Implementation of Systems-Level Learning in a Community College Mechatronics Program

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ABSTRACT

IMPLEMENTATION OF SYSTEMS-LEVEL LEARNING PEDAGOGY IN A COMMUNITY COLLEGE MECHATRONICS PROGRAM

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Northern Illinois University, 2018
Gene L. Roth, Director

This is a qualitative case study of the complete implementation of systems-level learning (SLL) pedagogy throughout a mechatronics engineering department in a community college in the United States. SLL was developed from the German engineering apprenticeship model, resulting in engineering graduates with what our German counterparts call Handlungskompetenz. Graduates of these programs have the flexibility to quickly adapt to new engineering systems and situations in a self-directed way without months of on-the-job training. This skill is related to adaptive expertise and is not the type of skill traditionally taught to engineering students.

Chronological and descriptive analyses were performed on semi-structured interviews with the faculty and administrator stakeholders. Interview questions pertained to why SLL was implemented, how SLL was implemented, what stumbling blocks and best practices were identified in implementing SLL, and how the participants believed or did not believe the call for changes in engineering curriculum could be met by SLL. Theoretical constructs were developed from emergent themes to position the study for future research. Few studies exist on SLL implementation in the classroom and its curriculum integration. Findings of the study can inform faculty and administrators about institutional SLL implementation.
IMPLEMENTATION OF SYSTEMS-LEVEL LEARNING PEDAGOGY IN A COMMUNITY COLLEGE MECHATRONICS PROGRAM

BY

MARGIE N. PORTER
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A DISSERTATION SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE DOCTOR OF EDUCATION

DEPARTMENT OF COUNSELING, ADULT AND HIGHER EDUCATION

Dissertation Director:
Gene L. Roth
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CHAPTER 1
INTRODUCTION

"Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow."

Many innovations have been brought to the field of engineering education in order to recruit and retain talented students in engineering and also to improve engineering graduates’ abilities to be productive in their first few years of employment. One of those innovations – systems level learning (SLL) - has not received the attention of researchers compared to many other innovations, such as problem-based learning (PBL). This research is a qualitative case study which focuses on implementation and current practices of SLL within a community college-level mechatronics engineering program.

Background of Engineering Education

Society has changed vastly in the last 20 years and so has the field of engineering. Felder, Sheppard, and Smith (2005) discussed some of those changes, including American engineers working with other engineers all over the globe, exploding access to new technology, and the requirement for both in-depth, specialized knowledge along with broad based knowledge. Fields that were once separate are now becoming integrated. According to the authors, change is rapid and constant, requiring engineers to become life-long learners.
The initial knowledge state of students entering the technician and engineering fields has changed significantly. Up until the 1980s, many technicians and engineers came from a background in which they tinkered with everyday objects such as automobile engines and radios, took them apart to see how they worked, and developed an understanding of design. Early engineers were able to design, build, test, and analyze their own inventions (Feisel & Rosa, 2005). Up until about 30 years ago, engineering students started their studies with hundreds of hours of their spare time spent on building a background of troubleshooting, repairing, and dissecting equipment.

Many current students do not start their studies with that type of background. Most products now are designed for manufacturing ease and cannot be easily dissected. Many plastic items snap together or are fabricated in one piece. The design intent is to have no repairable objects inside the system. Even if a person can open the product up, it is rarely composed of simple mechanisms. Inexpensive, lightweight microchips and circuit boards have replaced mechanical mechanisms. Over twenty years ago Buurman (1997) said the way in which “smart” products are designed to work is completely perplexing to most people due to the embedded electronics. Obviously, personal devices have only become more complex since then. Not being able to easily take things apart as past generations of engineering students did in their formative years, the majority of engineering students entering the field today have little hands-on practical understanding of how everyday objects work. Yet engineering educators have continued to teach engineering students via the 1950s-type traditional lecture/lab deductive pedagogy that worked for students with practical, hands-on experience (Duderstadt, 2008; Froyd, Wankat, & Smith, 2012; Prince & Felder, 2006).
The 19th and 20th century engineering students lacked the theory that corresponded to their practical experience. Engineering education, therefore, was designed to build a structure of engineering theory on top of students’ existing foundation of how systems work (Froyd et al., 2012). Recent students, however, have lacked both the practical experience and theoretical knowledge. And yet engineering coursework is still taught primarily deductively – starting with theories and principals and ending up, if there is time in the course, with practical applications or experiments applying those theories and principals (Prince & Felder, 2006). With the exceptions of isolated faculty utilizing innovations and implementations such as PBL, active learning, collaborative learning, flipped classrooms and the like, learning in engineering education classrooms is still mostly passive. In addition, graduates generally are not able to apply their theoretical studies to actual industrial problems once they graduate (King, 2007). Laboratory learning should be the hands-on portion of learning, training students to apply their knowledge, but the connection between lecture and laboratory is not as strong as it should be (Burrowes & Nazario, 2008; Feisel & Peterson, 2002; Feisel & Rosa, 2005; Salim, Rosmah, Hussain, & Haron, 2013). In fact, as Madhuri, Kantamreddi, and Prakash Goteti (2012) wrote, “Due to paramount pressure on students…to enter into premier engineering institutions, they learn chemistry and physics by rote, in particular neglecting laboratory work” (p. 119). Johnstone and Al-Shuaibi (2001) emphasized that it is easy for students to earn excellent grades in the laboratory without understanding what they are doing.

Inductive SLL pedagogy comes very close to the type of learning that made generations of 19th and early to mid-20th century American students into world-class engineers. In inductive systems level teaching and learning, lectures and hands-on activities begin with an
analysis of the system as a whole before delving into subsystems and then into the component parts. Traditional engineering education starts with component parts and then subsystems and will rarely cover the system as a whole. In SLL, students are immersed in interpretation of observations, answering questions, and solving problems from the very first day in the classroom (Siemens AG, 2011).

Backdrop of the Research Problem

Sheppard, Macatangay, Colby, and Sullivan (2008) along with teams of researchers from the Carnegie Foundation for the Advancement of Teaching performed years of research on the current and future status of engineering curriculum. They studied how experts are formed and how students learn and develop. They found the following:

- There is little time in the curriculum to give students deep learning experiences that mirror professional practice. The deductive teaching style and the effort to cover so much technical knowledge in each class limits the time students can become engaged in authentic problem solving.
- Hours spent in the lab are not used effectively to support integration and synthesis of knowledge, to solve problems, and to develop skills of collaboration.
- Design projects that mimic professional practice and require persistence, creativity, and teamwork are usually not part of the coursework until very late in undergraduate curriculum.
- There is not enough time in the current curriculum to expose students to the implications of being a professional in society.
A 2012 report, sponsored by the Royal Academy of Engineers in conjunction with Massachusetts Institute of Technology concluded that technician/engineering education needs a new pedagogical strategy that enables students to develop an integrated approach to all their coursework. Colleges and universities need to provide students with more practical applications to better understand and solve real problems (King, 2007). Although some college educators have integrated practical applications through capstone coursework, junior and senior level design courses, and isolated PBL projects within classes, these are isolated curricular experiences. Rarely are these approaches integrated throughout the entire curriculum. Another related problem is that when engineering educators try new teaching techniques without tying them to pedagogical theory, the larger purpose of building theory that could have come from the study is lost. This gap occurs because most engineering educators are not trained in education research (Streveler & Smith, 2006).

King (2007) stated “there is widespread agreement on the need to develop engineering graduates with the multidisciplinary approach required for successful systems integration” (p. 31). This goal is difficult to accomplish when courses in mechanical systems, electrical systems, and computerized control are taught as separate entities. The traditional silos of technical subject matter and the “chalk and talk” method of instruction has changed very little since the 1950s. Thus, Wulf and Fisher (2002) summarized the issue: “many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real world engineered systems. Although there are isolated ‘points of light’ in engineering schools, it is only a slight exaggeration to say that students are being prepared to practice engineering for their parents’ era, not the 21st century.”
Problems exist within engineering education beyond the chalk-and-talk lecture and the silo design of coursework. Low engineering student retention in general, and specifically among women and minorities, is a concern. The members of a 2007 National Science Foundation (NSF) workshop titled *Moving Forward to Improve Engineering Education* (Beering, 2007) listed reasons students drop out of engineering studies. Some of those reasons are listed below:

- Students experience poor teaching and little exposure to engineering during the first two years, leading to discouragement and departure from engineering studies.
- Talented students perform poorly in the initial math courses.
- Students perceive engineering practice to be exciting, but their coursework seems dull and lacks connection to what they envision to be “real” engineering work.
- Students have varied interests, but coursework seems too restrictive.

Even those students who do succeed in science-based engineering curricula have a difficult time applying their first year science and math courses to their later engineering coursework (Froyd & Ohland, 2005).

In summary, engineering education in the 21st century is problematic because too many graduates are starting at companies without integrated knowledge of how systems are designed and function as a holistic entity. They are unable to quickly understand how systems work and cannot quickly transfer their knowledge of one system to another. They lack teamwork skills. In other words, they lack what our German counterparts call *Handlungskompetenz*, which is “when a skilled worker is able to adapt to a new situation or system in a self-dependent, flexible and fast way of working” (Siemens AG, 2010, p. 6).
Improving Engineering Education: What Can Be Done?

The National Academy of Engineering (NAE) put together a report in 2004 titled *The Engineer of 2020*, the result of an educational summit that summarizes proposed changes to the curriculum. Suggestions included (1) the teaching of introductory courses in ways that would engage students and arouse their curiosity, (2) the encouragement of a systems-level and inductive approach rather than the traditional piecemeal approach, and (3) making courses interdisciplinary.

Aglan and Ali (1996) suggested new curriculum should involve mechatronics. According to the website of the journal *Mechatronics*, “Mechatronics is the synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes. It relates to the design of systems, devices and products aimed at achieving an optimal balance between basic mechanical structure and its overall control” (Mechatronics, n.d.). Aglan and Ali (1996) believed the new curricula should also incorporate teamwork, communication skills, hands-on experiences, and inter-, multi-, and open-ended disciplinary problems. Students should operate and troubleshoot the machines on which they are working. They should communicate their understanding of the function of the machine in different ways – oral, written, and graphical. Students should understand how components function and how these components are related to each other. They believe if students possessed the aforementioned skills, their design creativity would be enhanced and the contexts for other coursework would be augmented. Aglan and Ali have hit upon the very nature of SLL.
One of the issues in trying to implement change in engineering education is the lack of rigorous research tied to educational theory. Many of the classroom experiments that have taken place are tied only to a particular class in a particular institution of higher education. Progress can be made if techniques and experiments can be tied to a universal, overarching theory. Watson (2009) stated:

Action, uninformed by research, has led to mistakes, wasted resources, and inadequate foundations for future efforts. I know of no other area related to engineering where so many people who have succeeded in an activity would claim expertise in understanding how things should be designed without having to at least review the literature…It is going to take course changes, content changes, pedagogical changes, organizational changes, structural changes, and cultural changes to realize systems to educate the engineers of 2020. (p. 3)

Watson believed that research should be tied to the foundations of how engineering students learn. Results must be translated into methodologies of creating effective and efficient engineering learning environments and initiatives that will make needed changes to the organizations and cultures in which engineering is taught.

Isolated change has occurred in engineering education, but not the all-encompassing change needed to make a substantial impact (Borrego, Froyd, & Hall, 2010; Clough, 2004; Dancy & Henderson, 2010). Jamieson and Lohmann (2009) explained that although numerous ideas have been proposed to change engineering education, suggestions are scarce on how to make the changes. Confounding the issue is the scant research that has been conducted on all-encompassing change efforts at programmatic levels in specific engineering education contexts. For example, community colleges are unique educational institutions that serve very special missions within communities throughout the United States. Within these colleges across the country, engineering programs can be found that serve the needs of students who have varied
academic and career goals. Many of these engineering programs housed in community colleges follow the aforementioned traditional approaches to engineering education.

Purpose of the Study

Only smatterings of engineering programs across the country have adopted a SLL inductive pedagogy. The institutions of higher learning that have adopted SLL are listed in Appendix A. Very little research has been done on SLL, and research is particularly scarce that examines the implementation of SLL throughout a community college department. This gap in the literature creates an abyss for both practitioners and researchers. Faculty and administrators are lacking research findings that can help to inform them as they consider changing to SLL pedagogy.

I was interested in the ‘how’ and ‘what’ questions and historical background of SLL implementation. In this study, the understanding of how community college stakeholders implemented SLL for over ten years was the pressing issue. (The reason for selecting this particular community college is described in the chapter on methodology.) Some events in the implementation of SLL were historical; others are contemporary. This study was exploratory. According to Yin (2013), the desire to understand complex social phenomena, such as the challenges of implementing SLL within an entire department, lends itself well to a case study.

This qualitative case study provides a thick description regarding the current practices of SLL within a community college level engineering program. The thick descriptions describe and interpret the thoughts and feelings of the stakeholders (Ponterotto, 2006). Schwandt (2007) maintains that,
Most efforts to define [thick description] emphasize that thick description is not simply a matter of amassing relevant detail. Rather to thickly describe social action is actually to begin to interpret it by recording the circumstances, meanings, intentions, strategies, motivations, and so on that characterize a particular episode. It is this interpretive characteristic of description rather than detail per se that makes it thick (p. 296).

The stakeholders in this case study were the faculty and administrators who were involved in the change to SLL. The focus of my research was on implementation of SLL. It could be argued that students should have been included as stakeholders when exploring the implementation of SLL. However, students’ views would have taken me in a direction away from the historical background and current implementation of SLL from an institutional perspective. My study focused on the how and what of long-term implementation of a SLL pedagogy throughout a curriculum in a department. Students do not have the long-term perspective or in-the-trenches insight of the implementation of such an innovative pedagogy. They would not be the best source for answers to my research questions with the view that I was looking for – that of the institutional implementation of SLL.

My case study investigated a United States-based inductive SLL pedagogy that was adopted in a pioneering community college in the United States. Stakeholders of this engineering program were key sources of data for this study. The purpose of this inquiry was to produce a thick description, based on stakeholders’ accounts, of the design and implementation of a systems level inductive learning approach in a community college context.

Research Questions

The following research questions guided the inquiry, based on the perceptions of the stakeholders and additional sources of data related to this case study site.
1. How did this programmatic innovation emerge, grow, and develop according to the stakeholders of this case study site?

2. What practices were most effective and helpful in designing and delivering systems-level learning at this case study site according to the stakeholders?

