulting in less lab work than the ideal. The reason for that, s/he argued, related to the high cost of the lab equipment and TAs.

> How much do a chalkboard and a box of chalk cost? Nothing? Pretty much. We have got individual machines in that student lab over there that are $20,000 each. If you wanna run it, you need a TA. A TA is about $40,000 a year. That starts to add up really. That is different from just standing at a chalkboard with a piece of chalk in your hand. That is cheap.

A second tension was associated with time. Time to design new learning experiences, and students' time.

> Not always. What I just said, takes a lot of time: time is not always available. These kids are busy; I am busy. When we come together sometimes, we have to ... A lab takes two hours. That is a long time, but sometimes it needs more than that…. Preparation time is always a problem. Professors ... There's not enough of us to go around. We're pulled in many different directions at once. When you walked in here, there was a student sitting here. You sat down; there was another student at the door. She wanted to know when she could come back and talk to me. The part you did not see, is there's another guy downstairs running a test which expects me to come down there and help him. He is gonna be down there waiting for me too. I have a book due ... Same things with all professors. It is not just me. I love my job. I love it. I do not wanna be anywhere else, but in this environment, it is very difficult to sit down and say, "I am gonna spend an hour thinking about how I am gonna run a lab." What you wind up doing is on the way over there you think, "Okay, now how am I gonna do this?" When you walk in the classroom, whatever you got, that is what it is gonna be.

The third tension contrasted the use of a well-structured approach versus creating more opportunities for students to engage in a reflective process.

> It is easy to go into a lab and give them a procedure written down. It is very easy because the lab is organized, it proceeds at a measured pace, you know when it is gonna be done, and it is easy to move a lot of students through a lab that way. We have so many undergraduates that we do a lot of that. A more effective, but slower way to do it, is to ask them to calculate what they think is gonna happen before it happens and do it for a sample, then test, and see if they get the same answer.

A fourth tension contrasted the time required to teach labs versus other duties such as conducting research. It also revealed a tension related to institutional values and reward systems that do not foster the scholarship of teaching. When talking thing that could prevent a change in the lab activities, Tech_2 said,

> You're not gonna like this answer. It is focus. You can't go in there thinking about the grant you're writing, you can't go thinking about all the emails you have to do, you can't go in thinking, "I'll just let 'em work for a few minutes on their own, I'll run off and do something else while they're in the lab." You gotta be there, and you gotta not be thinking about anything else and not paying attention to anything else. And there's nothing about a university that encourages that, but you have to.

Summary. This participant expressed tensions that play a strong role in the decisions of other participants. Time, resources, TAs, institutional values, and so on. However, according to the reported practices, Tech_2 seemed to know how to cope with all the tensions in order to keep the alignment between her/his educational beliefs and the respective teaching practices. As s/he was oriented towards supporting student's professional development, s/he reported the use of open-ended activities associated to the profession. In these open-ended activities, Tech_2 agreed in guiding the students rather than providing precise instructions, or directions. It is important to notice that, no evidence from documents was provided.

6.4.11 Case eleven: Tech_3

Background. Tech_3 had prior experience teaching in higher education settings with also experience in labs. S/he dedicated 85% of her/his time to teaching, 5% to research and 10% to other duties. At the semester of the interview, Tech_3 was teaching a course that had lab and lecture components. S/he taught both the lectures and the lab components. Tech_3 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate to a higher level of need of professional development on all the areas presented in the questionnaire. S/he mentioned the use of traditional labs together with computational experiments, demonstrations, problem-based and discovery learning approaches. S/he used reports and exams to assess her/his students.

Beliefs and orientation. According to the analysis described in chapter five, this participant was oriented towards using labs to connect theory into practice. First, s/he conceived knowledge as internally constructed and characterized by the students' ability to be "self-learners." Also, s/he described teaching in the labs as a transmission of knowledge process where the faculty lectures about the theory, and then engage students in hands-on activities aiming to help them to make sense of the theory. Regarding learning in the labs, Tech_3 believed that students learn best through hands-on, structured activities. Also, to Tech_3, the agent responsible for transforming the knowledge in the labs is external, characterized by him/herself who keeps telling students the connections between what they are doing and the theory. As her/his main role, Tech_3 mentioned the role of a consultant who provides the answers and guides students during the activities.

Reported teaching practices. This participant reported practices that fitted with the use of traditional lab education. First, s/he aimed her/his students to be able to understand the principles associated with her/his discipline and make the connections between theory and practice. Second, reports were the only formal assessment mentioned, but Tech_3 also stressed the importance of interactions between the instructor and the students as a way to assess their progress. The pedagogical approaches involved running hands-on, structured labs every week to connect the classroom content with the lab experiments.

Evidence from documents. This participant adopted a traditional lab education approach and a small design project. Tech_3 provided the course syllabus and the lab handouts. The analysis of the syllabus indicated that the main goal of the labs was the application of concepts and principles in practical situations. The course was a lecture and labs course. There were 23 lectures and thirteen lab activities spread over 16 weeks. The assessment component of the design included exams (60%), lab reports (25%), homework, attendance, and assigned readings (15%). The lab manual included a summary of the related theory and provided step-by-step instructions on how to perform the experiments. The lab handouts included a summary of the related theory and provided step-by-step instructions on how to perform the experiments. The level of details prevented students from “figuring out” any step. Everything was detailed at the level of which component should be connected, turned-on, or turned off. Figures were provided to illustrate each step of the experiment. In addition to the highly structured instructions, Tech_3 included open-ended questions to engage students in a reflective process toward making associations between the experimental data and the theory.

Tensions. Tech_3 main tensions were totally associated with time. First, s/he argued it would be necessary to increase the time for the lectures in order to give students more time to understand the theory before going to the labs.

> But I think those one hour lecture is not enough for them to understand the theory, because it's new to them and they're trying to listen or grasp everything that I said as a professors and then when we do in the lab the hands-on, I feel like that's not enough time for them to kind of understand the theory before they do the hands-on… we need a little bit more time for the students to kind of understand the theory first before jumping on into a hands-on right away, which they are trying to figure, in their brain, what is the theory behind it.

Second, Tech_3 also wanted more time for the lab activities. S/he believed students needed more time to make all the necessary connections between the theory and the practice. S/he said, "… in regard to the lab, maybe have a little bit more ... slow it down a little bit so that the students can process what they are learning from the theory to the actual hands-on, I guess."

Third, s/he argued that students usually don't have time to be prepared for the lab activities. "... students not only ... they are taking 18 credit hours. They are not only taking my class, so there's a lot of other pressures from other classes. Not only that, they have socials, they have all this stuff that they need to balance. I mean, we have all been students before."

The last tension revealed a conflict of beliefs. In one hand, the apparent willingness to implement project-based approaches. On the other hand, the belief that the lack of time prevents him from adopting such approaches.

> I would, right now ... let's say, for example, [Course 1] again, because we have the theory; it is fine, I think, the lecture I believe is solid. The lab is solid, but to a point, I do wanna add a little bit more of a project for students, as in give them a project assignment that takes about 2 months or something like that, so they can learn themselves instead of giving them, "Hey, this is the manual, this is what we have to do", instead of kind of like a robot. If I have the power, I do wanna add more time.

Summary. According to Tech_3 interview, time is the only limiting factor the prevented him/her from adopting project-based approaches. S/he believed that, to adopt projects, s/he would have to "take out some experiments" and that caused tension because the experiments have to be done. Indeed, the conflict here regards the tension *content versus the learner*. However, the tensions expressed by Tech_3 did not cause any contradiction between beliefs and practices. Everything seemed to be aligned, despite some tensions. Indeed, maybe some of these tensions are a result of her/his orientation toward content rather than the learners' development.

6.4.12 Case twelve: Tech_4

Background. Tech_4 had prior experience teaching in higher education settings with also experience teaching labs. S/he dedicated 75% of her/his time to teaching, 10% to research and 15% to other duties. At the semester of the interview, Tech_4 was teaching a course that had lab and lecture components. S/he taught both the lectures and the lab components. Tech_4 primarily taught undergraduate courses, having an average number of three courses per semester. S/he did not report any need for professional development. Also, s/he mentioned the use of traditional labs together with computational experiments, demonstrations, discovery learning, and project- and problem-based approaches. S/he used reports, projects, and exams to assess her/his students.

Beliefs and orientation. This participant was oriented towards facilitating expertise development. S/he conceived the knowledge in the field as internally constructed and characterized by the ability to deal with uncertainty and the flexibility necessary to solve engineering problems. In addition, s/he described teaching in the labs as a knowledge construction process where students engage in open-ended activities that foster uncertainty, discovery, and failure. Thus, to this participant, students were responsible for transforming the knowledge in the labs. Furthermore, this participant saw the labs as places where students have the opportunity to develop complex thinking. Regarding learning in the labs, this participant believed students learn better by trial and error processes. For this reason, s/he tried to encourage failure early in the learning processes, so the students could "get comfortable with it." S/he described the instructor's main role, the role of a mentor who facilitates the learning processes in the lab.

Reported teaching practices. This participant reported practices that mixed traditional well-structured activities at the beginning, and open-ended problems and projects at the end of the labs. In the interview, Tech_4 provided general ideas of how s/he proceeded when teaching labs. First, s/he aimed her/his students to become familiar with the concepts of the course, and also knowledgeable about equipment and measurements. In addition, s/he wanted to instill confidence and problem-solving strategies. Second, Tech_4 did not mention any formal assessment but stressed the importance of observing students' level of motivation and apprehension as a way to assess her/his students. The pedagogical approach described by Tech_4 can be conceived as a mixed approach combining traditional labs, during the first third of the course, with less-structured activities in the second third of the course, and completely open-ended activities during the last third of the course.

Evidence from documents. This participant did not provide any written document.

Tensions. This participant did not bring many tensions in her/his voice. S/he just reported some tension when s/he was not able to teach the lab activities. According to him/her, this lack of interaction was a problem because normal assessments did not provide a "very good picture" of a student's progress in the labs.

> So, the lab is where I really get to see the progress of my students. And there are times when I do not get to teach in a lab…I do not feel as aware of their progress because you can only ... especially in a larger course, assessments don't entirely give you a very good picture of student understanding in my mind, and laboratory, really since we are teaching students that will be working with real devices in real applications, looking at how they work with those devices and their successes and failures with those devices and those types of activities really is a better measure of their progress than a quiz or an exam that might focus somewhat on real material, but you can't tease out a lot of higher level ... You cannot see those processes from that type of assessment.

Summary. The participant's reported practices were aligned with the beliefs expressed in the interview. Her/his orientation towards facilitating expertise development is aligned with the idea of progressively engaging students in structured activities at the beginning, as a way to familiarize students with equipment and procedures, and then move students to less structured activities and finally to completely open-ended activities at the final stages of the lab course. However, Tech_4 did not provide any written evidence of her/his lab practices.

6.4.13 Case thirteen: Tech_5

Background. Tech_5 had prior experience teaching in higher education settings with basic experience in teaching labs. S/he dedicated 40% of her/his time to teaching, 50% to research and 10% to other duties. At the semester of the interview, Tech_5 was teaching a course that had lab and lecture components. S/he taught both the lectures and the lab components. Tech_5 primarily taught undergraduate courses, having an average number of two courses per semester. S/he reported a moderate level of need for professional development on assessment practices, instructional practices, and information and communications technologies. Tech_5 mentioned the use of traditional labs together with project-based approaches. S/he used reports to assess her/his students.

Beliefs and orientation. This participant was oriented towards using labs to connecting theory into practice. S/he conceived the knowledge in the field as externally constructed based on a set of concepts and principles associated to her/his discipline. S/he described teaching in the labs as a knowledge construction process where students have to deal with open-ended problems. According to this participant, the labs must be aligned with the lectures, and the activities should be moderately structured in order to help students to succeed. Regarding learning in the labs, this participant believed students learn better through hands-on activities where students "can see things." S/he conceived as an instructor's main role, the role of guide, or consultant, who had the technical knowledge to give feedback to students whenever they needed. Tech_5 also mentioned her/his role as an instructional designer and referred how difficult and challenging is to plan and execute the labs, especially regarding balancing the level of complexity of the activities in a way that students feel challenged but still able to finish them.

Reported teaching practices. This participant reported practices that fitted with the use of traditional lab education. S/he was responsible for a lecture and lab course. S/he taught both the lecture and the lab component. TAs helped him/her to conduct the labs. S/he described the main components of the instructional design in the following way. First, s/he aimed her/his students to remember the meaning of a series of concepts associated with the course. Second, the only formal assessments reported were homework and exams. However, s/he stressed the importance of being in the labs seeing what students are doing and noticing their progress. The pedagogical approaches involved the use of well-structured instructions. “At this point, it is very much in manual, a guide where they have four sections and each section has one, two, three, four. ‘Connect here. Connect this and this. Measure, plot, question.’ So, not really much like an open problem, right?”

Evidence from documents. This participant adopted a traditional lab education approach. Tech_5 provided the course syllabus, slides, and one lab handout. The course was composed of lectures and lab experiments. The analysis of the syllabus indicated that the main goal of the course was to introduce students to fundamental concepts and principles associated with a particular discipline. The main goal of the lab component was to reinforce the concepts learned in the classroom through hands-on activities. The assessment component of the instructional design included homework (20%), quizzes (5%), exams (45%) and labs (30%). The lab handouts presented the objectives of each activity and gave a set of step-by-step instructions on how to perform the experiments to answer the proposed questions. These experiments aimed basically validate the theory from lectures with minimal connection with real-world applications. Students were asked to reflect on the results. However, everything was spelled out in details. A final experiment was proposed to engage students in a practical application that led students to make external measurements, analyze, and report results associated with a real-world application. The instructions to this experiment were also very detailed. In the lab activities described in the handout, students had to program and use different equipment and software.

Tensions. Tech_5 expressed several tensions. First, s/he mentioned the consequences of the large enrollment. Large enrollment results in more sections, and more sections increase the time necessary to run the labs. S/he argued that even with the help of TAs the problem of time persists since the TAs also require attention. An additional consequence of the large enrollment regards to the time necessary to manage all the demands of an increasing number of students.

> So you can have classes with a hundred students. In the lecture they can all fit, right? Big classroom and they all fit but in the labs, it is very difficult to have a lab that has a hundred stations. So they have to break it up into sections of 10, 15 students, and then what happens is, then you have to have multiple sections. Your class that meets once a week for lecture, then it has to meet five times a week for the lab, right? So it scales.

And more,

> ... It is faculty time, right? Even if I have a TA, the TA is going to run into problems; he is going to need my help, all right? So I think that is also part of what discourages people who are active in research. Now you have to take care of these labs. So it scales. Equipment, the scale, and in labs things break and don't work as planned sometimes, for whatever reason. The students manage to do something different or equipment breaks or is disconnected, or all these other issues. What worked everything nice in the lecture, in the slides everything is perfect. In the labs, reality kicks in and that brings another level of complexity to the professor or the TA.

Second, s/he believed the best way for students to learn is through open-ended problems. However, s/he argued that the time necessary to work with open-ended problems was beyond the limitations of the current labs. Thus, an intermediate approach has to be adopted. Instead of giving completely open-ended problems, s/he provided more guidance and supported students to guarantee their success.

> So, the dynamics are difficult. What we have been doing is something in-between. So I give them some help, some skeleton, and they can work on just to keep the dynamics of the lab under control. Otherwise, I felt that it is just out of control, they cannot finish in two hours, and that breeds resentment on them.

A third tension contrasted researching and teaching. According to Tech_5, the personal interest for research aligned with the institutional rewards system makes difficult the adoption of educational innovations.

> Right. So, that brings more work to the ... exactly. We have professors here that are…, their focus is just on teaching, and they are very good, and that is their passion, and they do very well. But there is another part in this department where a group of faculty who is, they also work in research, right? So that is where the passion is in research perhaps. So it is always a struggle, "Where do I put my time? On the research side or on the teaching side?" … I think it is personal. Also, the way people are promoted… people are promoted based on scholarship, so papers, publications.

Tech_5 also acknowledged her/his labs needed some upgrade regarding new activities. However, given her/his limitation of time, s/he could not make the necessary change. The following quote describes how Tech_5 described the main factor that prevented him from developing a new experiment,

> I think more planning. I think the more careful planning of ... or coming up with ideas that are like, "Wow. This lab is going to be really neat, and they will remember that." So when I developed this class, I was teaching at the same time… So I had the time pressure, but if I had more time I could now ... for instance, now I could sit back and reflect which labs are working, which labs are not.

Finally, as a corollary of all these tensions, Tech_5 described the main barrier to good teaching in the lab in the following way,

> So one could be technology, right? So things will break. Another barrier could be time. So, if the professor is thinking about his next proposal, that is where your mind is going to be, and you are going to think that that lab is just something between you and your proposal or your research. So, expectations. If I have a TA to help me, that is great, but the TA does not know as much as I do, didn't create the labs, right? …what is expected from the professor. Are you expecting to be getting big grants? I need time for that.

In summary, the most of the tensions expressed Tech_5 are associated with the tension research versus teaching. The large enrollments and the time required to design new labs required time, but her/his interest is in research, and there is where s/he wanted to put more effort and time.

Summary. The triangulation between the data from the interview, questionnaire, and written documents indicates a good alignment between beliefs and practices, and also between the reported and actual practices. Two beliefs seemed to be contradicted by the practices. First, Tech_5 believed open-ended labs were best for students to learn, but in the actual practice, there is no evidence of open-ended activities. Indeed, the participant already mentioned that given time constraints, her/his practices were very well-structured. Second, Tech_5 believed students and instructors are co-responsible for transforming the knowledge in the labs. However, given the same limitation of time, everything was spelled out in the handouts, and there was minimal space for students to engage in building any knowledge. Furthermore, the tensions expressed by Tech_5 revealed her/his main interest in conducting research rather than teaching. Moreover, certainly, this factor might mediate the relationship between this participant's beliefs and her/his teaching practices.

6.5 Discussion

Table 6.2 presents a summary of the thirteen cases arranged by orientation (see chapter five), practices, and the relationship between beliefs and practices. In the first level of analysis, it is possible to identify some relation between the orientations to teaching and learning in the labs and the teaching approaches adopted in the labs. From the table, it is evident that participants oriented towards reinforcing lectures (orientation one) adopted traditional lab approaches. That is, they used well-structured activities with minimal space for students to think or do anything out of the scope of the handouts.

Participants who were oriented towards connecting theory into practice also adopted traditional lab education. Thus, they also used well-structured activities with no space for students to think creatively. However, what seems to be different for these instructors compared with the participants oriented toward reinforcing lectures is the additional goal of providing students the opportunity to be in contact with practical situations where they have to measure, build, and operate equipment. The learning outcomes, implicitly or explicitly, include the development of hands-on skills. For example, Eng_4 (reinforcing lectures) and Tech_5 (connecting theory into practice) taught very similar courses. The concepts and principles students have to learn were basically the same. However, while the labs taught by Eng_4 have only simulation and programming activities, the activities conducted by Tech_5 included the use of instruments, software, and other equipment. In addition, practical activities outdoor were also part of the activities led by Tech_5. Similarly, the labs led by Tech_3 were full of hands-on activities where students had to assemble parts, connect instruments, measure things, and so on.

The two participants oriented toward developing professional ways of thinking also used traditional lab instruction. However, their lab activities were less structured. That is, students had to follow instructions with minimal space for creativity, but the instructions required reflection on how to proceed to get the desired results. The two participants with this orientation expressed a similar view of their learning objectives. They argued that although the theory was important, the labs were not the places for reinforcing it. Thus, these faculty tried to connect the lab activities with practical situations associated with their profession. However, a difference was evident in their documents. In the labs taught by Eng_1, the experimental apparatus was normally built in advance by a technician. Thus, her/his students had only to make measurements, take notes and conduct data analysis. In the labs taught by Tech_5, students had to assemble the experiments before to collect data. This difference may be associated with the characteristics of the two programs rather than to the difference between the two members' beliefs. In other words, participants from the College of Engineering Technology placed a stronger emphasis on the hands-on work than the participants from the College of Engineering.

The two participants oriented towards supporting professional development mentioned the use of open-ended approaches, sometimes combined with traditional approaches. The participants did not disagree with the use of traditional labs. However, they argued that the complexity of the students' activities must increase as the students advance towards graduation. The practices reported by them included the use of open-ended activities such as small task, problems or projects.

Finally, three participants were oriented toward facilitating expertise development. Two of these two participants, although not providing any document related to their instructional approaches, reported practices aligned with the use of open-ended activities where students had to deal with decision-making processes, problem-solving, and design thinking. One participant, Eng_5, although oriented towards facilitating expertise development, reported practices and provided documents that made evident contradictions between her/his beliefs and her/his practices. S/he adopted practices oriented toward reinforcing lectures and sometimes oriented towards connecting theory into practices. These practices were associated with the use of well-structured activities where students had minimal opportunities to think critically or go through decision-making processes as s/he believed to be the ideal learning process. To justify this contradiction, Eng_5 reported a series of tensions that will be detailed in the following paragraphs.