3. What caveats, stumbling blocks, and lessons learned were identified according to the stakeholders with regards to their goal(s) for the program?

4. How did stakeholders address the call for change to engineering education at the community college level?

Overview of Methods

The community college in this qualitative case study was chosen for its historical implementation of SLL. The site is known and respected as a Siemens partner college with Siemens certified instructors (see Appendix B for a description of a Siemens partner college and Appendix C for a description of Siemens certified instructors). The site has implemented the SLL pedagogy throughout the institution’s mechatronics curriculum. The details on the site selection will be covered in the methodology chapter.

Participants in this case study were selected based on purposeful criteria. The faculty and the chairs who were a part of the history and ongoing development of SLL at this college were selected for semi-structured interviews.

The initial analysis of the interviews was performed by coding to the research questions. Constant comparison was used to develop themes from the interviews. An inductive analysis was performed to code into themes using emic categories. Chronological and descriptive
analyses were also performed on the data. The outcome of the analysis resulted in the free nodes of ‘Beginnings’, ‘Implementation’, ‘Instruction’, ‘Challenges’, ‘Best Practices’, ‘Outcomes’, and ‘Future’. The discoveries and conclusions from each of those areas can be found in the chapter on findings.

Researcher Positionality

I entered the field of Mechanical Engineering during a stint in the Army, attending ten different colleges while being transferred to different Army bases in the United States and Germany. Finally, a longer deployment at the Fort Sheridan Army Base in the 1980s allowed me to complete a Bachelors and Masters degree at Northwestern University before being transferred to the state of Georgia.

Georgia had numerous paper mills when I was there in the 1990s, and it was there that I started a career in electro-mechanical engineering. Electro-mechanical engineering was a precursor to mechatronics engineering. At the time, electro-mechanical engineering skill sets included a combination of electrical engineering and mechanical engineering with only a smattering of controls engineering.

I worked in paper mills in Georgia, Oklahoma, and Wisconsin for ten years as a research and development engineer, eventually moving up to become a project engineer of multi-million dollar installations of equipment. Eventually, the day-to-day duties of a project engineer became tiresome and repetitive, so I left that industry and obtained a job at Buell Motorcycle in the early 2000s as a stress analysis engineer - part of the team that designed and manufactured the 2002 Buell Firebolt motorcycle. After two years at Buell, a position as chair of the
Mechanical Engineering Technology department opened up in 2002 at a community college of approximately 16,000 students in northern Illinois. I was hired for that position and have been with the college ever since.

I was the faculty leader of a national team of colleges who were given a United States Department of Labor grant in 2012 to create a mechatronics program with curriculum that could be disseminated free to any college wanting to start a program of its own. One of the outcomes of that grant was the incorporation of recognized credentialing for students. At the time, the credentials most widely recognized were the Siemens mechatronics certifications. These certifications are independent of any tie to Siemens equipment. The certification is a 3-tiered measurement of mechatronics skills in troubleshooting and fluid competence in mechatronics. The Level 1 certification is designed for students who have completed their first year of mechatronics education. The Level 2 certification is for second year, associate’s degree mechatronics technician graduates. The Level 3 certification is for fourth year, mechatronics college graduates.

In order to be able to offer those certifications, two faculty members from each institution must be trained in the Siemens method. I was trained to instruct students so that they can take both Level 1 and Level 2 certifications. This training encompassed a total of four weeks, 160 hours, of training, which included two weeks of training at the Siemens Technik Academie (STA) in Berlin, Germany. The training encompassed organized sessions on how to use the Siemens approach and classroom observation of SLL in action at the STA in Berlin. I became very interested in examining research related to this system, but found that there was amazingly
little about SLL in the literature. Thus, I decided to investigate the phenomenon of SLL in a community college that has been implementing SLL for over 10 years.

I am a stakeholder in this research. I am an ‘insider’ – a member of the group of people who implement SLL at their own institution. I have implemented SLL in my department for about five years and I am a firm believer that this method would benefit the engineering student in many ways, including having the option of earning a living wage after only one year of study. Enabling an engineering student to thoroughly understand how industrial automation equipment works by having them work with the equipment from day one increases the students’ enthusiasm for understanding the underpinnings of the engineering behind the design. I find the method engages students in a way that traditional engineering instruction does not.

In addition to being an ‘insider’, I am also an ‘outsider’ – I am not a member of the faculty or administration of this particular college. My insider/outsider status in this case study means I brought a bias to the research. The impact my status had on my study is detailed in the chapter on methodology – chapter four.

In summary, I brought research training and skills garnered from the Siemens Technik Achedemie - the originator of SLL; the experience gained as an engineer working for 12 years in manufacturing industries; and the experience acquired from more than 15 years as a full-time engineering faculty member and department chair in higher education. The experiences gave me 1) an in-depth skillset of how to apply SLL, garnered from the Siemens training; 2) a unique, first-hand knowledge of what my generational peers and I brought to the field of engineering as new graduates; 3) a supervisor’s knowledge of what skills young graduates bring to the table as new hires; and 4) a professor’s knowledge of the skills current students bring to college and the
skills they graduate college with as they go forth to become engineers. These experiences are interwoven into, and are an integral part of, this research investigation of SLL and the future of engineering education. Note also that a discussion of the topic of ‘insider’ and ‘outsider’ positionality will be covered in more detail in the chapter on methodology.

There are few studies in the literature on SLL pedagogy. My purpose for designing this study was twofold. First, I wanted to provide readers with a detailed description of SLL pedagogy and how it is different from traditional engineering education pedagogy. Second, I wanted to give readers a thick description provided by stakeholders of SLL implementation along with the challenges and discoveries of best practices that occurred during implementation and a section on best practices. Readers will gain a deeper understanding of instruction with SLL pedagogy. Readers will also gain understanding of SLL implementation even with the challenge of not having enough training equipment for all students. These research findings can help inform faculty and administrators about institutional SLL implementation as they consider a change to SLL pedagogy.

Chapter Summary

Researchers have identified several concerns regarding engineering education. Renovation suggestions include the need for a systems-level, inductive pedagogy; the need for interdisciplinary courses; and the need to excite students in engineering practice.

Research results have indicated inductive, systems-level pedagogy should be an important aspect of engineering curricula. These findings indicate that such an approach would
help engineering graduates apply their new learning to new systems. Currently, engineering graduates struggle with applying their theory to actual industrial systems (King, 2007).

The next chapter, chapter two, covers the relationship between constructivism and SLL, along with definitions needed for the understanding of the pedagogy. Chapter three provides a narrative of existing literature and a backdrop for the problem statement and research questions of this study. In that chapter, the existing literature is described and synthesized in order to provide readers with an understanding of the current state of engineering education. Chapter four describes the methodology of this case study and chapter five reports the data collection results. Finally, chapter six summarizes the case study and provides a discussion and recommendations about SLL implementation.
CHAPTER 2
SYSTEMS LEVEL LEARNING AND CONSTRUCTIVISM

“The most painful thing…is how far away you are from being able to use it after you have learned it.”
James Newman (1956, p. 1978)

Yilmaz (2011) stated, “Learning theories are essential for effective teaching in that they shed light on different aspects of the learning process” (p.204). But Streveler and Smith (2006) asserted that engineering educators often try new teaching techniques without tying them to pedagogical theory. This disconnect is due to the fact that engineering educators are not trained in education research. “Without an explicit, well-articulated tie to the specifics of a theory, it is difficult to generalize across studies and the opportunity is lost to build theory, rather than just be informed by it” (p. 103). Adding to that thought, Fosnot (1996) stated that, “We again run the risk of short-lived reform unless educators understand the theory behind the practice” (p. x).

If engineering educators can develop an adaptation theory of engineering education change, the need for the reports every decade or so suggesting what changes need to be made would become superfluous. One could refer to the theory to make constant, continuous, adaptive change as society changes. That theory is not forthcoming. In fact Pister (1995) stated “…there is no simple, universal prescription for dealing with complexity and constant change” (p. 2). But engineering students can be trained in how to learn and how to apply their skills to a wide diversity of problems; thus, specific curriculum change would be unnecessary because the curriculum would continuously evolve.
Over the years, calls for change in engineering education revolved around amalgamation of subject areas, better design skills, better communications skills, better teamwork skills, and adaptive expertise, giving graduates the ability to move from one project to another with confidence that they can apply their knowledge to design challenges. Inductive, systems-level learning is a constructivist pedagogy that instills all those desired attributes into the graduate.

Constructivism

The overarching learning theory behind inductive, systems-level pedagogy is constructivism. Constructivists believe knowledge cannot be passively received – individuals must construct their own meaning and understanding out of knowledge (Yilmaz, 2008). In constructivism, learners build on their own schemata, or mental structures, to make sense of, and integrate new information. If the new information is congruent with existing schemata, students will integrate it. However, if it is contrary to existing schemata, students will learn the information for the exam, but will not learn the information deeply. “…To be effective, instruction must set up experiences that induce students to construct knowledge for themselves, when necessary adjusting or rejecting their prior beliefs and misconceptions in light of the evidence provided by the experiences” (Yilmaz, 2008, p. 125).

Constructivism has its beginnings in cognitive science. It developed from the ideas of Dewey, James, Piaget, and Vygotsky (Yilmaz, 2008). It has evolved from researchers studying the role of representation in learning, such as Bruner, Gardner, and Goodman. Fosnot (1996) went on to state that it also has roots in the work of biologists and evolutionists such as Ernest Mayr, Lynn Margulis, and Stewart Kauffman in their research synthesizing physics with biology.
Fox (2001) listed basic principles and assumptions of constructivist view as follows:

(1) Learning is an active process.
(2) Knowledge is constructed, rather than innate, or passively absorbed.
(3) Knowledge is invented, not discovered.
(4a) All knowledge is personal and idiosyncratic.
(4b) All knowledge is socially constructed.
(5) Learning is essentially a process of making sense of the world.
(6) Effective learning requires meaningful, open-ended, challenging problems for the learner to solve. (p. 24)

Maclellan and Soden (2004) suggested when individuals create meaning for themselves, they can no longer be considered empty vessels to be filled. Instead, they are self-determining and can generate questions, theories, and knowledge. Therefore, teaching should emphasize the development and improvement of the individual’s thinking. Intellectual authority lies not with the instructor or any other source of knowledge, but it springs from the dialog and debate that is facilitated between teachers and students.

Inductive Teaching and Learning

One recommended change to engineering education which was first mentioned in the Mann report of 1918, was the move towards inductive, systems-level pedagogy. For more than 50 years, engineering instruction has utilized a deductive philosophy. An instructor using a deductive pedagogy will introduce a student to theories, show how those theories were derived, and finally, if there is time, show how those theories are applied (Prince & Felder, 2006). This method makes sense for those students in the pure sciences in which theory is in place before applications are sought after. However, in the day-to-day functioning of engineers, their work is all about applying theory and applying fundamentals to meet practical requirements of the job at
hand. An engineer is given a problem and then asked to find a solution. Therefore, in the training of engineers, the deductive method of instruction does not make sense.

The inductive methodology in which a student is challenged by a problem and needs to find a solution is an intuitively correct path to follow in training future engineers because that is what engineers do daily. The inductive method starts with the system as a whole and eventually works down to the nuts and bolts level. The advantage to using an inductive method of instruction, not only for engineering students, but for students in many other subject fields, is that it engages students, it results in increased retention of knowledge, increased participation, the knowledge retained is deeper, and it aids students to develop self-directed learning, furthering their intellectual development (Lancor & Schiebel, 2008; Prince & Felder, 2007; Van Valkenburg, 1989a, 1989b).

A number of instructional methods fall under the heading inductive methodology. Some of these methods include inquiry-based learning, discovery learning, project- and problem-based learning, case-based learning, just-in-time learning, and systems-level learning. These different methods vary in the type and scope of the challenge and the amount of facilitation students receive in taking on the challenge. Prince and Felder, in their 2006 and 2007 articles, summarized inquiry-based learning, discovery learning, project- and problem-based learning, case-based learning, and just-in-time learning. Below is a concise description of those method definitions.

In *inquiry-based* teaching and learning, students search for answers to interesting questions or they solve problems in class related to the topic at hand. As students get better at this, the questions and problems become more open-ended and there is less guidance from
instructors. The questions and problems serve as contexts for learning. Inquiry learning is the simplest inductive technique and most useful for understanding concrete, observable phenomena rather than understanding theories.

*Discovery* teaching and learning is largely student self-directed. Instructors set up the problem and give students feedback on their effort, but do not provide guidance or direction. The drawback to this method is the time required for students to discover things for themselves for each problem leaves little time to cover the course content.

*Problem-based* teaching and learning (PBL) and *project-based* teaching and learning typically involve complex, open-ended problems/projects that come close to mimicking professional practice. Problem-based learning integrates material from across the curriculum and therefore is typically used either as end-of-semester projects or as capstone course projects. The difference between problem-based learning and project-based learning is that in *problem-based* learning, in-class instruction has not covered the background needed in order to solve the problem and is typically the most difficult inductive technique to implement. In *project-based* learning, integrating knowledge learned in class is the main point of the project. Project-based learning can evolve into problem-based learning as the projects become more complex and instructor support is weaned away.

In *case-based* instruction and learning, students are analyzing a scenario (real or fabricated). Cases are typically well structured and contain rich contextual details in order to immerse students in the case. The details of decisions made in the actual case are not given to the students initially in order that students get an opportunity to analyze the case themselves.
*Just-in-time* teaching and learning requires students to answer conceptual questions about class content prior to the class. The results of the students’ responses to the questions are what drive the learning. Instructors use the results of these questions to organize learning to correct the misconceptions.

Constructivism and Systems Level Learning

Systems level teaching and learning (SLL) also falls under the umbrella of inductive pedagogy. All learning in SLL involves transfer of learning based on previous learning. Students are always able to link new learning to their prior knowledge as to how systems work. Bransford, Brown, and Cocking (1999) emphasized that the amount of time students are willing to devote to learning is affected by their motivation. Students are more motivated when they can see the usefulness of what they are learning and when they can use it to do something. The inductive, SLL pedagogy continuously provides context for learning.

Prince and Felder (2006, p. 125) described four principles of the constructivist method. I have aligned these four principles below with SLL from the Siemens Level 1 and Level 2 instructor training.