Indeed, the analysis of the thirteen cases revealed tensions and contradictions in the relationship between faculty beliefs and practices. First, all participants, implicitly or explicitly, revealed a series of tensions that challenged their beliefs and sometimes led the participants to adopt practices that contradicted their espoused beliefs. Among these tensions, the role and influence of TAs, the lack of resources such as time, equipment and space, the institutional reward system, and the influence of inheritance on the lab practices were evident. Second, five participants revealed practices that contradicted their espoused beliefs. The practices of those participants seemed to be mediated by different factors. Time, enrollment, resources and the student's interest and cognitive skills seemed to mediate the practices of Eng_2 and Eng_6, leading them actually to teach in opposition to some of their educational beliefs. The lack of rewards and inheritance of the course materials seemed to mediate the practices of Eng_4. Time, personal interest, and institutional reward system seemed to mediate the practices of Tech_5. Also, the reported and evident practices of Eng_5 were in total opposition to her/his espoused beliefs. The influence of factors such as time and large enrollment mediated her/his practices in opposition to her/his beliefs. The tensions revealed by Eng_1 and Eng_3 seemed to be alleviated by the attitudes these professors took toward the lab practices. While Eng_1 added a new lecture to provide context and discuss the experiments, Eng_3 tried to attend all the lab sections. Eng_7 did not provide any instructional document, and her/his reported practices were aligned with her/his beliefs. Finally, Eng_8 described similar tensions expressed by other cases. However, instead of adopting practices that contradicted her/his beliefs, s/he adapted the lab practices in order to balance the reported tensions.

The practices described by the participants from the College of Engineering Technology included a strong practical component, in the sense that students had to build the experiments from the zero. That practical component means students had to go to the labs and assembly the experiments, taking every component and connecting them in order to make the experiment operational. After setting up the experiments, students had to collect the necessary data, observe the results, do the data analysis and present the results in a specific way. On the other hand, students at the College of Engineering worked on experiments already set up for them and had to work directly on the data collection. In most of the experiments conducted by the students at the College of Engineering, TAs were responsible for operating the equipment while students observed and took notes.

The practices associated to the three first orientations to teaching in the labs, supplementing lectures, connecting theory into practice, and developing professional ways of thinking, can be characterized as traditional lab education, which means the use of well-structured activities with minimal space for creative thinking and problem-solving. The activities follow a recipe-based approach that often guides students during the experiments. Thus, the use of traditional lab education may indicate a participant's tendency to emphasize the content over the learners' development. On the other hand, the findings indicate that the two final orientations, supporting professional development and facilitating expertise development, emphasized the use of open-ended approaches that emphasized the learner rather than the content.

As discussed above, the participants of this study revealed a series of factors that influence their teaching approaches in the labs. One of these factors was already discussed in the previous section and refers to the role and presence of TAs in the labs. Beyond the TAs, participants mentioned the influence of institutional resources, including time, equipment, space, and staff. Also, some participants raised questions regarding the system of credits, the influential role of ABET and the institutional rewards system. The following paragraphs describe some of these influential factors.

Table 6.2 Summary of the cases

Participant	Orientation	Practices	Relationship Between Beliefs and Practice
Eng_2	Reinforcing lectures	Traditional labs. Very structured activities	Beliefs and reported practices with a moderate level of misalignment. The relationship seems to be mediated by external factors such as time, equipment and students.
Eng_4	Reinforcing lectures	Traditional labs. Very structured activities	Beliefs and practices are aligned, but with tensions. Lack of rewards prevented him/her to make changes in the course.
Eng_6	Reinforcing lectures	Traditional labs. Very structured activities	Beliefs and reported practices with a moderate level of misalignment. The relationship seems to be mediated by external factors such as time, equipment and students.
Eng_3	Connecting theory into practice	Traditional labs. Very structured activities	Good alignment between beliefs and practices. Tensions seemed to be mitigated by the participant.
Tech_3	Connecting theory into practice	Traditional labs. Very structured activities	Beliefs and practices are aligned, but with small tensions regarding time.
Tech_5	Connecting theory into practice	Traditional labs. Very structured activities	Beliefs and practices with a small misalignment. The relationship seems to be mediated by external factors such as time, personal interests and institutional rewards.
Eng_1	Developing professional ways of thinking	Traditional labs. Moderately structured activities and lab reports	Beliefs and practices are aligned with a minimal tension regarding the role of instructors.

Table 6.2 Continued

Tech_1	Developing professional ways of thinking	Traditional labs. Well-structured activities	Beliefs and practices are aligned with a minimal tension regarding the role of instructors. Other mediating factors seemed not to affect the practices.
Eng_8	Supporting professional development	Mixed of traditional labs, small tasks, and projects.	Beliefs and practices are aligned with tensions caused by factors such as time, resources and students. These factors mediated the level of work necessary to design the practices but did not cause any conflict of beliefs.
Tech_2	Supporting professional development	Open-ended activities	Beliefs and reported practices were aligned, but no evidence from documents was provided.
Eng_5	Facilitating expertise development	Traditional labs. Well-structured activities	Beliefs and practices completely in opposition. Practices were mediated by factors such as time and enrollment.
Eng_7	Facilitating expertise development	Open-ended activities	Beliefs and reported practices were aligned, but no evidence from documents was provided. Tension made evident how time-consuming is to manage lab classes.
Tech_4	Facilitating expertise development	Mixed of traditional labs, small problems, and open-ended activities.	Beliefs and reported practices were aligned, but no evidence from documents was provided.

6.5.1 The Role and Influence of Teaching Assistants.

A recurring theme among all the participants from the College of Engineering and three from the College of Engineering Technology regarded the role and influence of teaching assistants (TAs) on the laboratory activities. To those not familiar with the American educational system, TAs are normally graduate students, regularly enrolled in the university graduate programs, who assist faculty with many different teaching-related activities, including lecturing, grading, and running labs. For didactical reasons, I will list the main themes based on the number of participants who mentioned the referring theme.

TAs Run the Labs (All Eng / Tech_1)

The first finding, cited by all participants from the College of Engineering and one from the College of Engineering Technology, was the fact that laboratory activities are completely led by the TAs. In other words, the TAs play the role of instructors in the labs and are responsible for explaining the experiments, guiding students during the experiments, answering questions, operating the equipment, and sometimes grading the lab assignments, among other activities. A typical quote from one participant was,

> I do not teach a lab myself; I have teaching assistants doing it. I think by in large, this is how it works in college, where, the people who teach a lab are people who specialize in teaching a lab. They are not the instructor of the course. They are not a professor. They are more like staff people. (Eng_4)

TAs Require Training (Eng_3, Eng_6, Eng_7 & Eng_8)

A second theme, reported by four participants, is related to the training of the TAs. As labs require a good grasp of the theory plus a set of different skills, including the ability to operate the lab equipment and help students in troubleshooting, training is an important step in preparing those TAs. However, training the TAs for lab activities is not an easy task and requires time not always available. Reporting one of the main barriers to good laboratory education, one participant said,

> Another big barrier is nobody gets trained, not even the teaching assistants. One of my colleagues has an assistant, and we should train the TAS, having run the experiments before, that is not easy to do because everybody has time limitations. Teaching assistants, graduate students, they have their own job, writing their thesis, their research, taking classes and so on. (Eng_3)

Similarly, another participant said,

> Okay, so the short answer there is that the TA training, because in labs you have TAs, you cannot do it ... I do not do the labs; no professor does the labs. So you have another layer of management, that you have to put in place, that you properly develop those TAs throughout the semester. And the other problem, of course, is that, especially if you have many new ones, they come in ... Well, you have a lab the first week. We have not had enough time to develop those TAs. Right? So those first few weeks are always pretty rough. For both TAs and students. (Eng_6)

TAs Need to Be Monitored (Eng_4, Eng_5, Eng_6, Eng_7 & Eng_8 / Tech_1)

Another big concern reported by six participants was related to the need to control the TAs. As a consequence of having the TAs running the labs, the faculty in charge of those labs reported similar concerns on being aware of what is going in on in the labs. One participant expressed his concern, and also some measures to evaluate the TAs work in the following way,

> But part of my role with the lab, even though I have got both grad TAs and undergrad TAs in the lab, it is up to me to try to be aware of what they are doing. So, I will do things like ... I will have ... Last semester, I had (and I need to start it still this semester), but I had an open Qualtrics survey throughout the semester for students to provide comments and assessments of TAs and UTAs. And I gave a bit of bonus credit for doing a certain amount of that so I would get feedback on the TAs. (Eng_8)

Variability in TAs' Teaching Skills (Eng_5, Eng_6, Eng_8 / Tech_5)

Four participants reported some concerns related to the TAs' experience, background and teaching skills. One participant expressed her/his concern in the following way,

> The first of all, the other thing to consider in this, is that, at least in our case, because we have many labs, and many lab sections, we also have many TAs. Now as you can imagine, the TAs, first of all, they may be doing the course for the first time, they may be coming from some other international school, not even a US school. They come in with different levels of experience, and also different backgrounds. (Eng_6)

And another participant expressed her/his view on how this variability may impact the lab activities, in the following way, "The best, as I see the evaluation of all the TAs and I see how they perform, there is a lot of variabilities there." (Eng_5)

The Lack of TAs (Eng_2 & Eng_6)

Two participants expressed some concern related to the lack of enough TAs in their lab classes. These participants argued that the lack of TAs impacts on their teaching approaches in the labs. For example, Eng_2 revealed some dissatisfaction with the way her/his labs ran. S/he argued that, in her/his view, students should do the labs alone, or at least in pairs, but the lack of TAs makes this approach impossible. S/he said,

> Again, we could do two students, and we had enough TAs so that then they could be there all the time so the students could come one at a time and do the lab, but it is not possible. (Eng_2)

Instructors are Necessary (Eng_3)

One participant, although acknowledging the importance of TAs, stressed the importance of having an instructor in charge of the labs. S/he argued,

> I think the best thing to do is always to have instructors not just teaching assistants. Teaching assistants are good. The graduate students, they are being educated, but the experience of an instructor that has several or many years of experience already is much more valuable to better run the lab sessions, that is my feeling. And so what I do in these courses where I have a lab, I spend a lot of time in the lab sessions. I do not just leave to the teaching assistants.

6.5.2 Resources

Time. Eleven participants mentioned some level of concern with the influence of time on their classes. These concerns range from their own time to the students time. Regarding their own time, participants mentioned the time required to design the labs, coordinate the TAs, or even to upgrade the labs. Regarding students' time, the participants argued that the actual time for students to do the labs prevents the use of more open approaches. One participant said,

> There are an awful lot of techniques and skills that I could have students practice and demonstrate without the constraint of students' time and energy. Well, not to mention my own time and energy. Without the constraint of a number of credit hours in a degree. But another thing is that ... I really like open-ended projects, but they take an awful lot of time. They take a lot of time for the students, but they take an awful lot of time to manage and assess and observe what they are doing, so if I had the unlimited human bandwidth to work on this, I would do a lot more with projects. (Eng_8)

One participant justifies the use of very traditional approaches in her/his labs, based on the students' lack of time. S/he said,

> So ... And they can try different things and fail, and learn through that process of trial and error. And in order to do that, again, you need, first of all, time. Actually, that is probably the biggest resource that is lacking, because with large enrollments you just don't have enough time to get the students through the lab and give them enough time individually to try things. (Eng_6)

Another participant complained about time in complete opposition to Eng_6 above. S/he wanted to have more time for the lectures rather than the labs. Actually, her/his course was a one hour lecture followed by two hours lab. According this participant, the time for the lectures in not sufficient for students to learn the theory.