The first principle of the Prince and Felder (2006) constructivist method is that “instruction should begin with content and experiences likely to be familiar to the students, so they can make connections to their existing knowledge structures” (p. 125). Systems-level learning starts with an evaluation of how a particular system works. Students are introduced to an entire manufacturing cell on their first day of class. Instructors are building a base line or reference point of knowledge by demonstrating the holistic system. Although students may have
never seen an automation cell, the operation of the whole cell rarely fails to engage students. Instructors use the operation of the entire cell as the context in which all other learning about mechatronics takes place. This application of mechatronics is real-world. Everything learned after this juncture is always presented in relationship to the whole system.

Under the same idea above, Prince and Felder also state, “New material should be presented in the context of its intended real-world applications and its relationship to other areas of knowledge, rather than being taught abstractly and out of context” (p. 125). In systems-level learning, new material is presented in reference to the entire system.

The second principle of the Prince and Felder (2006) constructivist method is that “material should not be presented in a manner that requires students to alter their cognitive models abruptly and drastically… [Students should] be directed to continually revisit critical concepts, improving their cognitive models with each visit” (p.125). In the systems-level model, students continually review critical concepts of how the entire system works and how the sub-systems work as an integrated whole. Once they fully understand how a system works and how to troubleshoot it, they are directed to another system of the cell, which operates with completely different sub-systems and components.

The third principle of the Prince and Felder (2006) constructivist method is that “instruction should require students to fill in gaps and extrapolate material presented by the instructor. The goal should be to wean the students away from dependence on instructors as primary sources of required information, helping them to become self-learners” (p.125). When students are trained to look at the entire system and analyze how it is supposed to work, and are exposed to systems in every class, it becomes easier for them to “fill in gaps and extrapolate
material” (p. 125). Eventually they will become self-learners and will achieve Handlungskompetenz. Handlungskompetenz is a German term used to categorize a particular type of adaptive skill; that is, adaptive expertise. Adaptive expertise allows a skilled worker to be able to adapt to new situations or systems in a self-dependent, flexible and fast way of working. It is an intuitive method that helps students be productive in their first job and in their career as a whole.

The fourth and final principle of the Prince and Felder (2006) constructivist method is that “instruction should involve students working together in small groups”(p.125). In the systems-level instruction, students are always working in small groups. They are organized into small teams in the lecture classroom and small teams in the lab. In addition, students are trained in how to work as a productive member of a team.

Boud and Feletti (1991) asked, “If learning occurs best in context, how do we prepare ourselves for future contexts which are unknowable?” (p. 19). The answer to that question for engineering students may very well be the development of adaptive expertise via systems-level pedagogy. If a student can be trained to analyze a system – any system, holistically prior to delving into the subsystem and component levels, that student has adaptive expertise. Adaptive expertise is necessary for “future contexts that are unknowable”.

The Siemens Corporation developed the renowned Siemens Technik Akademie (STA) in Berlin, Germany. I spent almost two months in educator training at the STA. The following information is from the STA educator’s training and the Siemens Mechatronics Systems
Certification Program (SMSCP) website (Siemens, 2011) with viewpoints based on my experiences and observations.

The STA has been training its automation engineers and technicians using the systems-level, inductive pedagogy since the 1990s – they have over 30 years invested in mechatronics education using SLL. Their model is the 100-year-old German vocational and technical education tradition. Their pedagogy focuses on the holistic system. The overriding goal of this innovative pedagogy is to produce graduates with Handlungskompetenz -- graduates who have the flexibility to quickly adapt to new systems and situations in a self-directed way. In every class, the STA systems-level model melds theoretical and practical learning with the goal of improving a business’ bottom line (Siemens, 2011).

Siemens designed their curriculum to ensure students are immediately productive in their first job. Siemens knows what type of training works to get graduates to immediately fill openings in their worldwide corporation. Their graduates have adaptive expertise and can be exposed to any automation system and be able to troubleshoot it quickly and efficiently (Siemens 2011).

The idea behind the systems-level, inductive approach is to start with a complete understanding of how the entire system works before delving into the theory behind how the sub-systems and components work. This approach differs from the deductive American way of teaching engineering and technology students. In a typical American engineering curriculum, the starting point is learning about the individual components – the bearings, the shafts, and then the drive systems in a mechanical systems class, for example. Only in the capstone design course do students start to put the subsystems together into a unified whole. No wonder students do not
have the adaptive expertise at the end of four years. They were working with entire systems only in the last segments of their studies.

The German curricular system starts with an overview of how a machine performs its tasks. What does it do? How does it work? How is it broken down into subsystems? The following two slides on the next page are from a Siemens instructor training session on SLL (Siemens AG, 2012, p. 9-10). It is an excellent illustration of how the systems-level instruction proceeds from system overview to component level theory.

The German system of teaching and learning is unique in that instructors rarely lecture for more than 30 minutes at any time before the students can manipulate objects related to the lecture. In other words, within the lecture, students are manipulating lab components of the topic. Students are always working directly with objects that bear closely on what they are learning that day (see Figure 1).

Systems-level pedagogy affects the lecture as well as increases the amount of opportunities for hands-on learning and teamwork. It changes the very nature of the lecture classroom experience by utilizing a different focus in the lecture itself. The entire approach to the lecture focuses on the system in every class period. Students learn about complex systems in a holistic manner. This approach means that students start their first day in the curriculum looking at a complete system to understand how it works. The Siemens Technik Akademie online FAQ brochure (Siemens AG, 2011) further stated after students examine and experiment with the whole system: “…from day one, students are continually working with a complete mechatronic system. This ‘system approach’ teaching ensures that they always keep the ‘big picture’ of mechatronic systems in view”.
The advantages of this method are that students can more easily transfer their skills to systems they have never seen, whereas the majority of traditionally trained students tend to be perplexed when they see a system other than the one on which they were trained. This perplexity
is because the traditionally taught students were trained in each field separately. Siemens found that the traditional approach leads to students with little understanding of the inter-relationships between technical subsystems in most modern manufacturing systems (Siemens Instructor Training, Berlin, Germany, 2014).

In a traditional American engineering class, the instructor lectures and may include a few handouts or a demonstration or a component to pass around. Only later in lab, will the student get a chance to work with the system. It is possible in the traditional method for students to receive passing or even excellent grades in the laboratory curriculum and still not understand what they are doing (Johnstone & Al-Shuaili, 2001; Johnstone, Watt, & Zaman, 1998). In an SLL class, the students are always manipulating objects and laboratory time is fully integrated into the entire curriculum and not a separate component of the curriculum in the new paradigm. Lecture and lab are almost seamless and every component of lecture ties into learning about the systems and components in the lab (Siemens Instructor Training, Berlin, Germany, 2014).

Students in the German system are also working in teams in each of their classes. When they arrive during their first week of training, they take a number of assessments including the Meyers Briggs assessment. The instructors pair up the students based on the results of these assessments. Once paired, students are given training on how to work in teams and how to resolve conflicts. This approach leads to much better group learning than what is commonly done for group work in American classrooms (Siemens Instructor Training, Berlin, Germany, 2014).

In summary, what makes the German systems-level instruction unique is the emphasis on the entire system first; the interactive lectures in which students are always applying what they
are learning; and training in teamwork within courses to enable students to not only learn cooperatively, but enable them to fully function as productive team members.

**SLL in the Classroom**

One way to bring the excitement back into engineering curriculum in the United States is to immerse students in hands-on work in mechanical systems, electrical systems, programmable logic controllers (PLCs), and engineering graphics during their first semester, or even better, on their first day. Students continue their studies in pneumatics and hydraulics, robotics, a second level of PLCs, and an integrated automation course during their second semester. At the end of their first year, they are employable and can earn a living wage in the mechatronics industry. They understand and can explain how complete systems, subsystems, and components of a system work as a whole. The students will not be able to repair the individual components until their second year, but they will be able to pinpoint malfunctions to the components, they can identify the sources and causes of malfunctions, they can replace defective components, they can perform preventative maintenance, and finally, they can work effectively as a team member after nine months training (Siemens AG, 2010).

In an examination of American SLL programs, general education requirements are spread out so that the first and the second years are professionally productive and students can find living wage jobs after each year, like their German counterparts, helping them pay for their continued studies. At the end of their first year, they have a certificate in mechatronics from the college and qualify for industry-recognized certifications, such as the Siemens Level 1 exam, the Packaging Machinery Manufacturers Institute (PMMI) exams, the Manufacturing Skills
Standards Council (MSSC) exams, and the computer-aided design industry exam. Students have a choice to either find a full time job, find a part time job, and/or continue their studies to an Associate’s degree.

The differences between traditional pedagogy and SLL pedagogy can be illustrated by comparing the types of instructional material used in both pedagogies. A lecture on sensors from a traditional class will stress how a sensor works but never really show the way it is incorporated into a system other than in a cursory manor. For example, in the traditional lecture, students are told that photoelectric sensors (photo eyes), used in manufacturing to indicate an object is in front of the sensor, can be wired up two different ways. The traditional instruction proceeds to show a photo eye wired up in both ways -- as current sourcing and another photo eye as current sinking (Petruzella, 2010). The practical reason behind why this would be important is never discussed. The application may be relegated to lab work, if at all. It is a purely academic discussion.

Lecture in the systems-level class, on the other hand, will immerse the student in the operation of the photo eye, starting with how the photo eye works holistically in the system and the different ways the object can be sensed. After the student sees the photo eye in operation, a discussion and demonstration of how the photo eye can be wired up so that it can be either current sourcing or current sensing occurs (Siemens AG, 2012). Students are given sensors and a system and are asked to integrate that sensor in a system for which they have to determine whether the sensor should be wired as sourcing or sinking. The approaches are vastly different.
Challenges and Concerns Regarding Implementing Inductive Pedagogy

There are challenges in attempting to rigorously compare inductive teaching and learning methods to traditional lecture/lab methodology. Felder and Brent (2005) stated that even if one has the same instructor using the same method in two different classes, outcomes can vary based on student populations. Prince (2004) asserted that two different instructors using the same method in the same class could produce different results due to the varying degree of experience and skill of each instructor. Within particular types of inductive pedagogy there are wide variations in how teams are facilitated and to what degree the instructor is involved, making comparisons between studies difficult. The particular learning outcomes investigated could influence the conclusion drawn from the study. Finally, it can be difficult to sort out what portion of the results can be attributable to the method and what portion can be attributed to components of other methods embedded in the inductive method.

In addition to challenges comparing results of studies, there are also concerns regarding the implementation of the instructional methods when favorable results are reported and faculty want to try out the methods. Most of these non-traditional methods require a larger investment in time. Often the instructor must possess a wider degree of subject matter expertise, confidence, and flexibility because directions that students pursue can be “unpredictable and unfamiliar” (Prince & Felder, 2006, p. 130).

According to Hayden et al. (2011) student reaction to non-traditional instruction can also become a problem. Some students resist and may become hostile when they find themselves accountable for their own learning. It is possible that some may think they are not “learning the content of each subject area...as fully as they would if these disciplines were taught separately”
In addition, as teamwork is emphasized particularly in non-traditional instruction, gender, cultural, and style diversity within teams can lead to alienation, antagonism, and ineffectiveness in which learning becomes secondary to the conflict (Natishan, Schmidt, & Mead, 2000).

The intent of this case study, therefore, is to provide a thick description of the implementation of SLL to understand how this programmatic innovation emerged, grew, and developed at this site, what the perceived best practices of designing and delivering systems-level learning at this case study site are, what caveats, stumbling blocks, and lessons learned were identified regarding the implementation of systems-level learning in a community college context, and to ascertain to what degree systems-level learning at this site is aligned with external calls for change concerning engineering education at the community college level.

Chapter Summary

SLL is part of the constructivist, inductive pedagogy. Inductive pedagogy has a long history showing that the inductive approach leads to better engagement, deeper learning, and helps students to develop intellectually. In inductive teaching and learning, the student is an active part of the teaching and learning (Prince & Felder, 2007). SLL is one constructivist learning approach that makes use of students’ existing knowledge to build a deeper understanding of concepts and principles (Siemens AG, 2010; Siemens Technik Academie, 2010).

Boud and Feletti (1991) asked, “If learning occurs best in context, how do we prepare ourselves for future contexts which are unknowable?” (p. 19). The answer to that question for
engineering students may very well be the development of Handlungskompetenz via the SLL pedagogy. If a student can be trained to analyze any system holistically prior to delving into the subsystem and component levels, that student has adaptive expertise. Adaptive expertise is necessary for future contexts that are unknowable.

The next chapter provides an overview of the history of engineering education. This history begins with the Mann Report of 1918 and highlights events to the present.
CHAPTER 3
LITERATURE REVIEW

“Perhaps the most constant feature of American engineering education has been the demand for change.”
Bruce E. Seely (1999, p. 285)

This case study of a particular innovation in engineering education – systems level learning (SLL) is situated in the context of innovative higher education curriculum literature. The primary context for this study is the innovation which has taken place in engineering education. This particular case study is focused at the community college level. Often community colleges function as laboratories for innovation due to generally smaller departments, the commitment to learning, and the openness with which changes can be tried and supported.

Another context is the innovative curricula approach that is coming out of the German private industrial sector. The question of why industry is investing in the development and the implementation of their own curricula and how it is different than the traditional approach to developing curriculum will be investigated as well.

This chapter is comprised of the following sections:

1. Introduction
2. History of engineering education
3. The current state of engineering education: Innovation with impact
4. Community colleges and engineering education
5. Strengths and weaknesses in the existing engineering education literature
6. Summary
Introduction

The contexts above form the framework of the queries that were made of the literature. Engineering education has always been going through change. Investigations have been funded since 1918 and reports have been written about the need for change in engineering education. Recent efforts to change how instructors teach and what they teach are being funded by organizations such as the National Science Foundation (NSF) and the American Society for Engineering Education (ASEE) among others. The following sections chronicle the evolution and changes of engineering education.

History of Engineering Education

Many extensive and in-depth reports have been written on the state of engineering education starting with the Mann report of 1918. These reports encompass much more than just a recommendation on how to enhance and/or change undergraduate engineering curriculum. However, this literature review will be focused only on the discussions on and suggestions for engineering education curriculum reform found throughout those historical reports. The reports have a depth to them that is not apparent from looking only at the conclusions. Hollomon (1975) writes:

Our conclusions draw on only some of the data and, equally important, the recommendations deal with only some of the implications of the conclusions. To read only our recommendations would be to omit much of the value of this document and to frustrate its purposes. (p. 4)

This perspective is appropriate for the majority of reports in this literature review.
The Mann Report of 1918

In 1918, Charles R. Mann published a study of engineering education from its beginnings in the 1700s to 1918 called *A Study of Engineering Education*. It was the first major report on engineering education and was funded by the Carnegie Foundation for the Advancement of Teaching. One of the reasons for the study was to investigate what could be improved in engineering education, since 60% of all students entering engineering in the early 1900s failed to graduate (Mann, 1918).