> But I think those one hour lecture is not enough for them to understand the theory, because it's new to them and they're trying to listen or grasp everything that I said as a professor and then when we do in the lab the hands-on, I feel like that's not enough time for them to kind of understand the theory before they do the hands-on. Which is why sometime to me, I think I need a little bit more time on the lecture side or on the lab side where they can, once I give them the lecture, they can kind of think a little bit what I'm trying to say and then do the homeworks, a little bit of practice of the theory that they understand, and then moving on to the practice or hands-on. (Tech_3)

Equipment and Space. Five participants mentioned the importance of having the necessary equipment and space. While four out of these five participants hypothetically mentioned these factors, one participant revealed certain dissatisfaction with the infrastructure s/he is using compared to what would be an ideal lab.

> The big difference is ... Because labs are not well resourced, either in terms of equipment, or enough TAs, or enough time in the ... Days of the week. Because of large enrollments etc. (Eng_6)

6.5.3 The Credit System

One participant revealed that the lab course credits do not foster students' interest in taking labs. This fact influenced the way s/he designed the labs activities in order to be more attractive to students. S/he described her/his view in the following way,

> Well, because every time you take a course, it would have some credits. For example, if you are getting ... If you're doing a normal course, select your courses to credits. You get three credits. And then to graduate, you need some credits. Some courses are mandatory.

> For example, *Course A*, that is the first *field* lab, is mandatory. It is one credit, but it is mandatory. They have to take the course. But, for example, the second *field* course is optional. It is *Course B*. So; they are going to take that laboratory for one credit only, it is optional. So, they can take a theory course, and they get three. So, why are they going to take lab? They have to go there in the afternoon, they have to do the experiment, and then some professor asks them to make a report, 20 pages report. So they do not want that. I am not saying that I am not going to ask for a report. They are going to have the reports. But, it has to be something that they enjoy to do. They have to enjoy doing that. They have to say, "Oh, this is nice. Look at what we are presenting here. We are solving a real problem. We are engineers. We are learning." (Eng_1)

6.5.4 ABET and Rewards Systems

One participant when providing explanations on her/his difficulties to upgrade the lab activities, reported the influential role of ABET, and also how the reward system may prevent innovations in her/his course. S/he said,

> We need to have a consistent curriculum, and we have a structure in place to get approvals to make a change. There's ABET accreditation. There's a whole administrative structure that is very heavy, and there is no incentive, really, for faculty to do the work to change the lab, because, at the end of the day, the only thing you get is potentially better-educated students. You're not going to get more papers, in fact, you are going to get fewer papers. So, since there is no reward for teaching well, it is not actually evaluated either. We get a teaching evaluation score, but that probably wouldn't change if we had a better lab. And this teaching evaluation, of course, reflects probably other things. There would be no measurable impact. So no reward. Why would people do that, right? You have to be self-driven. (Eng_4)

Two other participants also stressed the lack of rewards and the institutional values as factors that may influence her decisions toward teaching in the labs. Both of these participants stressed the institutional focus on research rather than teaching. The basic argument was, “there is nothing about this university that encourages that (good teaching).” (Tech_2) Instead, the other participant said, “yeah, people are promoted based on scholarship, so papers, publications.” (Tech_5)

6.6 Summary of findings

In this chapter, I explored the relationships between faculty beliefs and their teaching practices in the labs. I found that participants, in general, had some level of alignment between their beliefs and practices, despite eventual tensions in the teaching process. However, there were cases where the reported tension led the participants to adopt practices that contradicted their espoused beliefs. In these cases, the level of misalignment between beliefs and practices was mediated by factors such as time, students, enrollment, and reward system, among others.

CHAPTER 7. DISCUSSION AND IMPLICATIONS

7.1 Overview

This chapter discusses the findings from the present study, their implications for engineering and engineering technology education, and potential directions for future work. The study answered two main research questions focused on exploring faculty beliefs regarding the integration of labs into engineering and engineering technology education, and investigating the relations between beliefs and teaching practice in the labs.

A two-phase multiple case study was conducted to answer the driving research questions. In phase one, thirteen faculty members were interviewed and expressed their views and conceptions associated with different dimensions of the teaching and learning processes in the labs. The resulting interviews were analyzed using the constant comparative method and the different categories of participants' beliefs were identified and analyzed. Given the various tensions contrasting idealistic beliefs and pragmatic beliefs, phase one focused on exploring the idealistic patterns of beliefs espoused by the participants. These idealistic beliefs were grouped using a qualitative approach and revealed the participants' orientations to teaching and learning in the labs. Comparisons of the patterns of beliefs and orientations espoused by the participants revealed differences across the two colleges.

In phase two, data from multiple sources were combined for each participant and compared across participants. The results shed light on the relationship between beliefs and teaching practices in the labs. Findings from phase one along with interviews, instructional documents, and questionnaires were triangulated to reveal how beliefs relate to the participants' teaching practices in the labs. The findings indicate a series of factors that mediate the relationship between beliefs and practices.

In the following sections, I will show how the findings addressed the research questions. Second, I will discuss the implications for engineering and engineering technology education. Third, I will discuss some limitations of the study. Fourth, I will present some recommendations for future work, followed by conclusions.

7.2 Faculty Beliefs, Orientations and Alignment with their Instructional Designs

Faculty Beliefs

> Research Question 1: What are the faculty beliefs about the integration of laboratories into engineering education?

Nine categories of beliefs were identified and explored. These categories revealed the participants' beliefs regarding the integration of laboratories into engineering and engineering technology education. These aspects were: (1) The nature of knowledge, (2) The role of labs, (3) Teaching in the labs, (4) Learning in the labs, (5) The agent responsible for transforming knowledge, (6) The desired learning outcomes, (7) The role of faculty and instructors, (8) The role of students, and (9) The view of students' abilities to deal with abstractions. In the first seven categories, the beliefs espoused by the participants could be arranged along a continuum ranging from a content-centered to a learner-centered perspective. After coding the participants' beliefs according to their emphasis towards the content or the learners, different patterns of beliefs were identified and grouped using a qualitative approach. The results from this approach indicated five main orientations to teaching and learning in the labs. These orientations reflected similarities and differences among the patterns of beliefs espoused by the participants, and also indicated the participants' greater or lesser teaching emphasis towards the content or the learners. In sum, the five orientations were (1) Reinforcing lectures, (2) Connecting theory into practice, (3) Developing professional ways of thinking, (4) Supporting professional development, and (5) Facilitating expertise development.

However, the interviews revealed tensions contrasting the participants' idealistic views of the teaching and learning processes in the labs with pragmatic beliefs grounded in their personal experiences in the classroom. These tensions were further explored in phase two of this study to address the research question two.

Table 7.1 Comparisons of the nine belief categories with findings from other studies

Belief Category	**Present study**	**Other studies in higher education**
The nature of knowledge	(i)Externally constructed or (ii) internally constructed	(1) externally constructed vs. personalized (Samuelowicz & Bain, 2001) (2) existing body of knowledge vs structured by the teacher vs discovered by the students vs socially constructed (Martin & Ramsden, 1992)
The role of labs	(i) Connection theory and practice, or (ii) develop professional ways of being, or (iii) develop complex thinking	Not explored in the literature of beliefs
Teaching in the labs	(i) Transmission of knowledge, or (ii) co-construction with focus on the content, or (iii) co-construction with focus on the ways of think, or (iv) construction of knowledge through open-ended activities	Not explicitly explored in the literature of beliefs. (1) teaching as imparting information, or transmission of knowledge, or facilitating understanding, or conceptual change, or supporting students' learning (Samuelowicz & Bain, 1992)
Learning in the labs	(i) Through hands-on experiences, or (ii) through trial and error	Not explored in the literature of beliefs.
Agent responsible for transforming knowledge	(i) external, or (ii) faculty with students, or (iii) students	(1) teachers, or teachers with students, or students with teachers, or students (Samuelowicz & Bain, 2001) (2) students vs teachers (Martin & Balla, 1991; Pratt, 1992; Prosser, Trigwell, & Taylor, 1994) (3) external agency vs teachers(Prosser et al., 1994)
Desired learning outcomes	(i) students will know more, or (ii) students will know differently	(1) know more vs intermediate vs know differently (Samuelowicz & Bain, 1992) (2) reproduction of knowledge vs meaningful use of knowledge (Dall'Alba, 1991; Martin & Balla, 1991; Pratt, 1992)
Role of instructors	(i) consultant, or (ii) mentor	Not explored in the literature of beliefs.
Role of students	(i) preparation, (ii) participation, (iii) teamworking, (iv) report generation	Not explored in the literature of beliefs.
View of students' abilities	(i) students have difficulties with abstract concepts, (ii) learning styles are different and (iii) developmental view	Not explored in the literature of beliefs.

The nine categories of beliefs represent the participants' perspectives about different dimensions of the teaching and learning processes in the labs. Although no other study exploring the same constructs was found, some beliefs have similarities with studies that focused on faculty beliefs about teaching and learning higher education in general. Table 7.1 presents a comparison between the present nine categories of beliefs with those reported in other relevant studies. Four out of the nine categories of beliefs found in this study have similar counterparts in studies conducted in higher education settings. These categories express the academics' views of (1) the nature of knowledge, (2) teaching, (3) the agent responsible for transforming knowledge, and (4) the desired learning outcomes. Five out the nine categories of beliefs have no counterparts in the literature on academic beliefs and represent an additional contribution of the present study to the research in engineering and engineering technology education. In other words, this study adds five new categories of beliefs to the present literature on faculty beliefs.

Relationship between beliefs and instructional designs

Research Question 2: How do faculty beliefs relate to their current instructional designs for laboratory education?

A series of tensions characterized the relationship between the participants' beliefs and their espoused practices. These tensions had major or minor impacts on the participants' teaching practices. Participants who revealed minor tensions adopted practices and behaviors that aimed at minimizing the tensions and keeping the alignment between their beliefs and practices. Other participants adopted practices and behaviors that contradicted their idealistic beliefs. Instead of looking for solutions to minimize their tensions, these participants just acknowledged the conflict and provided justifications for their decisions. One participant revealed tensions in almost all categories of beliefs, and at the end, adopted practices utterly contrary to what s/he identified as ideal practices. Indeed, the analysis of the reported tensions revealed that the relation between beliefs and practices are mediated not only by the espoused beliefs but also by factors associated to the socio-cultural context such as time, resources, institutional reward system, and departmental values, among others.

Second, the patterns of beliefs associated with the different orientations to teaching and learning in the labs seemed to indicate preferred modes of teaching in the labs. Participants who espoused orientations located at the left side of the continuum described in chapter five (see figure 5.2), usually place greater emphasis on the content of the courses rather than developing new engineering skills. The practices reported by such participants revealed a continuous focus on aligning lectures and labs, and the use of traditional well-structured activities followed by reports and surveys. Participants oriented toward developing professional ways of thinking (in the middle of the continuum) revealed practices that placed less emphasis on the content but still relied on well-structured activities, reports, and surveys. Finally, the two orientations located on the right side of the continuum placed a higher emphasis on fostering the professional development of the students.