Mann described how engineering education came to be as it was in the early 20th century. America in the colonial years was an agricultural economy. Manufactured items such as machinery, tools, and the like, had to be purchased from England. Society underwent a revolution when the colonies agreed to the non-importation agreement of 1774 that curtailed imports from Britain and was implemented to force Britain to recognize political rights of colonists. As a result of the agreement, there was a great need for machinery, tools, and manufactured goods in the colonies, along with skilled engineers and workers. At the time, engineering training in both Britain and North America was in the form of apprenticeships. Apprentices worked alongside professional engineers for a few years where they could learn the practical aspects of engineering prior to setting off on their own (Reynolds, 1992). Once the industrial revolution took hold, ingenuity and entrepreneurial initiative started to take the colonies by storm. Between 1830 and 1870, the number of American patents exploded from approximately 200 per year to over 13,000 per year. To get a feel for the magnitude of this change, statistics show that in 1870, the total value of manufacturing production was $8.4 billion. In 1916, it claimed to $32.0 billion (Mann, 1918). The apprenticeship model of engineering
training was no longer adequate to produce the number and quality of engineers needed by North America. Once the industrial revolution started and the number of innovations in manufacturing exploded, machinery became more specialized and intricate, resulting in the need for engineers trained in mechanical engineering.

The demand for people to develop scientific knowledge to increase production and efficiency in both agriculture and in manufacturing was tremendous. Farming the land at the time resulted in soil depletion and farm abandonment because the scientific knowledge behind sustainability was not widely available. In addition, manufacturing without efficiency and production know-how resulted in scrapping one third to one half of all products.

The first formal engineering program was inaugurated at West Point in 1802 (Reynolds & Seely, 1993). In 1829, the Rensselaer Polytechnic Institute began to offer civil engineering. Up until the mid-1800s, those were the only two schools of engineering. When the number of patents exploded from approximately 200 per year to over 13,000 per year, between 1830 and 1870, machinery became more specialized and intricate resulting in the need for engineers trained in mechanical engineering (Mann, 1918).

Mann continues the historical account: The Morrill Act of 1862 was the driving force behind an exponential growth of colleges offering engineering courses. By 1880, there were 85 schools offering engineering and with the boom in colleges offering engineering training came a variety of engineering courses and curricula that were designed with local manufacturing and industry needs in mind. Separate engineering disciplines started to emerge such as civil, mechanical, automotive, aeronautical, and agricultural along with specialized engineering disciplines such as metallurgical, marine, cement, textile, and ceramic engineering.
With this growth came changes to the curriculum involving the addition of engineering science in addition to the multitude of applied engineering skills in all the different disciplines of engineering. Requirements were now so diverse that the same degree from different institutions did not mean graduates had the same skills. An engineer graduating from school A that valued the hands-on approach did not finish the program with the same set of skills as one graduating from school B that valued an engineering science curriculum.

The first real discussion about the state of American engineering education was conducted in 1876 under the auspices of the main engineering societies: the Society for the Promotion of Engineering Science, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Society of Electrical Engineers, and the American Chemical Society. A Joint Committee on Engineering Education was formed with committee members drawn from the engineering societies above. They wrangled with the question of whether the curriculum should provide a grounding of hands-on fundamental skill or whether it should cover primarily the theoretical underpinnings of engineering – engineering science. The meeting of these two societies resulted in an impasse. Half the members advocated for hands-on skills and the other half advocating for engineering science. As a result, American engineering schools continued to be divided on what constituted a fundamental engineering curriculum. Some schools embraced a fully hands-on curriculum, others embraced engineering science, and still others incorporated both approaches. They soon discovered that the type of investigation into what would constitute a model engineering curriculum would require funding that none of the organizations had.
Eventually the Carnegie Foundation for the Advancement of Teaching was invited to assist in the investigation and to contribute the funds needed. The Carnegie Foundation agreed to fund this project with a caveat: that Dr. C.R. Mann, a physicist from the University of Chicago – trained in applied science, be the study coordinator. The report resulting from this study, called the Mann Report of 1918, surprisingly contains some of the very same arguments engineering educators are having 100 years later. The focus of the study was to examine how the teaching methods and the curriculum can be improved to better serve the needs of industry and to make sure that the students who have a real aptitude for engineering were not dropping out due to failures of the curriculum.

At the time of the Mann Report, less than 40% of all students graduated in four years. Drop-out rates were greatest in the freshman year – 50% of all dropouts occurred in the freshman year and another 25% of the dropouts occurred in the sophomore year. Mann wrote, “many students are sent away from the technical school without having had any fair test as to their capacity for engineering practice or study” (p. vi). The Mann Report did find that many students who dropped out in the first two years did become good engineers, presumably by apprenticing with accomplished professional engineers.

Even as early as 1918, proponents of change to engineering education sought to persuade instructors to try a different method of teaching – using inductive techniques rather than deductive ones. Mann stated that instructors can use an actual object such as a generator to entreat the student to discover the principals behind its operation, “…lead[ing] the student from practical applications by analysis to a comprehension of theory, instead of from theory to applications as under present methods of teaching…. The student must not merely observe and
analyze the operation of the dynamo [generator]: he [sic] must also actually run it and repair it when out of order” (vii). This statement of Mann’s recommendation was prescient. One of the innovations in 21st century engineering education is in fact this method, which will come to be called systems level learning (SLL).

In summary, the Mann Report reviewed the history of engineering education and also proposed changes to the curriculum that would increase retention. Mann also recommended a commonality of curricula among colleges so graduates from one institution of higher learning would have the same basic engineering skills of graduates of any other institution of higher learning.

The Wickenden Report of 1923 – 1929

The Report of the Investigation of Engineering Education is often referred to in the literature as the Wickenden Report. W.E. Wickenden was the Director of Investigation of this report. Volume I, the fact gathering volume, was issued in 1930, followed by volume II, the final report, in 1934.

The model for engineering education came initially from the few colleges in existence prior to the Morrill Act. The colleges offering engineering education after the Morrill Act used this curriculum as a model. The results of the Mann Report were made public just when society was in flux (upheaval) and trying to re-adjust after the end of the First World War. During the war, engineering training was designed to be condensed to only the practical essentials so that soldiers being trained in engineering could contribute to the war effort as quickly as possible to get ready for battle. But now it was time to agree to a philosophy of engineering education and
to re-invent engineering education with planning and direction from industry, faculty, and professional engineering societies.

The Wickenden Report surveyed engineering education during a time of integration of the achievements of science and engineering as a result of the war. The purpose of the Wickenden study was to answer the question “What can the Society [Society of the Promotion of Engineering Education, SPEE, forerunner of the American Society for Engineering Education, ASEE], do in a comprehensive way to develop, broaden, and enrich engineering education?” (ASEE, 1930, p. 2). Engineering colleges were searching for a direction and needed a philosophy of engineering education. SPEE surveyed engineering schools, engineering students, members of engineering societies, and industry with the overarching goal to divine guiding principles to direct the training of future engineers rather than to standardize engineering training so that the engineering of the future can respond to challenges of the future (Prince & Felder, 2006). At the time, there was no overarching set of educational outcomes and industry had not been able to come up with a listing of qualifications. In addition, neither the colleges nor industry were satisfied with the current state of engineering. Graduation requirements among engineering colleges and universities varied considerably. In the civil engineering field of study, the survey conducted resulted in the finding that total credit hours for graduation varied from 125 to 191.

Also mentioned in the Wickenden Report was a need for technical schools in addition to the formal engineering schools. In the engineering schools, freshman year was to be spent “…in methods of study, systematic work processes, clearness of expression, standards of accuracy, orderliness and punctuality, and problem analysis” (p.1101). The second and third years introduced lectures that covered the experimental methods by which the technical and scientific
knowledge was honed. Design work was also introduced at this time. The fourth year offered honors studies and further, specialized training. Inclusion of economics and studies of how engineering impacts society was considered very important.

The use of textbooks as a whole was seen as short-circuiting critical thinking skills because textbooks did not (nor do they today) describe the way in which knowledge was developed. Due to the use of the textbook,

…college and engineering students have been and are being trained to accept, to memorize and to take for granted, rather than to question, to analyze, to think for themselves and to develop mental initiative. They rarely distinguish between observations, definitions, conventions, principles, and hypotheses. They have been and are being taught how to solve certain problems by approximate and superficial methods without having a sufficiently sound scientific background of fundamental principles to enable them to appreciate the approximations involved and the corresponding limitations of their solutions. If education means mental training, they have not been educated; they have been shown just what to do and how to do it – in many cases they [students] have it done for them – and they imagine that they are educated (p. 1093).

The consensus was that European schools, which did not use textbooks, succeeded in training very well qualified students and that the American system of textbooks and hands-on work was suited to the average lower ability student.

The Wickenden Report of engineering education was not an assessment of the current state of engineering education as much as it was a call to continue to review, experiment, and adjust the curriculum. Wickenden (ASEE, 1930) stated, “Each [engineering school] was to work out its own destiny with whatever light could be gained from the experience of all and with such guidance as the engineering professions and industries might supply” (p 1041). The reason for this assertion was that industry was still trying to ascertain what specific attributes it wanted in an engineering graduate.
Wickenden wrote, “In engineering education, we seek a unity of purpose rather than standardization…What has been accomplished is not to be regarded as a completion of the task but rather as the first step in dealing with a continuing problem” (ASEE, p. 12). The SPEE’s function, according to Wickenden, was to help to develop instructors who can effectively train engineers. In summary, Wickenden recommended that major changes not be made to engineering education, but only refinements to improve the quality.

**The Hammond Report of 1940**

The *Report of Committee on Aims and Scope of Engineering Curricula* or *The Hammond Report of 1940* as it became known, was commissioned for two reasons: 1) to determine if the engineering curriculum was long enough, and 2) whether students should undergo a period of liberal arts study before pursuing engineering education. A committee drawn from members of the SPEE was formed for this study. An initial report was drafted and presented to other members of the society, professional engineers, and educational leaders for their input. The resulting final report made a number of suggestions for curricular improvement.

First, it was recommended to par down the advanced topics in the undergraduate years so that more time could be spent refining analytical skills such as the mastery of the engineering method, critical and reflective thinking, and communication skills. It was acknowledged that making the program longer would negatively impact a student’s finances, would not contribute more to the needs of industry, and would not serve the abilities of a large number of students (p. 561).
As for requiring liberal arts study prior to starting engineering education, it was recommended to develop an integrated core group of social and humanistic courses that lead to understanding of how the public welfare plays into engineering design and also a life well lived rather than to make the path to an engineering degree longer (p. 564).

Other recommendations included setting higher admissions standards by sending those students interested in hands-on technology to technology schools and a recommendation not to standardize curriculum because curriculum diversity should be valued to best serve the evolving conditions of the needs of society.

The Hammond Report of 1944

The Report of Committee on Engineering Education After the War or The Hammond Report of 1944 seems to imply that it was authored after the Second World War. However, it was dated 1944 and U.S. involvement in the Second World War did not end until 1945. It was a report that attempted to look ahead to the end of the war and anticipate the changes that would be needed in engineering education once the war was over. As was the case during World War I, engineering education during the Second World War was trimmed to its essentials. The Hammond Report recommended going back to the full engineering program as soon as possible after the war was over. This Hammond Report of 1944 corroborated the Hammond Report of 1940.

The Hammond Report was the first to start to outline engineering education outcomes students should attain after four-years of training. This report was the first to define the art of engineering, which the authors believed was essential to a successful career in engineering. The
art of engineering according to the authors, is, “the development of rudimentary skills of execution, understanding of the limitations in the application of principles to practical situations, the beginnings of powers of decision and of judgment, the encouragement of creative talent, [the] ability to deal with the factor of values and costs, and the acquirement of that appreciative sense which is satisfied only by skillful execution or precise verbal expression” (p.599).

The art of engineering is the “integrat[ion of the] application of [scientific] laws, assumptions, data, and codes so as to accomplish a desired result safely and economically. This requires a combination of resourcefulness, skill, experience, and judgment – amounting at times almost to intuition” (p. 599).

As far as instructional procedures were concerned, the authors of the report recommended thoroughly integrating lecture, lab, and design work in every course. Instructors were to assign problems to students so they will master basic principles, and the projects were to be utilized to “integrat[e] thought procedure and practice in the art of engineering” (p. 599).

A separate course on the engineering method was recommended, where engineering analysis was practiced with problems from actual engineering practice. In this course, the aim was for the instructor not to lecture, but to work with students on the general approach to problems, help them come up with the scientific principles needed in the solutions, and to encourage a creative approach to the solution of the problems. Creative ability of students was to be additionally honed by project work throughout the curriculum. The authors felt these skills were usurped in the engineering coursework for specifics of subject matter.

In summary, the authors of the Hammond Report of 1944 started to lay out goals of engineering education as follows:
These goals include mastery of fundamental scientific principles, mastery of engineering modes of thought, basic knowledge in some major branch of engineering, elementary competence in the art of engineering application, some understanding of cost relations, skill in the use of English, insights into social relations and processes, and concepts essential to worthy personal and professional life. The goals of advanced knowledge and specialized technique belong properly to graduate and post-college training. The major paths along which progress is to be sought in the undergraduate period include the choice of essential matters and the elimination of non-essential matters of instruction, the grouping of the chosen materials into coherent major sequences, the inculcation of effective habits and standards, skillful combination of teaching methods, the development of creative as well as analytical abilities, and the evaluation of the attainment of the larger goals as well as the details of learning. (p.607)

**The Grinter Report of 1955**

The *1955 Report on the Evaluation of Engineering Education* is known as the *Grinter Report* in the literature. This report was the second of two studies – the first being the *Preliminary Report on Evaluation of Engineering Education*, prepared in 1953. The preliminary report was sent to all colleges with accredited engineering curricula for their review.

The studies that led to the *Grinter Report* were designed to make recommendations for engineering education curriculum that will be dynamic and flexible enough to “keep pace with the rapid developments in science and technology and to educate men [sic] who will be competent to serve the needs of and provide the leadership for the engineering profession over the next quarter century” (Grinter, 1994, p. 74).

The authors of the *Grinter Report* delineated two major objectives of engineering curricula, which mirrored the Hammond reports: (1) the core engineering science objectives with the ability to understand the limitations of the science and the application of the science, and (2) the development of the ability to understand and consider the humanistic, social, economic, and
ethical ramifications of the solution to engineering problems and practice. Added to these objectives, as in previous reports, is the inculcation of the habit of life-long learning.

The *Grinter Report* authors encouraged the teaching of the coursework that will show the inter-relationships and similarities in analytical methods between problems in different subject fields within engineering science in order to approach new problems graduates have never seen before using the engineering method. They also recommend dispensing with instructor designed lab classes and instead recommended having the students themselves design labs to test theories. They thought the practice in the art of measurement in these labs was essential, along with the use of statistics in the interpretation of the data.

Another similarity between the *Grinter Report* and previous reports is the assertion that the recommendations in the *Grinter Report* are not designed to be rigid requirements. In fact, the authors stated, “The great need of engineering education at this time is for experimentation with, rather than standardization of, curricula” (p.85).

The authors recommended a general curriculum outline with the following content: one quarter of the curriculum consisting of the basic sciences (physics, math, chemistry), one quarter of the curriculum consisting of the “six engineering sciences”, meaning mechanics of solids, fluid mechanics, thermodynamics, transfer and rate mechanisms, electrical theory, and the properties of materials. Another one quarter of all coursework was to be spent in design and analysis and the “art” of engineering. One-fifth of the curriculum was to be spent in humanistic and social sciences, and the remainder should be spent in electives. The authors were quick to point out that this listing should not be static and should accommodate new coursework in engineering sciences as they develop.
In order to achieve this proportion in the curriculum, four suggestions were given: (1) increase the student admission requirements so that instruction can proceed at a faster pace, (2) emphasize engineering science rather than engineering art, (3) increase instructor skill in teaching, and (4) extend the curriculum to more than four years.

The Walker Report of 1968

The Goals of Engineering Education Report, or The Walker Report of 1968, was the culmination of a 5-year study resulting in preliminary, interim, and final report. The overarching goal of the study was to “…delineate significant trends in engineering education and to relate these trends to the future needs of practicing engineers” (Walker, 1968, p. 373). The report concluded that “there is little demand for radical changes in academic programs” (p. 374). The continued growth and development of engineering education to prepare graduates for the future of engineering was of paramount concern. The study attempted to look ahead 32 years – to the turn of the century to predict and guide present engineering education.

The Walker Report suggested focusing on a few of the multiple engineering fields and sub-fields according to what the college or university does best. The authors also recommended effective advising for engineering students and to allow students the freedom to choose the courses based upon personal interest.

Recommendations of the committee were as follows: (1) Expose engineering students to social science theory to understand the social issues, (2) Develop the student’s intellect “…to be agile, flexible, alert, and active” (p. 388), (3) Imbed the value of the need for life-long education, (4) Instill the importance of the engineer’s role incorporating conscientiousness, wisdom, and
competence to solutions to engineering problems, (5) Develop sensitivity, farsightedness, responsibility, and dynamic interaction between technology and societal institutions in the solution to engineering problems, and finally, (6) Cultivate the knowledge and skill to employ engineering methods to a wide variety of problems.

The general recommendations for the administration of engineering curricula were (1) To make programs of engineering study flexible to meet the changing needs of the future by offering a wide range of electives to meet the interest of entering students (2) To expand interdisciplinary study opportunities (3) To reduce the credit hour requirements so students can take advantage of collegiate activities that will contribute to their broadening perspective and creative imagination, (4) To get rid of pre-requisites so that students from other subject fields can take courses in engineering, (5) To create provisions for transfer credit, and (6) To encourage co-op education.

The recommendations above are generic. The Goals Committee did not intend for these recommendations to create standardization in institutions of higher education. In fact, standardization would be antithetical to what they were trying to achieve. “Diversity and not uniformity of educational institutions as well as the programs they administer is the recommendation of the Goals Committee…. The Goals Committee urges each institution to offer those programs (and only those) which will optimize its individual contribution to engineering education” (p. 391).

This 1968 Committee saw many advances in education that were not fathomable to earlier committees, including programmed learning, closed circuit TV, self-instructional labs,
films and video tapes, all designed to facilitate learning. However, they also discovered that very few educational innovations were being adopted. The authors stated:

Many ancient practices continue unquestioned such as the 50-minute, three-days-a-week lecture, the chalk-board as the main visual aid, the one-teacher course or section, the two- or three-hour laboratory, ten-year-old cookbook experiments, the 18-20 hour load, the 16-week semester, the rigidly prescribed curriculum (25% engineering science, 20% social-humanistic studies, etc.), the policy of designing curricula exclusively along traditional lines, etc. The Goals Study has sensed an unrest not only among the younger members of the faculty in engineering, but also among the indomitable innovators who have over the years met with strong resistance whenever and wherever significant changes have been proposed. (p.394)

The suggestions for a basic engineering curriculum included everything in the Grinter Report. The same engineering science courses were recommended, engineering science being defined as “…the study of physical phenomena utilized in artificial or man-made devices and systems as distinguished from basic science which is concerned with the phenomena of nature” (p. 437). Further recommendations come from technological advances that were not present at the time of the earlier reports. For example, the addition of computer science was recommended. The importance of extending/implementing communication arts into every class to include the written, oral, pictorial, and symbolic communications, as in engineering graphics. The systems analysis and design have been expanded to include creative design, inventiveness, and imaginative thought throughout the entire program of study. A capstone design course was recommended as a demonstration of the student’s construction and synthesis of knowledge developed during an entire four-year curriculum.

Yet another recommendation was the enhancement of laboratory work to hone experimental engineering skills such as precision in measuring, using instruments effectively for
measurement, providing supplementary learning opportunities beyond the classroom knowledge, and enlightenment on “supplemental effects often disregarded in theories” (p.439).

Finally, the authors suggested weaving ethics and professional attitudes into current coursework rather than within specific courses. They suggested incorporating/integrating the history of engineering into individual courses, emphasizing the legal aspects of engineering work, and “the consideration of the issue of divided loyalties” (p.439).

The Hollomon Report of 1975

A quote from the *Future Directions for Engineering Education* or the *Hollomon Report of 1975* started out with the statement,

There has been a growing uneasiness in many engineering schools. This uneasiness has often become a conviction that:

1. The world is changing around the whole engineering education system, and that
2. A broader perspective is necessary to understand the problems and perceive the opportunities.

…This study was initiated to examine the engineering education system in a changing world. Its purposes were to describe the new environment of engineering education and to suggest how institutions ought to respond. (p. 3)

Prior to the *Hollomon Report*, recommendations were made that the engineering curriculum should contain social sciences, humanities, and the fine arts so that engineering graduates become well-rounded citizens. The older studies pointed out that engineering students of the 1950s and 1960s were uninterested in courses that were outside of the engineering field. They had more stereotyped thinking, less social awareness, less empathy, more need for external structure, felt less at ease with ambiguity, and had a more practical bent than students who left engineering studies to enter other fields (p. 18). The results of the *Hollomon Report* showed agreement. According to the *Hollomon Report*, “They
[engineering students] are noted for authoritarian behavior…a tendency toward ordering others and being the most dominant individual in an activity” (p.17), which made inclusion of social studies and humanities studies still important as it was in the early 20th century, but for different reasons. Instead of needing the social studies, humanities, and the fine arts to become a well-rounded individual for personal growth, as was the suggestion in earlier reports, it was needed to become aware of societal needs so that these needs can be integrated into engineering design.

In 1972, an analysis of educational, social, and economic trends was performed to predict how these trends would affect engineering education and to recommend how institutions ought to respond to the trends. The authors of the Hollomon Report stated,

Many of these conclusions and the recommendations derived from them [in the current report] are not very different from those of other studies of engineering education since the Second World War. We believe that the recommendations of these earlier reports were not implemented because the great growth of federally-financed programs, beginning in the early 1950s and ending in 1970, interfered with and distorted the response of engineering schools to the long-term basic needs of society. Thus, we conclude that the situation now is even more critical because of the delay. (p. 46)

The authors noted that during World War II and until the 1960s, there was plenty of funding for research and development not only for national security and the war effort, but later for the health and the space programs. It was for this reason that the primary emphasis in engineering education became theoretical rather than practical. The Hollomon Report urged a return to practical emphasis of design. The final curricular recommendations were as follows:

(1) Educational experience in design should be provided as early as possible for the student and should be available as an integrated part of the engineering programs.
(2) Clinical experience should be provided as a significant and integral part of the engineering education.
(3) The school of engineering must have responsibility for the quality of the education of engineering students in the university, including those parts of the student’s program traditionally offered outside the departments of engineering.
(4) Faculty and administration must share responsibility at the school level for the total education of students.
(5) More schools ought to offer “Bachelor of Engineering” degree programs for students planning graduate study in the professions, including engineering, law, and medicine.
(6) Both entry and exit ought to be facilitated in the educational program.
(7) The school and the departments must ensure increased student interaction with the academic community and more effective counseling.
(8) Schools must prepare for a possible period of little or no growth.
(9) The performance of students, programs and institutions must be evaluated as rigorously as possible. (p. 47)

A National Action Agenda for Engineering Education Report of 1987

In the 1980s, the American Society for Engineering Education (ASEE) was concerned that engineering education was not responding well to the rapidly changing society. A task force from the ASEE developed a set of recommendations to address that problem. ASEE recommended “repackaging” the curriculum for efficiency; encouraging an “apprentice-mode” in which engineering design is given a predominant role in the curriculum; encouraging the overhaul of laboratory experiments to incorporate innovation and more information technology and simulation; and finally, finding creative ways to improve communication skills in the classroom (David, 1987).

In 1989, according to Ernst, the NSF started to fund programs to revitalize engineering education. They wanted to fund innovations that would foster higher-level cognitive thinking than what was seen in the past. The reforms suggested and listed below are more nuanced than what was seen up to this point in the history of the engineering education reports. They included:
• Analytical Ability - the critical thinking that underlies problem definition (modeling, simulation, optimization) and derives from serious understanding of the physical, life, and mathematical sciences, as well as the humanities and social sciences”.
• Innovative Ability – the creation and elegant implementation of useful systems and products including their design and manufacture;
• Integrative ability – the recognition of engineering as an integrative process in which analysis and synthesis are supported with sensitivity to societal need and environmental fragility; and
• Contextual understanding – the appreciation of the social, economic, industrial, and international environment in which engineering is practiced and the competence to accept the responsibility for societal leadership effectively.

The repackaging of curriculum, one of the ASEE’s recommendations, was addressed by a NSF project by Texas A&M, which did this by integrating engineering science courses, thereby reducing the number of required courses (Ernst, 1989).

The suggestion to incorporate more information technology and simulation into the curriculum was problematic because the time at which an innovation is implemented to its dotage can be as short as five years, making the investment in the 5-year old technology almost worthless as new technology changes emerge. The trend currently is to go beyond technological innovations, which have a short life span, to flexibility that can serve curriculum changes that need to occur with time.
The Green Report of 1994

After World War II, the standard of excellence of engineering education was the research-intensive university. However, times have changed – society needs new models of engineering education. As mentioned as far back as the Mann Report, ASEE again emphasizes that engineering education should not be a single model followed by all. ASEE recognizes the need for a variety of models that correspond to the strengths of the institution of higher education and to the needs of the larger local industrial and societal community.

We live in a time of revolutionary change…Engineers create a huge potential for the private sector to develop national wealth. As noted by Richard Morrow, past chairman of the National Academy of Engineering, “the nation with the best engineering talent is in possession of the core ingredient of comparative economic and industrial advantage. (Dowell, Baum, & McTague, 1994, p. 1).

Although the American Board of Engineering Education (ABET) tends to follow rather than lead change (McKenna, Froyd, King, Litzinger, & Seymour, 2011), it is attempting to shape changes to engineering education through its accreditation process. The ASEE is one of ABET’s member societies. ABET realizes engineers will be serving as decision makers in technology and policy arenas. As such, ASEE and ABET recommends curricula that will (1) incorporate training in the basic engineering fundamentals featuring collaborative, multidisciplinary, and active learning geared to students’ learning styles; (2) utilize a multidisciplinary, systems perspective; (3) train in ethics and the impact of engineering decisions on society, economics, and the environment; (4) improve students’ communication skills; (5) improve the ability to work as an effective team member and also team leader; (6) recognize the advantages of diversity; (7) embrace challenges of globalization and working with diverse cultures and
business practices; (8) develop understanding and commitment to quality and continuous improvement; (9) and the necessity of life-long learning (p.2).

The Current State of Engineering Education

Globalization and the Internet have changed society more than anyone could have imagined, and has had a huge impact in the area of the distribution of wealth and the socioeconomic structure of countries. Tryggvason and Apelian (2006) explained, “[The] creation of wealth is related to a nation’s ability to make products that other nations want to purchase” (p. 14). Related to this concept of wealth and the production of products is the realization that with the Internet, subject matter experts are no longer the keeper of the expertise. With the explosion of the use of inexpensive computers, the internet, and common 3-D printers, the average person can now create almost anything they can imagine. For innovators, this ability can drastically affect their own wealth, producing products that larger companies cannot or will not produce and yet still fill a need.

Current issues faced as a global society impact what current and future engineers need to understand in order to create a sustainable future. Broadly speaking, knowledge of environmental issues such as EPA guidelines, and zero waste to landfill programs are just starting to be recognized as necessary training for the engineer in order to create sustainable designs. Health and safety, business and production decisions such as time-to-market, quality, and customer satisfaction also play a big role in the everyday decisions engineers must make on the job (Prados, 1998).
The day to day activities of the engineer of this new century require the possession of entrepreneurial spirit, imagination, and managerial skills to see needs, come up with ideas, and develop those ideas; communications skills to be able to work effectively with anyone, on teams anywhere on the globe; fluency in engineering to be able to understand not only what needs to be done, but has the knowledge and the tools needed to get it done; and knowhow to find any information they need and turn it into knowledge. These engineers must become lifelong learners because their careers will take on so many different directions. Ultimately innovation will be the key to our future survival in our careers and in the global community. “It is unthinkable that U.S. society can remain competitive and can sustain its present standard of living without a large number of people with the knowledge and know-how to innovate” (Tryggvason & Apelian, 2006, p. 17).