In addition, the five different orientations to teaching and learning in the labs no counterparts in the literature since the other studies focused on teaching and learning in general, and this study focused on lab education. However, some comparisons can be made to relate the general conceptions of teaching and orientations to teaching and learning in higher education with the orientations to teaching and learning proposed in the present study. Table 7.2 presents a comparison of the orientations to teaching and learning in the labs and similar concepts found in the literature. First, the orientations to teaching and learning in the labs can be arranged along a continuum ranging from a content-centered to a learner-centered perspective. This idea was also present in the works of several authors (e.g., Kember, 1997; Prosser et al., 1994; Samuelowicz & Bain, 2001). Second, the five orientations to teaching and learning in the labs have parallels with other works focused on exploring faculty beliefs. Although the nomenclature is not unified in literature, the constructs that they embed are very similar and indicate the different ways faculty conceive the teaching and learning processes, and probably act accordingly. For example, the orientation one, reinforcing lectures has a parallel with the transfer theorists proposed by Fox (1983). In common the two constructs express conceptions or orientations to teaching and learning where knowledge is seen as “commodity that can be transferred, by the act of teaching, from one container to another or from one location to another.” (Fox, 1983, p.152) In the case of labs, the knowledge is normally supposed to be transferred from manuals, handouts, and books to the students’ minds. The orientation two, connecting theory into practice has parallels with Dall’Alba’s (1991) conception of teaching as “illustrating the application of theory to practice” (p.294). These two constructs express conceptions that goes beyond just imparting or delivering information to students. They embed the faculty intention in providing the students the opportunity to see the connection between theory and practice. The orientation three, developing professional

Table 7.2 Comparison with findings from other studies in higher education settings

Orientations to teaching and learning in the labs (present study)	**Conceptions and orientations found in other relevant studies**
Reinforcing lectures	(i) Transfer theorists (Fox, 1983); (ii) Presenting & transmitting information (Dall'Alba, 1991; Kember, 1997; Martin & Balla, 1991); (iii) Delivering content (Pratt, 1992); and (iv) Imparting information (Samuelowicz & Bain, 1992, 2001)
Connecting theory into practice	(i) Shaping theorists (Fox, 1983); (ii) Illustrating the application of theory to practice (Dall'Alba, 1991); (iii)Transmitting knowledge (Kember, 1997; Samuelowicz & Bain, 1992, 2001)
Developing professional ways of thinking	(i) Building theorists (Fox, 1983); (ii) Developing concepts/principles and their interrelations (Dall'Alba, 1991) (iii) Apprenticeship conception (Kember, 1997; Pratt, 1992); (iv) Encouraging active learning – motivation focus (Martin & Balla, 1991)
Supporting students' professional development	(i) Traveling theorists (Fox, 1983) (ii) Facilitating understanding (Kember, 1997; Samuelowicz & Bain, 1992) (iii) Developmental conception (Pratt, 1992); (iv) Relating teaching and learning (Martin & Balla, 1991)
Facilitating expertise development	(i) Growing theorists (Fox, 1983) (ii) Capacity to be expert (Dall'Alba, 1991) (iii) Helping students develop expertise (Samuelowicz & Bain, 2001) (iii) Developmental conception (Pratt, 1992);

ways of thinking has parallels with the apprenticeship conception proposed by Pratt (1992) and Kember (1997). This orientation reflects the belief that "a body of well-established wisdom and knowledge exists, in the form of expert practitioners, and is to be handed down from those who know, to those who don't know" (Pratt, 1991, p. 211). Orientation four, supporting students' professional development has parallels with the conception of teaching as facilitating understanding proposed by Kember (1997). In common, there is a shift towards the learners and "helping the student to learn. The emphasis is on student learning outcomes rather than upon defining content" (Kember, 1997, p. 267). In the labs, this orientation brings the faculty intention to support students to achieve the learning outcomes through well-designed activities and controlled guidance. Finally, the orientation five, facilitating expertise development has parallels with the orientation towards helping students develop expertise proposed by Samuelowicz and Bain (2001). They both share the belief that "students have to become independent learners" (p. 314) and that faculty has the leading role to facilitate or help students to learn. In the labs, this orientation may be associated with the use of open-ended activities where students learn through trial and error and decision-making processes.

7.3 Implications for Laboratory Education in Engineering and Engineering Technology

Faculty decisions and attitudes toward teaching and learning in the labs

Faculty decisions and attitudes toward lab education are influenced by different beliefs, but external factors may mediate such decisions and attitudes. These mediating factors gave rise to conflicting beliefs that needed to be reconciled by the faculty when planning or conducting their lab courses. Two different approaches adopted by the faculty to reconcile conflicting beliefs and practices were identified. In this section, I describe and analyze these two approaches in the light of the theoretical frameworks of beliefs. In the light of these theories, I hypothesize that the mediating factors reported by the participants of this study to justify their practices may not necessarily represent the real causes of the tensions, and further studies are necessary to investigate such phenomenon.

The findings indicate that espoused beliefs and teaching practices were typically aligned. However, some disturbances occurred due to the tensions in the socio-cultural context. When facing such tensions faculty in this study adopted different approaches. Some of them just looked at fixing the conflict by developing behaviors that helped them to reconcile the tensions without violating their espoused beliefs or broader orientations. For example, this situation happened when Eng_1 added a new lecture to interact with students as a way to compensate her/his absence in the lab sections. Acting in such a say helped him/her to keep her/his orientation toward developing students' professional ways of thinking. That also happened when Eng_8 adapted their instructional designs and activities in a way that made possible to deal with students' behaviors toward "cook booking" the lab activities. Thus, the first approach was adaptation. This adaptation behavior may indicate the presence of reflective processes that led participants to think about their roles as educators and to act according to their espoused beliefs. This process has connections with Dewey's notion of "reflective thought" discussed in chapter three.

Other participants adopted a pragmatic approach. Instead of looking for ways to tackle the tensions in the system, some participants developed justifications for their particular teaching approaches. In such cases, the teaching practices reported or identified in the documents were in opposition to the participants' espoused beliefs. This behavior may have explanations in the theory proposed by Rokeach (1972). According to this theory, human beliefs can be conceived as a system of views with a central-peripheral organization. In this system, the most central and strong beliefs are those learned through direct contact with the object of the belief and reinforced by social acceptance. To Rokeach, some of these beliefs grounded on personal experiences may prescind social acceptance and persist even when subject to controversy. In the present study, participants who adopted practices as opposed to their espoused beliefs provided justifications that may hide inner and more central beliefs than the espoused ones. For example, to Eng_6, students learn best through trial and error processes. However, s/he also espoused the belief that her/his students have weak cognitive skills to deal with abstractions. As a consequence, the practices needed to focus on showing the students such abstractions to reinforce the lectures. In addition, given such weak skills, and the lack of time, lab instructions had to be well-structured to leave minimal space for mistakes, and often the TAs had to "hold" the student's hands. Thus, the belief about how students learn best is subjugated by other beliefs regarding the students' cognitive skills and time limitations. It may also reflect a belief in the need to cover every content from the lecture in the lab activities. Thus, given the scarce time for the labs, the solution is to prevent trial and error and foster cook booking approaches that led to faster practices.

Three participants, as follow Eng_7, Tech_2 and Tech_4 revealed practices aligned with the espoused beliefs. These cases, however, did not provide enough evidence to elicit eventual tensions and conflicts between beliefs and practices.

Another potential explanation for the contradictory teaching practices relies on the sociological theory proposed by Wuthnow (2004). According to this theory, behaviors are influenced not only by beliefs but also by social norms and roles defined within a social context. In this case, the social norms and roles associated with each participant might have impacted on their decisions regarding teaching in the labs. Eng_4, Eng_5, Tech_4 explicitly revealed the influence of the institutional reward system which emphasizes research over teaching. It is clear from the findings that, in the case of labs, the reward system causes more problems to lab education than to the traditional classroom courses. In the case of labs, faculty involved in research, especially in the College of engineering, had minimal or no participation in the lab sections. Indeed, the TAs led the labs and faculty stressed their roles as managers or CEOs. As the social environment not only support but promote such behaviors, labs are relegated to staff and new instructors, and no interest is demonstrated in improving the quality of the lab practices. This finding has similarities with the findings presented by Sheppard et al. (2008).

Indeed, the present study confirms the findings presented by Coutinho, Stites, and Magana (2017) indicating that faculty decisions regarding laboratory education were mediated by a series of factors including time, resources, institutional rewards, departmental values, ABET, and faculty beliefs among other factors. In this study, the influence of TAs was also identified. However, it is important to notice that the present study did not aim at identifying such mediating factors, and did explore how these mediating factors affect the pragmatic beliefs responsible for the teaching practices in the labs. Further studies must be conducted to investigate how faculty relate the differences between their idealistic beliefs compared to their pragmatic beliefs and identifying the main grounds for such pragmatic beliefs. The question is, are the mediating factors described by the faculty to justify their decisions the real cause of the tensions? For example, the lack of time for students to conduct the experiments was reported by several participants as a primary cause of tensions. A question that arises is: is the time the real cause of the problem? Alternatively, is there any other hidden belief at play? A potential explanation for the reported lack of time regards the belief about the need to cover all the lectures in the labs which results in the need to align lectures and labs, and may lead participants to design more activities than the necessary. A solution that focuses only on adding more time to the practices will probably not solve the problem. Moreover, this situation was already reported by a participant from the College of Technology. Although complaining about time, s/he wanted to add more time for the lectures rather than the labs. Thus, given the pressure to cover all the contents, time will always be a required resource.

Teaching and learning in the labs: The active-passive paradox

Another important question that needs attention is the effectiveness of some laboratory activities for the education of engineers. As one can notice from the findings reported in chapters five and six, several participants expressed some dissatisfaction with the way their actual laboratory practices have been conducted. Participants oriented towards reinforcing lectures or connecting theory into practice, in general, complained about difficulties in creating ideal conditions for teaching and learning in the labs due to the presence of mediating factors. To explain the issues regarding the effectiveness of such practices I will describe what I called the Paradox Active-Passive in lab education. To explain such a paradox, I will analyze some tensions reported by the participants through the lens of the Active-Constructive-Interactive framework proposed by Chi (2009).