Clough (2004) summarized the importance of making engineering education relevant to the needs of society with the following words:

If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for a new wave of change…. Engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today. (p. 5).

**Amalgamation of Disciplines and Length of Study**

Clough (2004) wrote that since the late 19th century engineers knew that that solutions to problems often lay in the amalgamation of disciplines, yet when engineers are trained, they are trained in a single discipline. Courses in single isolated subject fields have become deeper and more specialized as time goes on and there seems to be no change in that respect for the future.
The depth of knowledge with which students are expected to graduate is increasing tremendously while the breadth is significantly decreasing. The challenge is to increase breadth in the engineering curriculum without increasing the length of time or the credit hours needed to graduate.

Pister (1995) believed the answer to this dilemma is for the engineering education system “… to become much more flexible and adaptable. Establishing interdisciplinary collaborations with science and liberal arts departments and business schools, in pursuit of both research and pedagogical developments, is an approach that could be useful” (p. 33). Pister went on to say, Collegiality, or the shared sense of mission, purpose, and values among the faculty… is essential if the actions and objectives of engineering education…are to be achieved. The new collegiality will be enhanced through organizing introductory courses through professors lecturing in each other’s courses – not only within the departments and the engineering school but across the entire university…(p. 33)

Another partial answer to the dilemma is to train students in mechatronics. A key factor in the mechatronics philosophy is the integration of microelectronics, computing, and control into mechanical systems, so as to obtain the best possible design solution and a product with a degree of intelligence and flexibility. Design of such products and processes, therefore, has to be the outcome of a multidisciplinary activity rather than an interdisciplinary one (Acar, 1997, p. 14).

Acar (1997) elaborated on the importance of multi-disciplinary understanding among engineers: The importance of mechatronics design must be stressed at all levels in the teaching and training of engineering, particularly in mechanical and electronic engineering. It is perhaps not possible nor desirable to convert every mechanical and electronic engineer into a mechatronics engineer, but the point is that traditional engineers must learn to appreciate the other specialist disciplines and hence to communicate with them at the product design stage. (p.19)

McKenna et al. (2011) stated that there was just a single transformational change to engineering education in the last 100 years.
This was the change from engineering curricula that emphasized hands-on, practice oriented courses to engineering curricula that emphasized engineering design derived in a deductive fashion from theoretical foundations in mathematics, science, and engineering science. (p. 5)

This change occurred because physicists and scientists, and not engineers, were the ones who predominantly developed the technology that won World War II. McKenna continued:

[This] forced engineers and engineering faculty members to take a hard look at how engineers were educated and to understand why engineers and engineering had not played a more prominent role in that effort. Emerging from this self-reflection were the engineering science-based curricula that have been the norm for the past 50 years. This transformative change in engineering education provides an example that counters broadly accepted assertions that engineering education cannot change. (p. 5)

Seely (1999) wrote that engineering educators are trying to undo the current imbalance of too much time spent in the curriculum on engineering science, which occurred in the 1950s and 1960s when federal funding for research was enormously plentiful. This funding drove an over-emphasis on incorporating theory into the curriculum, which was needed for graduates going into federally funded research fields, and it short-changed design work in the curriculum which was needed for graduates going into industry.

Change or Lack of It

It is not surprising that engineering education undergoes calls for change almost every decade. Society is changing fast. Innovation in manufacturing and in design is increasing at an extremely rapid rate.

Wulf (1998) pleaded for reform to take place. He observed, “We have studied engineering education reform to death. While there are differences between the reports … [they] are not great. Let’s get on with it! It’s urgent that we do so!” (p. 30). Wulf believed that
recommendations to modify engineering education have been shared and recommended, but little has changed. In fact, Wulf believed that graduating engineers are trained for the state of the world 60 years ago. There is so much that has occurred in technological change since Wulf wrote his article. At the time, he mentioned changes in the design of everyday objects into which microcontrollers have been embedded to create “smart” technology, the need to include discrete mathematics training, since it is part of the massive IT growth, new biological and chemical materials and processes, and globalization. In 2018, society is facing even more developments and challenges to the engineering profession including threat to personal liberties, the green movement to ensure the sustainability of our planet, engineering biology inspired design, customizable DNA, globalization of the workforce and the nature of work, climate change issues, and the fight against terrorism. Wulf wrote, “…our society is not only dependent on technology, it is addicted to technological change” (p. 30). He urged that there should be gender and cultural diversity in engineering. “As a creative field, without diversity, engineering cannot take advantage of life experiences that bear directly on good engineering design” (p. 29).

Rigor and discipline can become so extreme in engineering education that they become counterproductive to the extent that talented and capable students are not retained because they become alienated and lose interest (Seymour & Hewitt, 1994). Competition has also been a deterrent to diversity, because women and minorities, when exposed to a hostile, competitive environment, are likely to drop out unless they possess a high degree of self-confidence to combat the attitudes facing them.

Wulf (1998) stressed, “…we must question the value of narrow specialization at a time when engineered systems are becoming larger, more complex, and involve components and
processes from many more fields of engineering” (p.29). He recommended “Virtual fabrication in a high-fidelity simulated environment can greatly enrich the undergraduate experience” (p.30). Considerable technological change has indeed taken place if one looks at massive open online courses and the explosion of online education.

As one can see, change in engineering education has been called for since 1918. Prados (1998) was one of the first to call for the implementation of change rather than trying to continue to develop ideas for change.

McKenna, Froyd, and Litzinger (2014) reported, “The continuing calls for transformation for more than two decades suggest that previous investments have not resulted in breadth of adoption and systemic transformation” (p.188). Instead of systemic transformation of engineering education, the emphasis among education research is predominantly on specific curricular or course changes. They went on to say,

Considerable work has been done at a local level- that is, in the context of an individual faculty member, a small project team, a course or curriculum or institution; a particular pedagogical technique; or around developing a process or skill. However, changes in these local contexts rarely extend to ever-expanding spheres of influence inclusive of different cultures, institutional missions, and policies, types of leadership and values, and economic and political factors (p.189).

Although curricular techniques such as problem-based learning and peer-led team learning have the potential to lead to systemic transformation, systemic transformation is not addressed in the literature as much as local curricular techniques. What is needed is more emphasis on tools and approaches that can facilitate lasting, systemic change.

The degree of systemic change that has occurred might be ascertained by the percentage of students in one of more engineering majors that has been affected by the change, while the degree of sustainable change that has occurred might be ascertained by the length of time that a change has remained in place or led to further changes (Froyd, Layne, & Watson, 2006, T1B-3).
The goals suggested by Prados (1998) for the implementation of systemic change include the following:

Develop and use advanced educational materials grounded in learning theory and cognitive sciences research that promote student-based learning; provide learning experiences that meet the needs of students with different learning styles; stress active, collaborative learning with less dependence on lectures; integrate subject matter by showing relationships from the beginning of the student’s program; utilize emerging information technologies and network communications; and develop students’ capability and motivation to engage in lifelong learning. (p. 3)

McKenna et al. (2011) described the single most important aspect of system change as resistance to change, not the innovative change itself.

Overemphasizing the innovation and its advantages and ignoring or de-emphasizing the resistance usually leads to failure [to sustain systemic change]. Also, emphasizing the curricular or pedagogical innovation and ignoring beliefs, capacity, and input of departmental faculty members who will implement the change usually leads to failure… Promoting adoption at other sites requires a focus not only on developing the innovation, but more importantly a focus on taking into account elements of the system such as culture, beliefs, the goals, and agents involved. (p.6)

Froyd et al. (2006) constructed a seven-element framework for constructing curricular systemic change: (1) Determining the goals of the change, (2) describing exactly what is to be changed, (3) exploring the barriers to change, (4) determining available tools and mechanisms that can promote change, (5) discovering models of change, (6) identifying people who will implement the change, and (7) supporting the change by means of faculty development. It is left to be seen how change is implemented and becomes widespread as we approach the year 2020.

Strengths and Weaknesses in the Literature

Many suggestions in the early reports were made without any empirical study to back them up or without specific details about who the people were that made up the committees. For
example, the 1944 *Hammond Report* was the result of two meetings among 21 members of SPEE with a smaller group (of the same members or not is unclear) creating the drafts. The entire committee reviewed the drafts and they were “circulated among a large group of educators both in and outside of engineering education” (p. 590). There is no real indication of who the committee members were or to which organization they belonged, except for a listing of their names, nor the exact size of the “large group of educators.” In another example, groups of academics, members of professional societies, and people in industry were invited to advise a SPEE committee in the February, 1954 SPEE meeting. The resulting 1955 *Grinter Report* stated the attendees preferred nearly all of their engineers to be trained in scientifically oriented curricula… “The industrialists emphasized that their sales, manufacturing, operation, and maintenance engineers need strong scientific backgrounds just as much as do their research and development engineers and their designers” (p. 85). These suggestions are nebulous – they are suggestions without empirical evidence.

There continued to be a push to add advanced coursework to the engineering curriculum. Oftentimes, the very engineers making those suggestions did not use those advanced subjects in their own practice. Walker (1968) stated:

> Strong recommendations were made by practicing engineers for the inclusion of modern physics and physical and organic chemistry in future curricula despite the fact that many had no occasion to use such subjects themselves…From one half to one third favored such subjects as geology, biology, and astronomy despite low proportions indicating personal use of these subjects. (p. 436)

In addition, there is a call for treatment of topics that typically are taken over by industry. For example, the advice that graduates need knowledge of EPA guidelines, time to market, life cycle costs, and other issues of the same nature are typical knowledge the graduate learns as they
gain experience. There may be value only in the exposure to those concepts rather than spending time on them in a highly saturated curriculum since the job description of the graduate can vary greatly from one engineering job to another. For example, graduates who create and revise logic circuits may not place immediate value or return on investment in understanding zero waste to landfill until they move up in the organization to undertake corporate environmental challenges.

The current prestige of theory-based engineering will not easily give way to the practical as witnessed by the number of engineering students that are being told they have no choice but to study for a high-level, research-based degree. Perhaps the answer to this dilemma currently exists – the technology degree. However, many institutions have eliminated the technology degree.

Missing entirely in the literature is the different role that community colleges play in the reform of engineering education. Community colleges, by their very nature, are the ideal proving ground for changes to curriculum. They are not moribund by tradition, which can grind innovation to a halt; they tend to have small departments, which makes curriculum change and acceptance of innovation much quicker and easier; and teaching effectiveness is paramount. Community colleges take in the masses – from those needing remedial education to high-level students, and mold them into college graduates. This feat is not within the mission of research institutions. First of all, the research institution typically has selective admissions. The students are higher caliber than institutions with open enrollment. Secondly, professors at research institutions are expected to focus their efforts on research, with teaching and service being secondary responsibilities. The community colleges have a much greater emphasis on teaching.
The SLL paradigm has received scant attention from educational researchers, yet it incorporates many of the characteristics that have been recommended for change in engineering education, such as interdisciplinary coursework, inductive pedagogy, and the development of fluid competence.

Chapter Summary

In reviewing the reports on engineering education as a congruent whole, a few things remain consistent across the decades. The first is how every generation states that society is changing drastically, the pace of change is accelerating, and engineering education needs to keep up with the changes. Change in the early part of the 20th century revolved around changing from an agricultural society to a manufacturing one. Massive building projects were undertaken such as the Panama Canal, the Hoover Dam, and the nation’s interstate highway system. Major changes of the past few decades have emerged at the other end of the size spectrum - DNA engineering, Nano-technology, and revolutions in new materials (Pister, 1995).

The recommendations for change, surprisingly enough, have not varied in over 100 years. The reasons for the recommendations have changed. For example, the recommendation that students take more social science and humanities courses in the early 1900s was to give students a richer life. Today those same recommendations are designed to give students a better awareness of societal concerns and global issues that are so necessary for the solution to current and future design problems.

Across the decades, the most concern has been with engineering graduates’ lack of problem solving abilities and their lack of design experience (Seely, 1999). Other
recommendations consistent across the decades are that engineering education: (1) should keep a solid foundation on mathematics and physical science, (2) should incorporate more design practice, (3) should develop better communications skills in the graduates, (4) should have the highest quality teachers as instructors, preferably with an industry and design backgrounds, (5) and should instill the skills and habit for life-long learning. Additionally, from the 1970s and onward, the recommendation to move away from the lecture method of teaching and towards the incorporation of more cutting-edge technology and education research-driven instructional methods has been encouraged.

The recommendation that has changed over time is the incorporation of greater or lesser engineering science, depending on the time in history. Prior to World War II and up until the mid-1960s, the emphasis was on greater engineering science. At present the recommendation is for less engineering science, replaced by more practical problem based instruction. Seely (1999) summed up the situation of engineering colleges in the 1990s by stating that they were trying to correct an imbalance caused by too much emphasis on the analytical approaches of engineering science. In effect current reforms are responding to changes made in American engineering colleges in the years immediately after World War II, when engineering curricula first fully embraced an analytical mode of engineering science. (p. 285)

The second recommendation that has changed is the need for interpersonal skills and teamwork. Initially, at the start of the 20th century, the need was for engineering graduates to become leaders in industry. This emphasis has changed due to the rapid globalization of the world. The need now is for graduates to learn to work in multi-disciplinary teams as an effective team member, not only within the realm of engineering and science, but also in terms of working
with other professions and fields so that the graduate is flexible enough to work in a variety of disciplines as an integrated workforce rather than a segmented one (Pister, 1995).

Throughout the history of engineering education, there was dialog on the outcomes of engineering education and how best to achieve those outcomes. All reports emphasized that training in design, analytics, modeling, self-development, interpersonal skills, and so forth, should continue since engineering is always dynamic in nature, leading technological innovation into the future.

Finally, researchers in this new century are emphasizing ways to implement and sustain lasting change to engineering education. McKenna et al. (2011) suggested giving funding priority to research, development, and assessment of models of lasting systemic change in engineering education. The next chapter describes the methodology used in this qualitative case study of the implementation of SLL pedagogy.
CHAPTER 4

METHODOLOGY

“To state a theorem and then show examples of it is literally to teach backwards.”
E. Kim Nebeuts (as cited in Eves, 1988)

This chapter covers the research design and methodology for a qualitative case study. The study focus is on the implementation of systems level learning throughout the curriculum of a mechatronics program in a community college in the United States.

Case Study Design

A qualitative case study method was used in this research because there are numerous points of interest in the implementation of SLL. A qualitative case study is a particularly valuable vehicle to study innovative practices, focusing on the ‘how’ and the ‘what’ of innovations. It relies on interviews and site visits and is advantageous because it supports conclusions with multiple sources of evidence (Merriam, 1988). According to Yin (2013), the desire to understand complex social phenomena, such as the challenges of implementing SLL within an entire department, lends itself well to a case study. This qualitative case study heuristically illuminates the process and day-to-day challenges of the SLL methodology.

The objective of this research was to gain an understanding of how a community college implemented SLL. Some events in the implementation of SLL were historical, such as how the college decided to implement SLL. Other events were contemporary, such as how current
challenges in using SLL were addressed. This particular qualitative case study of SLL is important because few studies exist on SLL implementation in the classroom and its curriculum integration. The interview questions in this qualitative case study pertained to why SLL was implemented, according to stakeholders; how SLL was implemented, according to stakeholders; what stumbling blocks and best practices were identified by stakeholders in implementing SLL; and how stakeholders believed or did not believe the call for changes in engineering curriculum could be met by SLL. The intent of this single qualitative case study was to provide a thick description of the implementation of SLL pedagogy throughout a mechatronics curriculum in an American community college. As noted in chapter one, a thick description describes and interprets the thoughts and feelings of the stakeholders (Ponterotto, 2006).

Stake (1995) described two types of single qualitative case study designs in his *Art of Case Study Research*. *Instrumental design* focuses on studying something other than a particular situation – the issues within a particular case, for example. That focus will not be the situation in my research, since I will be focusing on a particular mechatronics department at a particular community college, and not the issues involved within that department. I used Stake’s *intrinsic design*, in which the case itself was chosen because of its value as an example of innovative curriculum implementation (Baxter & Jack, 2008). Yin (1989) described this approach as a holistic design rather than an embedded design because the case will be examined as one unit versus examining a number of sub-units within the major unit.
Site Selection

The community college chosen for this study is a multi-campus college and is located in a rural area. The associate degree is the highest degree awarded. Total student enrollment is 5000 among all of its campuses (college website, accessed on January 1, 2018).

The college is located in a county with a population of 40,500 and a median income of $36,000. The percentage of people living in poverty is 19%. The percentage of the working population (adults between the ages of 18 and 65) is 59%. Approximately 79% of adults 25 and over are high school graduates. Thirteen percent of adults 25 and over have a Bachelor’s degree or higher. The unemployment rate is 3.5% for the county (Data courtesy of the U.S. Census Bureau website).

According to Maxwell (2012), different types of sampling purposes lead to a researcher’s sampling decision. He goes on to say that most texts on qualitative research recognize only two types of sampling – (1) probability sampling: random sampling where every member of a population has a chance of being selected, and (2) convenience sampling, which is every other type of sampling; non-probability, non-random sampling and is frowned upon by qualitative researchers because it is not strategic or purposeful. But Maxwell contended that qualitative researchers recognize a third type of sampling that is quite often used and is valuable in qualitative research. This is purposeful sampling. Purposeful sampling is one in which “particular settings, persons, or activities are selected deliberately to provide information that is particularly relevant to your questions and goals, and that can’t be gotten as well from other choices” (p. 96). Maxwell noted that researchers concur there are large numbers of sampling types in research that are based on purposeful selection.
The community college in this case study was purposely chosen for its historical implementation of SLL. The site is known and respected as a Siemens Partner College (SPC) with Siemens certified instructors; thus, the site has implemented the SLL concept throughout the mechatronic department curriculum. (The attributes of a Siemens Partner College and a Siemens Certified Instructor are detailed in Appendices B and C. Note that this case study is not about the Siemens SLL training. It is about implementing a SLL curriculum in an American community college.) The site name is not important because it is an example of a model adoption of SLL; thus it did not have the problems associated with implementing a new pedagogy throughout a department that used a different approach to engineering education. The college developed the mechatronics program from scratch using the SLL approach.

All SPCs offer the same courses and content for the certificate and for the associate degree level technical coursework. A SPC’s course content is reviewed by Siemens to make sure it complies with the requirements of a Siemens Partner College.

This site offers a 16 credit hour certificate in mechatronics. The 16 credit hour certificate follows the Siemens recommended curriculum and consists of the following four core courses at three credit hours each:

- Electrical Components
- Mechanical Components and Electrical Drives
- (Electro) Pneumatic and Hydraulic Control Circuits
- Digital Fundamentals and Programmable Logic Controllers
A 63-credit-hour AAS in mechatronics is also available at this college. It incorporates the four courses above and adds the following six advanced technical courses, also at three credit hours each:

- Process Control Technologies
- Introduction to Totally Integrated Automation
- Automation Systems
- Motor Control
- Mechanics and Machine Elements
- Manufacturing Processes

The general education requirements fill out the remaining coursework for the degree. Course descriptions can be found in Appendix F.

The college has offered mechatronics courses using the SLL pedagogy for almost 10 years. The mechatronics program is accredited by the Association of Technology Management and Applied Engineering.

Participant Selection

As was the case in site selection, the choice of participants followed the purposeful sampling criteria. The faculty and the department administrators who were a part of the history and ongoing development of SLL at this college were selected for semi-structured interviews. Students in the mechatronics department of the college were not interviewed because the study focused on the long-term implementation of SLL pedagogy throughout a curriculum in a
department. Students typically do not have the long-term perspective or in-the-trenches insights of the implementation of such an innovative pedagogy.

Six out of seven full time mechatronics department members at this college were interviewed for this study. The seventh department member was employed at the college for less than one semester and did not respond to the request to participate. Of the six full-time mechatronics department members interviewed, two are administrators and the others are full-time faculty members. All participants worked several years in industry prior to employment at the college.

I designated the participants employed as administrators as Administrator Bates and Administrator Roberts. The remaining four full-time faculty participant members were designated as Faculty Austin, Faculty Elias, Faculty Taylor, and Faculty Michaels.

Administrator Bates was the first person hired to build the mechatronics program at this site college. Administrator Bates is a tall, quiet, middle-aged man with graduate and undergraduate degrees in mechanical engineering. He said he spent most of his working life in industry before coming to work for this college. His last position prior to his current position with the college was director of engineering and operations in the consumer products industry. He was with the college for eight and one half years at the time of my interview with him.

Administrator Roberts has a very friendly countenance and is easy-going. He has talent relating positively to staff and faculty and from my observations, they liked and respected him. He described obtaining his mechanical engineering degree and then working 17 years for a company that supplied components to the automotive industry. He worked his way up from
employee, to supervisor, to manager of manufacturing and engineering, to manager of all engineering for the company, eventually becoming the company’s general manager.

Administrator Roberts was one of the first people hired by Administrator Bates as a faculty member. Two years ago, he was promoted to the Director of Mechatronics when Administrator Bates was promoted to Dean of Business and Technology.

Administrator Bates and Administrator Roberts teach courses in mechatronics in addition to their administrative duties. Administrator Roberts spent six and one half years at the college at the time of my interview with him, initially as a full-time faculty member and then in his third year he was appointed as an administrator in the department.

Faculty Austin is a very likable, enthusiastic man who has been with the college as an assistant professor since 2012. He is passionate about what he does at the college. One can tell because he spends hours and hours outside of class to help students with their class projects, according to other faculty members. He stated he is in charge as a faculty advisor of students who are involved in mechatronics state and national competitions. In my interview with him, he described that he had an undergraduate degree in mechatronics. He also has a masters degree in aerospace engineering and a PhD in electrical engineering and his industrial background is as a system design engineer. His job in industry, he recalled, was that of a PLC programmer and designer of circuits. Faculty Austin worked in industry in a non-research capacity for two years and was at the site college for six and one half years teaching using the SLL approach at the time of my interview with him. While he was a graduate student, he taught electronics using the traditional approach at a major university.
Faculty Elias spent 50 years of non-research, industry experience, including spending two years in the military. He is a very likeable, capable, gregarious man who likes to tell people, “I’m one day younger than dirt. And I've been around a long time. Done a lot of stuff.” I was able to see him interact with students and it is obvious to me how much he likes and cares for all his students – and how much they liked and cared for him. He told me that he advises students in the following way:

I tell them, ‘What you need to be thinking about in terms of career development, is not what you can do when you're 20 years old, or 25 years old. You can work 4 days straight. You can walk on concrete [all day long]. You can never go home and take a shower, and you can do that when you're 20, 25. Your career path needs to be about what you don't want to be doing when you're 50 years old.

Faculty Elias had six and one half years of teaching using the SLL approach when I interviewed him.

Faculty Michaels is a tall, amiable man. In talking with him, one will find that he is very clear, direct, and to the point. It is obvious from the things he said in the interview that he has a great deal of respect for Administrator Bates and the other members of the department.

Faculty Michaels has been with the college for approximately five years. He told me that he spent 20 years in the military as a civil engineering officer, working with quite a few contractors in the area of facility maintenance and construction. After he retired from the military, he was hired by this college and has been with the college for five years, first as an adjunct instructor and then as a full-time instructor.

Faculty Taylor is a tall, thin man who has a passion for what he is doing at the college. One can recognize this passion from his interactions with other faculty and with students.

Faculty Taylor said he graduated with an electrical and electronics degree from overseas. He has
10 years of non-research industry experience both overseas and in the United States. He was with this college as a full-time faculty member for two and one-half years at the time of the interview.

I made a distinction between non-research and research capacity employment because in a non-research, industrial capacity, employees have a direct responsibility to keep production lines up and running and must troubleshoot and analyze problems quickly. That ability is what they are training their students to do. Individuals employed in a research capacity often do not experience the daily stress of working directly on a production line to troubleshoot production problems as quickly as possible. Research often takes years to bear fruit for the company. A research position typically does not have the high-level urgency to solve problems on the production line immediately. Administrator Roberts explained what it was like in industry:

For us in the Mechatronics [certificate] program, we're training ... our students … to be industrial maintenance [personnel] or engineers. As industrial maintenance [person]... their main job [will be] to keep the line up and running, and keep it running. That [will be] their day-in and day-out job. (Administrator Roberts)

A summary of the participants’ background is found in Table 1.

Table 1
Participants’ background

<table>
<thead>
<tr>
<th>Name</th>
<th>Job Function</th>
<th>Years in Industry/ Military</th>
<th>Years Teaching Using SLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bates</td>
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<td>8.5</td>
</tr>
<tr>
<td>Roberts</td>
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<td>Elias</td>
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<td>6.5</td>
</tr>
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<td>5.5</td>
</tr>
<tr>
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<td>2.5</td>
</tr>
<tr>
<td>Michaels</td>
<td>Full-time Faculty</td>
<td>20</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Insider/Outsider Researcher Status

Qualitative researchers can be insiders (a member of the group studied), outsiders (being a complete stranger to the group studied), or they may be situated somewhere along the continuum. There are advantages and disadvantages to each of the ‘sides’, which are described below.

Bonner and Tolhurst (2002) summarized the advantages and disadvantages of being an insider researcher. Their list of insider advantages include the savings in time in performing the research, because the insider knows the culture and the jargon; the tendency of the researcher to move away from stereotypes; and the ease at which acceptance of the researcher is gained. Some insider disadvantages include the possible bias towards findings, reliance on people with which the researcher feels comfortable, the tendency to pay less attention to routine and more attention to drama, and the researcher’s experience of role conflict.

Brannick and Coghlan (2007) made practical suggestions on how an insider needs to approach a study:

In considering insider-research projects, potential researchers, through a process of reflexivity, need to be aware of the strengths and limits of their pre-understanding so that they can use their experiential and theoretical knowledge to reframe their understanding of situations to which they are close. They need to attend to the demands that both roles—organizational roles and the researcher role—make on them. They need to consider the impact of organizational politics on the process of inquiry, who the major players are, and how they can be engaged in the process. (p. 72)

Bonner and Tolhurst (2002) described the advantages and disadvantages of being an outsider researcher. Advantages include a lack of attachment to the group under study, the observation of things the insider may miss due to familiarity, the possibility of being party to sensitive information due to the temporary nature of the researcher’s visit, and objectively
viewing the day-to-day activities and gathering data without judging participants’ capabilities or values.

Outsider disadvantages include the time needed to establish trust, the possibility of getting predictable responses rather than actual knowledge and attitudes, and the long time needed to understand the culture and jargon. These disadvantages can be offset, according to Bonner and Tolhurst (2002), by recording first impressions in field notes, such as the general feel of the organization, the routines, the staff members and their collegiality and teamwork; and ensuring the researcher is not impinging on the day-to-day routine due to the negative impact this could impart.

Many qualitative researchers, such as Breen (2007), emphasize that insider-outsider duality does not adequately capture the role of qualitative researchers. Breen argues, “The role of the researcher is better conceptualized on a continuum, rather than as an either/or dichotomy” (p. 170). This position is at the ‘hyphen of insider-outsider’, as Dwyer and Buckle (2009) term it. Dwyer and Buckle further explain,

As qualitative researchers we have an appreciation for the fluidity and multi-layered complexity of human experience. Holding membership in a group does not denote complete sameness within that group. Likewise, not being a member of a group does not denote complete difference…. Accepting this notion requires that noting the ways in which we are different from others requires that we also note the ways in which we are similar. This is the origin of the space between. It is this foundation that allows the position of both insider and outsider. (p. 60).

Dwyer and Buckle go deeper into the position of being at the “hyphen of insider-outsider,”

The process of qualitative research is very different from that of quantitative research… We are firmly in all aspects of the research process and essential to it. The stories of participants are immediate and real to us; individual voices are not lost in a pool of numbers. We carry these individuals with us as we work with the transcripts. The words, representing experiences, are clear and lasting… The intimacy of qualitative research no longer allows us to remain true outsiders to the experience under study and,
because of our role as researchers, it does not qualify us as complete insiders. We now occupy the space between, with the costs and benefits this status affords. (p. 61)

Northway (2002) said,

Researchers need to be aware that insider and outsider status are not always mutually exclusive categories and that perceptions can differ. They need to maintain a high level of critical self-awareness and remain alert to how identity can impact on the research process. (p. 6)

In other words, it is crucial that we are cognizant to how our researcher identity impacts our process of working in qualitative research and with qualitative data and that we identify what advantages and disadvantages lie in our positionality.