According to Chi, students are active when they do something while learning. From this point of view, students are likely to be active in the labs, since they usually are involved in activities such as measurement, the operation of equipment, and note-taking. However, if the activity relies on a sequence of behaviors that aim just following step-by-step instructions, the mental engagement is minimal. Students are constructive in the labs when they go beyond just doing something, and engage in producing new ideas and knowledge that are not already presented in the learning material. Again, students are likely to be constructive when they engage in producing the outputs from the lab activities. Lab reports, presentations, and projects are common outputs from learning activities students do in the labs. However, the only existence of such outputs does not guarantee that a constructive process occurs. A student may generate outputs like those by just filling blanks, memorizing information, and reproducing knowledge already presented to them. Students are interactive when they collaborate with each other and make significant contributions during the knowledge construction process. Once again, lab activities are likely to foster an interactive process, since students very often work in groups and collectively generate the outputs. However, activities that do not foster collaboration, and students' pragmatic strategies such as the divide and conquer approach, may impair the learning efficiency of such lab activities. Finally, there is also a passive role in the labs. This passive role mostly refers to students that don't engage in the activities and contribute poorly to the success of the lab experiments or the group.

Furthermore, Chi concludes her discussion by arguing that, regarding learning gains, to be "active is better than passive," to be "constructive is better than active," and to be "interactive is better than constructive." Thus, laboratory activities have all of the conditions to offer to students the ideal environments for them to be interactive, constructive and active. However, the participants' voices indicated that in several cases, none of these behaviors had been explored in its full potential in the labs. Conversely, the reported activities indicated that, although active in the labs, the students' engagement was minimal. Thus, although students seem to be active, constructive and interactive in the labs, the reality reported in some labs is paradoxically the opposite. In such labs, students are nothing more than very passive learners with minimal engagement with the learning activities. Thus, the paradox active-passive in lab education serves to explain situations like that which leads to the low effectiveness of the reported laboratory practices.

Teaching and learning in the labs: Reflections on the affordances and disadvantages of the orientations to teaching and learning in the labs

Understanding the different orientations to teaching and learning in the labs may help educators to better plan, design and conduct actions toward improving learning in the labs. Indeed, the five orientations found in the present study indicate different patterns of faculty beliefs regarding teaching and learning in the labs. The findings also indicate that these orientations were associated with different learning goals which led to differences in the reported practices. For example, the first three orientations adopted practices associated with traditional laboratory instruction. This traditional approach is characterized by the use of well-structured activities where students have to follow step-by-step instructions to perform the experiments. Reinforcing lectures, connecting theory into practice, and developing professional ways of thinking both were associated with this type of pedagogical approach. Affordances and disadvantages of such an approach are discussed by different scholars including Sheppard, Macatangay, Colby, and Sullivan (2008), and Wankat and Oreovicz (2015). In general, traditional labs are appropriated for lower-division engineering labs and foster the learning of fundamental concepts, principles, and skills (Sheppard et al., 2008). The main disadvantages of traditional labs rely on the fact that students they may lead to rote learning and retention of atomized information only. In addition, these labs do not foster creativity and complex thinking.

It is relevant to notice that there is nothing wrong in being oriented towards reinforcing lectures, connecting theory into practice or developing professional ways of thinking. These orientations embed different learning goals, and, as well posed by Wankat and Oreovicz (2015) "no laboratory can be optimal for all purposes." (p.179). The problems may arise when wrong or not well-designed activities impair the development of the students. That frequently happens with traditional labs. To overcome such limitations, Wankat and Oreovicz (2015) proposed the use of the "scientific learning cycle" (p. 181) to engage students in a discovery learning process before the lectures. Furthermore, approaches such as problem- and project-based learning can also be used as pedagogical approaches associated with these three orientations.

The two rightmost orientations were associated with the use of open-ended activities. Participants oriented toward supporting students' professional development or facilitating expertise development reported the use of less structured practices where students have to deal with a problem or a project, and minimal guidance is provided. In these cases, students do not know the solutions in advance, and they do not even have clear steps to perform. Almost everything needs to be framed by the students. However, it is natural that, depending on the level of the students, some scaffolding activities must me provided to orient the students towards the solutions. According to Wankat and Oreovicz (2015) open-ended activities "appear to be the most effective." (p.181) However, as the participants also revealed, the use of open-ended activities requires more time for the design and constant updating them, to prevent students' attitudes toward "cook booking" the activities, or just copying and paste the work from others. In addition, this kind of activities may be challenging for the TAs, and this fact may also prevent the adoption of such open-ended activities. This kind of tension was revealed by Eng_8. Thus, as a consequence, the university and departments must reward those who dedicate their time to improve their teaching approaches.

Institutional and departmental values: Recommendations for Policymakers

The findings of this study indicated that the well-known tensions between research and teaching in research universities have an impact on laboratory education. Indeed, this study was conducted at a doctoral university with the highest research activity (for details see The Carnegie Classification of Institutions of Higher Education, 2015). Thus, this university places a strong emphasis on research. This emphasis on research reflects on departmental values and reward systems with further consequences in the faculty decision making processes. Furthermore, it is well-known in the literature that the tension research vs. teaching brings consequences for the teaching and learning processes (Astin & Chang, 1995; Felder, 1994; Peter, Gray, & Froh, 1992; Rowley, 1996). However, our findings indicate that these consequences might be worse for the laboratory education than the traditional classroom courses. First, all participants from the College of Engineering and one from the College of EngineeringTechnology reported that their TAs were the responsible for leading the labs. They argued that large enrollments increased the number of sections, and for that reason, they would not be able to attend the sections. They also revealed a series of concerns regarding the TAs' instructional skills and experience to conduct the labs. Second, one participant argued that the system of credits does not value laboratory courses in the same way it values the lecture courses. Lab courses are more time consuming but result in fewer credits. Third, most engineering courses investigated in this study reserved fewer hours for the labs compared with the lectures. At the same time, time was the most cited factor that, according to the participants, prevents better learning outcomes from the labs. Finally, three participants explicitly revealed the influence of the reward system on their attitudes, or lack of attitudes, towards labs. They argued that there is no reward for those who engage in improving the labs. In addition, all participants revealed how teaching labs could be much more challenging and time-consuming than teaching lectures. Thus, why to engage in such challenging and time-consuming activities if there is no benefit to that?

A potential area that deserves further investigation is associated to the role of professors of practice, or non-tenure track faculty who could focus on teaching in the labs. These faculty members may be in constant interaction with the faculty engaged in research to bring the benefits of research to the undergraduate labs. Another potential solution is to create programs that foster innovations in the labs. That approach seems to work well in some environments. Indeed, participants from the College of Engineering Technology revealed a major shift in the college towards the adoption of project- and problem-based approaches. Three participants manifested the intention to revamp their courses to introduce such approaches.

Professional Development Programs

The findings of the present study can be used to support the development of professional development programs. Indeed, the knowledge about beliefs and practices may support actions that aim at promoting educational innovations for laboratory education. In addition, these findings also indicate that the current professional development programs must add content related to laboratory education. The majority of the participants in this study reported needs on instructional practices and assessment tools for laboratory education. Furthermore, the current programs for the development of teaching assistants have no component related to laboratory education, and may not fully prepare the TAs for the types of instruction required in labs. Indeed, six participants reported tensions caused by the TAs teaching skills and lack of training related to laboratory education. The positive impacts of professional development programs on faculty and TAs' performance are well-discussed in the literature. Thus, adding components focusing on laboratory education will likely reflect on the quality and effectiveness of the laboratories in engineering and engineering technology education.

7.4 Implications for Research in Engineering Education

It is essential to compare and distinguish this study from the studies conducted by Samuelowicz and Bain (1992, 2001). First, since phase one of the present study used the framework proposed by those authors, inherent differences must be clarified. Samuelowicz and Bain proposed the framework to explore the academics "typical ways of thinking about teaching and learning, and their dispositions to teach in particular ways" (Samuelowicz & Bain, 2001, p.299). They interviewed thirty-nine academics from different disciplines, including nursing, psychology, entomology, and engineering, among others. The present study focused only on academics from engineering disciplines. Second, Samuelowicz and Bain did not make any explicit statements regarding the use of labs. In this study, I focused on academics teaching laboratory courses. The original interview protocol proposed by Samuelowicz and her colleague was adapted, some questions were modified, and new questions were added to accommodate the focus on laboratory education. However, a significant methodological difference occurred during the data analysis phase of phase one. While Samuelowicz and Bain focused on eliciting the beliefs grounded in the participants' practices, in this study, I first focused on identifying and categorizing the idealistic or espoused beliefs. The beliefs grounded in the practice of the participants were further analyzed in phase two of this study to identify the relations between beliefs and practices, and to make evident the mediating factors at play. Also, as those authors aimed at relating the beliefs grounded in practice with the respective practices, they conducted an initial stage to identify the orientations to teaching and learning through the use of the constant comparative method. In such stage, each interview was considered a single unit of analysis, and the orientations were identified before the analysis of the underlying beliefs. In the present study, I first analyzed the participants' espoused beliefs and after that grouped the different patterns of beliefs to find the espoused orientations to teaching. In other words, while the orientations to teaching presented by Samuelowicz and Bain are grounded on pragmatic beliefs, in this study, they reflected the participants' espoused beliefs. In this way, it was possible to elicit the influence of the different factors that mediate the relations between the espoused beliefs and their related practices. However, the findings from the phase two revealed that minimal changes in the participant's orientations to teaching would occur if I had focused on their pragmatic beliefs rather than the espoused, or idealistic ones. Indeed, only one participant reported pragmatic beliefs entirely in opposition to her/his idealistic beliefs.

CHAPTER 8. CONCLUSION, LIMITATIONS AND FUTURE WORK

This study investigated faculty beliefs about the integration of laboratories into engineering and engineering technology education. It also investigated the relationship between educational beliefs and teaching practices in the labs. Through a multiple case study design, I first identified the participants' beliefs and then triangulated the resulting beliefs with data from questionnaires and instructional documents used by the participants in their lab activities. Findings revealed nine belief dimensions, five orientations to teaching and learning in the labs, and a series of tensions that may prevent the ideal alignment between beliefs and teaching practices. In this chapter, I present the main limitations of the present study, followed by directions for future work, and a final conclusion of the overall work.

8.1 Limitations

The limitations of this study are those generally associated with qualitative case study research (Yin, 2014). The first limitation regards generalizability of case studies. Indeed, case studies are not generalizable to populations. However, as well-argued by Yin (2014), case studies do not aim to develop generalizable conclusions. Instead, case studies aim to expand theories to create a better understanding of different phenomena. Thus, although not generalizable, this study contributes to a deeper understanding of faculty beliefs and practices regarding laboratory education. Now, considering the particularities of this study, I acknowledge the following additional limitations.

First, the study was conducted in a single setting, in this case, a doctoral university with the highest research activity. Contributions to the literature would be more substantial if data from more institutions were considered.

Second, my personal experience as a faculty member working with laboratory education might have created eventual bias during the analysis. Several measures were taken to overcome this possible bias including bracketing, peer examination, and inter-rater reliability.

Third, despite all the measures to identify and recruit participants currently teaching lab courses, not all participants were teaching labs at the time of the interviews. Three out of the thirteen participants were in such a situation. Thus, although it is unlikely that their beliefs about labs would change significantly, their reported practices might not reflect the reality of their lab activities.

Fourth, although the interviews were the main data source for the analysis of the participants' beliefs, the lack of instructional documents and questionnaires limited the analysis of the relationship between the beliefs and actual practices of those participants who did not provide such information. Indeed, a complete triangulation process at the individual case level would be achieved if each participant provided the complete set of information, including the interview, the instructional documents, and the questionnaire. In the present case study, seven participants provided the whole set of information; four provided interviews and questionnaire; one provided interview and documents; and one provided only the interview. I acknowledge such limitation in my analysis. However, as the data was triangulated at an individual case level, and at a cross-case level, it was possible to develop a meaningful understanding of the phenomenon under investigation; that is, the beliefs about labs and their relationship with the teaching practices of the participants.

Fifth, although revealing important mediating factors that, directly or indirectly, may affect the faculty educational decisions, it was not the focus of the present study. Thus, further investigation needs to be conducted to explore such factors and elicit their influences on the faculty.

Nonetheless, this study represents a first attempt to investigate the beliefs and teaching practices of engineering and engineering technology faculty responsible for laboratory education. In addition, this study also indicated a series of factors that may mediate the relationship between belief and teaching practices in the labs.

8.2 Future Work

As a result of an exploratory study, the present findings provide a foundation for future studies aiming at exploring the faculty in the lab. The understanding of the beliefs, practices and mediating factors that affect faculty decisions about lab education still require further studies to create a broader theory relating their beliefs and their practices in the labs. For this purpose, I suggest the following future work:

(1) Conduct similar studies in different institutions. The inclusion of more institutions with different aims will provide a broader and generalizable perspective of the beliefs and practices of engineering and engineering technology faculty. Thus, future studies exploring the perspectives of faculty in doctoral universities, master's colleges & universities, and baccalaureate colleges will contribute towards a generalizable theory.

(2) Conduct studies aiming to explore how faculty relate their beliefs and practices. While in this study the goal was to investigate how beliefs and practices are related, future research exploring how faculty perceives and justifies such relations will shed light on the influence of the mediating factors, and also elicit the pragmatic beliefs and the roots of them.

(3) Conduct studies to explore the relations between beliefs, teaching practices and students' approaches to learning in the labs. The knowledge about how students perceive the different pedagogical approaches in the labs and the consequences of such approaches on the students' learning approaches will shed additional light on the consequences of the faculty beliefs and practices on the educational outcomes of laboratory education.

8.3 Conclusion

Faculty educational beliefs in higher education settings have been explored by several theoretical and empirical studies. From these studies, just a few explored such educational beliefs in engineering domains. However, no study investigated the beliefs and their relationship with the laboratory teaching practices of engineering and engineering technology faculty. The present study is a first attempt to fill this important gap in the literature.

Two main research questions were addressed focusing on identifying the faculty beliefs about the integration of laboratories into engineering education and exploring the relations between beliefs and teaching practices in the labs. The findings revealed nine different categories of beliefs, five orientations to teaching in the labs, preferred teaching practices according to the different orientations, and also tensions and mediating factors relating beliefs and practices.

This study contributes to the literature of educational beliefs, in particular the literature of faculty beliefs in engineering domains. The particular emphasis on laboratory education helps to shed light on this important component for the education of engineers. In addition, since the understanding of faculty beliefs is a relevant step for the promotion of innovation and change, this study also contributes to a broader discussion about the adoption of innovations and change in engineering education.

Further research will focus on expanding the range of institutions aiming to creating a broader understanding of the roles of faculty beliefs on the outcomes of laboratory education.

APPENDIX A. INTERVIEW PROTOCOL

In this interview, we will be exploring some of your beliefs about the role of laboratories in undergraduate engineering education. The interview has five main sections. First, we want to hear you about the knowledge and skills necessary in the field. Second, we will discuss your perceptions about the actual and ideal role of labs in engineering education. Third, I will ask you about teaching and learning in the lab. The fourth section aims to explore your ideas about the instructional design of lab activities. Finally, we will discuss the lab education in a broader perspective.

Let's start by exploring important engineering knowledge and skills

Section1: Engineering Knowledge and Skills

1. Tell me about your path to purdue…

2. You mentioned that your primary discipline is ……………………………. . So, what are the most important knowledge these engineers must have to be good professionals in this discipline?

- What about skills (or knowledge)?

3. How do you think they learn best such knowledge and skills?

- Could you develop further ….

Section 2: The Role of Labs (perceptions and beliefs)

In this section, I want to hear about your view of the role of laboratories in engineering education (actual versus ideal)

4. What role do labs play in the current state of engineering education? (actual)

5. What do you think should be the main role of labs in engineering education? (ideal)

Section 3: Teaching and Learning in the labs

Now, we will be moving gears toward the teaching and learning processes in the labs.

6. How do you think laboratories must be taught to prepare engineers better?

- Based on what you said, you believe that …. help(s) students learn better in the lab. Could you develop further this point? How do you think ……… can help students learn better in the lab?

7. What aspects of a course are difficult for students to learn in the lab?

    - What makes them difficult for students to learn in the lab?
    - How do you address such difficulties?

8. What are the main differences between teaching in the lab and teaching a lecture section only?

Very good.

Now, I want to hear how do you conceive your role as an instructor in a lab, and what would be the students' role. So,

9. What do you see as your role in the teaching and learning process in a lab setting?

    - What are the main faculty responsibilities as related to the design and teaching of the lab?
    - What is your main concern when teaching in the lab?

10. What do you see as students' role in the learning process within a lab context?

    - What are your students' main responsibilities in the lab?

11. What are the characteristics of a good laboratory instructor/faculty?

12. What are the main barriers to good teaching in the labs?

Section 4: Instructional Design

Now, let's talk a bit about your instructional design to the laboratory activities.

13. First, what do you want your students to know or be able to do at the end of the lab course?

    - Do you think you usually achieve your aims?
        - If yes, what do you do to be successful?
        - If not, what happens in practice? What does prevent you from being successful?

14. How do you know that your students have learned something?

    - What are the signs that students have learned something in the lab?
    - If you were to ask your students at the end of the course 'what have you learned from this course?' what would you hear?

15. Tell me about your pedagogical approaches.

    - What kind of activities do you promote in the labs?
    - How do you feel your activities support the development of the skills you want your students to learn?

16. What is your level of autonomy to make changes in the lab course?

17 . If you have the power to make the changes you wanted, what would you change in your lab?

Conclusion

18. Suppose that you are a faculty in a college/university where students do not have access to laboratory education, do you believe these students will be as prepared as a student who had laboratory instruction? Why?

19. Based on what we talked about today, are there any ideas or recommendations you would have for the design of better lab activities?

We are finishing the interview. I would like to ask you to provide me some of your laboratory materials such as syllabus, laboratory manual, one typical lesson plan, and one assignment.

Thank you very much.

.

APPENDIX B. QUESTIONNAIRE

Section 1 – Demographics

1. Please mark the highest degree you have earned: (Mark one)

- ☐ Master's (M.A., M.S.)
- ☐ Ph.D.
- ☐ Professional Doctorate (Ed.D., Psy.D., etc.)
- ☐ Other

2. Gender

- ☐ Male
- ☐ Female
- ☐ Other

3-What is your age?

- ☐ 20-24 years old
- ☐ 25-34 years old
- ☐ 35 – 40 years old
- ☐ 41 – 50 years old
- ☐ 51 – 60 years old
- ☐ 61 years old or older

4. What is your primary discipline

- ☐ Aerospace or Aeronautical Engineering
- ☐ Chemical Engineering
- ☐ Civil Engineering
- ☐ Computer Science and Software Engineering
- ☐ Electrical and Computer Engineering
- ☐ Industrial Engineering
- ☐ Materials Engineering
- ☐ Mechanical Engineering
- ☐ Nuclear Engineering
- ☐ Other (please specify)_________

Section 2 – Institutional context

5. Rank: I am a/an:

- ☐ Associate Professor
- ☐ Assistant Professor
- ☐ Lecturer
- ☐ Instructor
- ☐ Professor of Practice
- ☐ Graduate Teaching Assistant
- ☐ Other: (please specify)

6. What is your tenure status at this institution?

- ☐ Tenured
- ☐ On tenure track, but not tenured
- ☐ Not on tenure track, but institution has tenure system
- ☐ Institution has no tenure system

7. Is your full-time professional career outside academia?

☐ Yes ☐ No

8. Please, estimate the distribution of your time spent in each area below as you perceive it. (please ensure the total is 100%)

Research

Teaching

Service

Other

Total

Section 3 – Teaching background and evidence of professional development

9. Years of teaching experience at college level

☐ 0 – 5 years ☐ 6 – 10 years ☐ 11-15 years ☐ 16+ years

10. Years of teaching experience in laboratories at college level

☐ 0 – 5 years ☐ 6 – 10 years ☐ 11-15 years ☐ 16+ years

11. Thinking of your own professional development needs, please indicate the extent to which you have such needs in each of the areas listed.

(Please mark one choice in each row.)

	No Need at all	Low Level of Need	Moderate Level of Need	High Level of Need
a) Content and performance standards in my main subject field(s)	☐	☐	☐	☐
b) Student assessment practices	☐	☐	☐	☐
c) Classroom management	☐	☐	☐	☐
d) Knowledge and understanding of my main subject field(s)	☐	☐	☐	☐
e) Knowledge and understanding of instructional practices (knowledge mediation) in my main subject field(s)	☐	☐	☐	☐
f) Information and Communication Technologies (ICT) skills for teaching	☐	☐	☐	☐
g) Expertise in laboratory equipment	☐	☐	☐	☐

12. What types of courses do you primarily teach? (Mark one)

☐ Undergraduate courses

☐ Graduate courses

☐ Developmental/remedial courses

☐ I do not teach

13. How many courses do you typically teach per semester?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 or more

14. What types of courses are you currently teaching? (Mark all that apply)

☐ Only lectures

☐ Only laboratory

☐ Laboratory and lecture sections

☐ Other (specify)____________

15. During the present term, how many hours per week on average do you spend on each of the following? (Responses: None, 1-4, 5-8, 9-12, 13-16, 17-20, 21+)

Scheduled lectures
Scheduled Labs
Preparing for lectures (including reading student papers and grading)
Preparing for labs (including reading student reports and grading)
Research and scholarly writing
Administrative work
Others

Section 4 – Teaching practices and technology

16. Which of the following approaches do you use in your lab sections? (Mark all that apply)

- ☐ Traditional laboratory experiments
- ☐ Computational experiments
- ☐ Demonstrations
- ☐ Problem-based learning
- ☐ Project-based learning
- ☐ Inquiry-based learning
- ☐ Discovery learning
- ☐ Other (please, specify)

17. Which of the following laboratory types are you familiar with:

- ☐ Physical or hands-on labs
- ☐ Virtual/Simulation labs
- ☐ Remote labs

18. Which of the following laboratory types are you currently using:

- ☐ Physical or hands-on labs
- ☐ Virtual/Simulation labs
- ☐ Remote labs

19. During my lab section I assess students' learning through:

- ☐ Lab reports

- ☐ Projects
- ☐ Exams
- ☐ Surveys
- ☐ Other: (please explain) _______________________

APPENDIX C. LESSON PLAN FOR CONTENT ANALYSIS

<table>
<tr><td>Name</td><td>Subject(s)</td><td>Course</td><td>Date</td></tr>
<tr><td colspan="3">General Description of the Lab Course</td><td>Course Nature</td></tr>
<tr><td colspan="4">1. Description of Content & Content Type (Fact, procedure, concept, principle, or skill)</td></tr>
<tr><td colspan="4">2. Learning Outcomes</td></tr>
<tr><td colspan="4">3. Curriculum Connection (How This Lesson Fits into Unit Plan)</td></tr>
<tr><td colspan="4">4. Instruction
A. Engagement (Motivational Activity)

B. Instructional Sequence (Teaching Methodology with Student Activities)

C. Application Activity (Practice and/or Reflection)

D. Materials & Resources</td></tr>
</table>

5. Assessment Strategies & Grading System
6. Homework (If Appropriate)
7. Resources
8. Instructional Guidance

APPENDIX D. CODEBOOK AND PROCEDURES

Definitions

Belief: Belief is considered an internal state or habit of mind in which a person accepts something as true and real.

Procedures

This codebook will assist you in identifying and code the participants' beliefs about the integration of laboratories into engineering education. Please, notice that you may find tensions in the participants' beliefs that may cause some confusion in the coding process. For example, a participant may argue that s/he believes that students learn best if they work on open-ended problems but, given one or another constraint, s/he decided to use well-structured activities. In cases like this, please, code the idealistic belief instead of the resulting one. Thus, code the espoused belief as: students learn better through open-ended activities.

In the table 1, you will see the nine categories of beliefs that I identified through my analysis. Please, read each interview and code the participant's beliefs. To facilitate the process, I am attaching a table at the end of each interview. This table contains all the identified categories and subcategories. You can print them, or just code electronically by placing a check mark on the identified belief.

If, during the analysis, you find any tension or emerging theme, please just highlight the passage and add a comment !

Table 1. Beliefs Categories

Belief	Description
Category 1. The nature of knowledge	
This dimension reveals how each participant describes the knowledge and skills in their disciplines. Some participants described the knowledge and skills regarding the subject matter plus some technical and non-technical skill such as programming, teamwork, communication, and safety. Other participants described the knowledge in terms of the expertise, or ability to deal with and solve engineering situations.	
Externally constructed	A faculty who espouses this belief sees the engineering knowledge as an external and well-defined body of concepts and principles, grouped by subject-matter or stated in the curriculum.
Internally constructed	A faculty who espouses this belief sees the engineering knowledge as an internal ability to deal with the complexities of the profession. It may be characterized by the ability to use the different concepts, principles, and skills when dealing with real-world engineering situations. These faculty acknowledges the importance of learning concepts, principles, and skills but argue that engineering goes beyond just having such knowledge.
Category 2. The role of labs	
This dimension reveals how each participant describes the main role of labs. Three main roles were identified. They range from the simple view of labs as a way to help students to see in practice the concepts discussed in the classroom, to a more sophisticated view were labs help students to develop critical thinking and expertise in the field.	
The connection between theory and practice	Faculty espousing this belief see the labs as a place where students reinforce the theory learned in the classroom by watching demonstrations, conducting well-structured experiments, or just playing with tools and concepts. These activities allow students to go beyond abstractions and learn

	through experiencing by seeing, touching, feeling, measuring and other embodied processes.
Develop professional ways of being	The faculty believes that laboratories aim to allow students to get in touch with real-world practical applications that foster the development of new professional ways of being. To these faculty, the labs are not the place to develop a theory but a place where students deal with examples from the common situations in the field to develop practical expertise.
Develop complex thinking	Faculty espousing this belief see lab as playing different roles in students' developmental processes. They argue that labs must progress from very basic activities, focusing on developing students' conceptual understanding, to more advanced and complex practices where students learn to deal with open-ended situations and decision-making processes.
Category 3. Teaching in the labs This category aims to describe the participants' beliefs regarding the ways laboratories must be taught.	
Transmission of knowledge	A faculty who espouses this belief believes that teaching labs involve showing the students the phenomenon, a theory or a tool, and after that, trying to engage students in hands-on activities aiming that students could be able to understanding and reproduce such knowledge.
Co-construction of knowledge by mentoring	A faculty who espouses this belief believes that teaching labs involve being in constant interaction with students while they are performing the experiments. The idea is to be mentoring the students, asking questions that would support the students' process of knowledge construction. Indeed, the faculty knows that the knowledge is already transformed in the experiment handouts, but believes that the mentoring process can lead students to more advanced knowledge. However, despite of bringing a co-construction perspective,

	this belief is still grounded on a transmission of knowledge perspective where the knowledge from books and lectures must be transmitted to students. The lab activities facilitate the transmission process.
Co-construction of knowledge by exploring ways of thinking	A faculty who espouses this belief believes that teaching labs involve first engaging students in a co-constructive process where the faculty not only introduces the topic and makes connections with the profession, but also involves students in a reflective process that connects the demands of the profession with the experiment related activities. The idea is to help students to create interrelations between the theory, the experiments, and the professional ways of using such knowledge. In a second step, this faculty engage students in the hands-on activities and provides some kind of guidance. This perspective is also heavily grounded on transmission of knowledge approach, but this time the knowledge comes mainly from the instructor.
Knowledge construction through open-ended activities	A faculty who espouses this belief believes that teaching labs involve designing open-ended situations where students need to go through a solution process that goes "beyond just following a formula or following steps."(Eng_8)
Category 4. Learning in the labs This category aims to describe the participants' beliefs regarding the best ways students learn in the labs.	
Trough hands-on experiences	Students learn best through hands-on experiences because they have the opportunity to see, touch, and work with real-life equipment. These faculty believe that the experiments help students to see the relation between the theory and the practice in the field, and also develop different skills such as team working, measurement, and communication. It is interesting to note that, although these faculty stressed the

	importance of the hands-on activities on students' learning, they did not place any emphasis on eventual trial and error processes that occur during the experimentation.
By trial and failure	Students learn best in the labs by through trial and error. This trial and error can be thought either as experimenting within an experiment, trying different possibilities within the scope of an already defined experiment, or by trying and failing while having to operate within a broader scope of an open-ended problem.
Category 5. The agent responsible for transforming knowledge This dimension aims to reveal participants' beliefs regarding who is responsible for organizing/transforming the knowledge in the labs.	
External agent	Faculty who espouses this belief believe that students have a minimal effort in constructing/transforming the knowledge in the labs. They argue that it is important to align everything from books and manuals to facilitate students' activities. In this case, the knowledge is transferred to students through well-structured lab manuals and handouts, or directly from instructors during the activities.
Faculty/Instructors with students	The faculty believes that students must be actively engaged in building the own knowledge with different instructional support from the faculty and instructors.
Students	The faculty believes that students must be responsible for creating, transforming or organizing the knowledge while developing the lab activities. In this case, the faculty or instructor is responsible for creating and maintaining the learning environment where students feel safe to explore different ideas.
Category 6. Desired learning outcomes This category aims to describe particpants' desired learning outcomes from the laboratory education.	

Students will know more	To participants holding this belief, the desired learning outcomes of laboratory activities can be expressed in quantitative terms. The idea is that at the end of the lab courses, students will have learned concepts, principles, and skills according to a series of learning objectives expressed in a syllabus.
Students will learn differently	According to this view, at the end of a lab course, students must be able to think differently. Participants still expressed the importance of knowing more, but the focus is in on changing students way of thinking towards the profession.
Category 7. Role of faculty and instructors This category aims to describe the participants' beliefs regarding the role of instructors in the labs. As some faculty do not teach labs, but have some other duties, I divided this belief in two components. First, what faculty see as their role on the teaching and lab processes. Second, what faculty sees as the role of instructor (the person who teach the labs). Please, below complete what faculty sees as her/his role as encharged of labs, and the what s/he sees as her/his the instructor'role.	
Subcategory 7.1 Role of faculty	
Management	The reported management activities. Different words can be used to describe her/his managing activities, including management, coordination, supervision, organization, and monitoring.
Lecturer	The partcicipant mentioned a role as a lecturer. This means that s/he is responsible for the theoretical part of the courses.
Instructional designer	The participant described some level of involvement with instructional designing activities. This involvement can be related to changing the contents of lab activities or towards improving the pedagogy in the labs and the development of assessment strategies.
Motivator	The participant believes s/he has the responsible for motivating students.

Provide feedback	The participant stressed the importance of providing formative feedback to students. S/he sees this feedback as an important element to help students improve their performance.
Grading	The role of grading reports was expressed by the faculty.
Subcategory 7.2 Role of instructors	
Mentor	The participant stressed the importance of being aside of students asking questions, challenging them and also coaching them during experiments. S/he may argue that the instructors must not provide immediate answers to students but, instead ask questions that would foster a reflective process on students minds.
Consultant	The word consulting serves is related to the amount of support students must receive during the lab activities. It is associated to a process by which the instructor provides the answers to students while they are in the labs. It is the inverse of mentoring.
Lecturer	Beyond the lecture component in a course that has both lecture and labs, participants also stressed the importance of having lectures on the labs. In general, these lectures aims to introduce some theory and explain the lab procedures.
Grader	The participant has graders to evaluate the lab reports.
Category 8. Role of students This category aims to describe the participants' beliefs regarding the role of students in the labs.	
Preparation	Whenever the particpant stresses the importance of students' prior preparation before the lab activities. Example of preparatory activities are reading the theory, being familiar with the lab procedure, and running pre-labs.
Participation	Whenever the particpant stresses the importance of being actively engaged during the lab activities. This engagement can e associated to respecting safety rules, following

	instructions, showing up on time and collaborate with other members of the group. It also includes intellectual engagement and trying different approaches and asking questions.
Teamwork	The participant stressed that group work is part of their lab activities
Reports	The participant mentioned reports as part of students assignments
Category 9. View of Students This category of beliefs describes how participants view their student's cognitive abilities to deal with the concepts, principles, and skills in the classroom and in the labs.	
Students have difficulties to deal with abstractions	The participant believes that students are not prepared to deal with abstractions.
The learning styles are different	The participant believes that her/his students have a learning style that is highly grounded on concrete experiences, instead of abstractions.
Developmental view	The participant espoused a perspective that acknowledges that students begin college with a basic set of skills and competencies, and eventually face difficulties in grasping the knowledge. However, they argued that the engineering knowledge must be built through a developmental process, starting from well-defined experiences but, as soon as possible, engaging students in open-ended approaches that help students to build their own knowledge. In sum, the participant sees the students moving from novices who need to learn the basics, to a more advanced level of expertise where knowledge is built by themselves.
Students are highly capable	The participant views her/his students as highly competent, able to learn whatever necessary, as longs as the students have the right motivation.

Not stressed	The participant does not mention any statement regardings students cognitive skills

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