My researcher position is within the continuum of insider-outsider. Towards the inside end of the spectrum, I belong to the group of higher educators who are in their prime as instructors (as opposed to neophyte instructors); to the administration side of education as a chair of the mechatronics department and as a chair who also put a mechatronics program together ‘from scratch’, as did Administrator Bates; to educators who have significant industrial experience; and to the group of people whose training is in mechatronics. I studied a group of faculty members and department administrators that have multiple skill sets in common with me.

Towards the outside of the continuum, I came to the organization not knowing the people or the particular organization with which I became engaged. I was experiencing the interactions through the window of experiences with a community college in a different state, following different imperatives based on their state requirements, and being unfamiliar with the organization’s politics and personalities.

In summary, as I was being positioned along the insider-outsider continuum due to the circumstances in which I found myself, I tried to be careful to be flexible and open to new
directions the semi-structured interviews took. Those new directions were informative and contributed to the thick descriptions. I also endeavored to be circumspect about assumptions made and to realize the value of first impressions. I made notes of them in the reflective journal I kept in order to address concerns that may come up as I analyzed the data. In addition, I was watchful that my presence and identity had as little impact on the research as possible.

Data Collection

The first phase of the data collection involved identifying the institution to study, identifying sources of data, and getting approval for the study by the Institutional Review Board (IRB). The second phase involved contacting the institution and the subjects and asking them to participate. As part of this contact, the participants were told how and why their institution was selected for the research. Thoughtful selection was involved in the data collection phase, reflecting the best people to interview along with the best place and occasion to interview participants and visit the laboratory facilities. The third phase involved setting up interview times; traveling to the institution; distributing IRB consent forms (Appendix D) and collecting and obtaining signatures on those forms; and performing the research (Stake, 1995).

This research site is located hundreds of miles from where I live and work. Therefore, I scheduled the interviews and visit to take place during a single week to minimize the disruption my visit would cause to the participants and to the classes I teach. A total of five site visits were made during a one-week period, with the first visit on 11/07/2017 and the final visit on 11/11/2017. Each visit lasted between 6 and 8 hours.
The main data source was the results of semi-structured interviews of six faculty (four were full time faculty and two were both faculty and administrators) members. Interviews were conducted face-to-face at the case study site. The interviews lasted between one to two hours. The interviews were digitally recorded and were transcribed into a Word document by a transcription service. Confidentiality was maintained by using pseudonyms for all participants and by not naming the college or its state location.

When performing case studies, triangulation is needed – that is, multiple data collection methods to support research findings. The concept of triangulation involves including multiple data sources with their own strengths and weaknesses to perform the function of supporting the conclusions of the research, theoretically reducing bias (Maxwell, 2012). Denzin (1973) explained that by using triangulation, the flaws of one method can be outweighed by the strengths of multiple, dissimilar methods. Utilizing multiple methods to study a population, according to Merriam (1988), is a major strength of case study research.

Yin (1989) recommended six types of data that can be used as part of triangulation: archival records, direct observations, documentation, interviews, participant-observation, and physical artifacts. Therefore multiple sources of evidence were used to triangulate data in this study including interviews with faculty and administrators who were involved in the implementation of SLL; interviews with faculty using SLL in the classroom; examples of the curriculum used; viewing, taking pictures of, and taking field notes of classrooms layouts and laboratories with equipment used in SLL; and also viewing, taking field notes, and taking pictures of student projects developed in the context of SLL.
Interviews

Interviewing is valuable for understanding the goals and perspectives of people involved in the phenomenon under study. For this study, interviews were conducted of faculty and administrators to get the perspective of people who were involved historically in this implementation of SLL. The research focused in part on understanding the experiences of the people involved in the implementation of SLL, not to control or to predict that experience. As Seidman (2013) stated,

The researcher’s task is to present the experience of the people he or she interviews in compelling enough detail and in sufficient depth that those who read the study can connect to that experience, learn how it is constituted, and deepen their understanding of the issues it reflects. (p. 54)

Merriam (1988) observed, “it is necessary to interview when we are interested in past events that are impossible to replicate” (p. 72). The purpose of interviewing someone is to enter into their perspective – to ascertain their feelings, thoughts, intentions, and the meaning they attach to events (Merriam, 1988)

The interviews were semi-structured. There were two sets of questions – one set for the administrators of the mechatronics department, and one set for the full-time faculty who had a history at the site with SLL and who currently taught using the SLL pedagogy. These questions can be found in Appendix E.

I took Merriam (1988) and Stake (1995) recommendations to record the interviews and to discuss details for maintaining confidentiality of data and sources with the participants. I had the participants sign Institutional Review Board (IRB) consent forms as part of the IRB requirements. I provided them a copy of the consent form before the interview and a transcript
of their interview after the interview so that they could review the transcript for accuracy and to give them the opportunity to retract or correct statements. These actions were part of the member checking, which was intended to increase the authenticity and trustworthiness of this research. Both hard copies of interviews and electronic copies were offered to the participants. I followed the advice of Carlson (2010) to tell participants that I would use brackets to insert grammatical corrections if needed and I provided the participants with a sample of one of their own quotes from their interview in order for them to see what it would look like when complete. Finally, at the end of the interviews, the participants were formally thanked.

**Documentation, Records, and Field Notes**

Yin (1989, p. 86) stated: “the most important use of documents is to corroborate and augment evidence from other sources” (p.86). The utilization of documentation allows the researcher to gain new insights, discover new inferences and clues, and to possibly raise new questions about the subject studied. Formal and informal materials such as historical and current curricula, course listings, photographs that documented implementation of SLL, online documentation, lesson plans, and student assignments, were collected. Each document was related to the implementation and best practices of implementation of SLL. These documents were utilized in order to corroborate and augment evidence from other sources.

There is a disadvantage to the use of documents in research. First of all, documentation typically is historical and not produced specifically for the case study, meaning that documentation can be incomplete, biased, or inaccurate. On the other hand, precisely because documentation was created independently of the case study, documentation offers a glimpse into
the particular study under investigation without the possible distracting influence of having a researcher present as the events unfold. In summary, “Documents of all types can help the researcher uncover meaning, develop understanding, and discover insights relevant to the research problem” (Merriam, 1988, p. 133).

Garson (2014) advised researchers to identify a list of things to observe prior to the site visit to act as reminders while at the site. In my case study, items observed and viewed included the physical setting – how the classrooms and the mechatronics labs were set up; the participants, their role and informal interactions with one another and with students; the student projects and how the projects worked; and examples of curricula and textbooks used in the SLL classroom.

I wrote down field notes during the data collection phase. Emerson, Fretz, and Shaw (1998) described field notes as: “involv[ing] inscriptions of social life and social discourse. Such inscriptions inevitably reduce the welter and confusion of the social world to written words that can be reviewed, studied, and thought about time and time again” (p.12). My field notes were intended to be just that - an additional source of data that I could reference over and over as my analysis of the data evolved. It was intended not only to supplement the interview transcripts as I analyzed the data, but it also included notes about time I spent during my stay in the mechatronics department.

I set aside a time every day for introspection and used my field journal to write down personal impressions, subjective feelings, mistakes, confusion, brainstorming, ideas for follow-up, and a chronological record of the daily visits. The entries for each day were dated and coded. Some of my notes were condensed, such as background information which was taken both
during and soon after the interview. I also included such things as first impressions along with descriptions and photos of classroom layouts, lab layouts, and student projects.

Shortly after the visits to each classroom, lab, and student project location, I expanded my condensed notes to fill in gaps as much as possible to enable me to revisit the location in my mind during data analysis in the months to come. Spradley (1980) found that with condensed notes, the ability to recall events and conversations increased dramatically and the expanded account becomes a rich, thick-recorded experience.

Data Analysis

I maintained a reflective journal for introspective thoughts of my research progress and my development as a qualitative scholar. This reflective journal was used as another source of data as my research progressed. In the beginning, it consisted of items such as articles and quotes that could be useful to my research along with emerging ideas and directions the research could take. Towards the end of my research this journal included reflections such as the choices and decisions I made when analyzing data along with my possible biases. It helped to maintain transparency, as described below in the ‘Trustworthiness of Data’ section.

I used a transcription service to transcribe each interview into a Word document. I analyzed the interview transcripts multiple times. In addition, I entered the Word transcript documents into NVivo software, which allows a researcher to gather, analyze, and explore relationships between data such as interviews. The goal of the data analysis was to discover links between data.
Coding is a method that enables a researcher to see patterns in an ocean of data by organizing the raw text in various ways. *Open coding* was a first stage of my data analysis and involved looking for data within the interviews and field notes that initially might be potentially useful, interesting, important, or relevant to SLL implementation (Merriam, 2014). According to Auerbach and Silverstein, a “*relevant* text refers to passages of your transcript that express a distinct idea related to your research concerns” (p.46).

The middle level of analysis entailed uncovering themes. Auerbach and Silverstein (2003) defined a theme as “an implicit idea or topic that a group of repeating ideas have in common” (p.62). According to Auerbach and Silverstein (2003), “A *repeating* idea is an idea expressed in relevant text by two or more research participants” (p. 54). I used inductive analysis, constant comparison analysis, and axial coding whereby themes were challenged by the addition of new data and were then placed into free nodes, which were containers of coherent or related themes that could stand alone (Merriam, 2014).

The major themes in this case study revolved around the participant stakeholders view of why SLL was adopted, how SLL was implemented, what stumbling blocks occurred, what the recommended best practices were, and how participants saw SLL as an answer to changes in engineering education. The initial coding of the data was performed by open coding to the research questions (Appendix E).

Chronological and descriptive analyses were performed on the results of the questions ‘Why did the college look at implementing the SLL?’, ‘How were you introduced to SLL?’, ‘How were you trained in SLL?’, and ‘How is SLL different than other ways you have taught
engineering curriculum?’. The axial coding of these questions resulted in a free node entitled ‘Beginnings’. This free node was changed to a tree node with three children.

Open coding on the answers to what the first year of implementation was like and how the SLL training was disseminated resulted in the free node of “Implementation”. Axial coding supported three children.

The free node “Instruction” with five children was developed from the questions ‘What makes a class a good example of SLL?’, and ‘What do you do in the classroom that is unique to SLL?’. The question on stumbling blocks to SLL implementation resulted in the node ‘Challenges’ with six children and the question asking for effective and helpful practices used to implement SLL evolved into the node ‘Best Practices’ with four children. The free node ‘Outcomes’ with two children resulted from the question on how the participants knew SLL was working. Finally, the question on how SLL addresses or does not address the call for changes to engineering education resulted in the free node ‘Future’ with two children.

In summary, the data analysis used for the responses to the interview questions above resulted in the free nodes of ‘Beginnings’, ‘Implementation’, ‘Instruction’, ‘Challenges’, ‘Best Practices’, ‘Outcomes’, and ‘Future’. Axial coding was then used in each of these instances to develop the free nodes into tree nodes with the resulting children.

The final stages of analysis involved creating theoretical constructs which were woven into a theoretical narrative. Auerbach and Silverstein (2003) stated, “A theoretical construct is an abstract concept that organizes a group of themes by fitting them into a theoretical framework” (p.67). They continued with the definition of a theoretical narrative.

A theoretical narrative describes the process that the research participants reported in terms of your theoretical constructs. It uses your theoretical constructs to organize
people’s subjective experience into a coherent story. It employs people’s own language to make their story vivid and real. (p.73)

Auerbach and Silverstein (2003) stated the theoretical narrative is where the study ends, where the study is summarized, and is where the researcher reformulates the research concerns and theoretical framework. It positions the next study in the research area. I organized the themes into a consistent, chronological narrative, which documented the implementation of SLL at this college from its *Beginnings* to the *Future*. In Chapter Six, I positioned this research for further study.

**Trustworthiness of the Data**

Trustworthiness of the data during the analysis was ensured by ongoing analysis of the data and by the utilization of a reflective journal. The reflective journal helped to maintain transparency, which was especially advantageous due to my insider status.

A post hoc strategy I implemented to help insure trustworthiness involved member checking. I sent each participant a copy of their transcript to verify the accuracy of the transcription and to give the participants an opportunity to retract or rephrase statements.

Auerbach and Silverstein (2003) asserted that in order for qualitative data to be reliable and valid, it must be justifiable. In order for data to be justifiable, it must be transparent, communicable, and coherent.

*Transparency* is achieved, according to Auerbach and Silverstein (2003) by showing the steps that were involved in arriving at interpretations. I produced a transparent analysis by following the analysis steps in the data analysis section above. In addition, my reflective journal contributed to transparency since it served as a place to revisit my assumptions and
interpretations and was a repository for thoughts on my insider status. By following the data analysis steps described in the section above and by recording what I did to arrive at conclusions, my interpretations satisfy the transparency step of justifiability.

*Communicability* means that the themes and constructs developed make sense and can be easily understood not only by researchers and readers of the study, but also by the participants. I used member checking as part of communicability. Member checking allows interviewees the opportunity to review their interviews for accuracy and to comment on the themes I developed from their transcripts. I used the participants’ own words in this research as much as possible. I also described the themes and constructs to other researchers to verify that I was being understood.

Finally, theoretical constructs occur when repeating themes in the data are organized into more abstract ideas. When the theoretical constructs fit together well into a logical, consistent, organized narrative, it is considered to have coherence. Coherence is the third step of justifiability (Auerbach & Silverstein, 2003).

I attained coherence by the following actions: after the initial coding, constant comparison was used to develop themes from the interviews. The themes were then placed into the free nodes of ‘Beginnings’, ‘Implementation’, ‘Instruction’, ‘Challenges’, ‘Best Practices’, ‘Outcomes’ and ‘Future’. The layout of the findings, from the node ‘beginnings’ to the node ‘future’ organized the chronological narrative of SLL implementation, giving the story coherence. Thus, all three of the Auerbach and Silverstein (2003) criteria for trustworthiness (transparency, communicability, and coherence) have been satisfied in this case study.
Chapter Summary

The general research questions for this qualitative case study involved how systems-level learning was implemented according to stakeholders; what stumbling blocks were identified by stakeholders in delivering the SLL content; and what the most effective and helpful practices were in implementing SLL according to stakeholders.

Triangulation (multiple data collection methods) was used to support my research findings. In this qualitative case study, an amalgamation of field notes; a reflective journal; on-site interviews with faculty using SLL; interviews with faculty and administrators who took part in the change to SLL; and viewing examples of student work in the context of SLL were all used to support conclusions of my research. The integration of these multiple sources of data theoretically reduce bias (Maxwell, 2012). By using triangulation, the flaws of one method are outweighed by the strengths of multiple, dissimilar methods (Denzin, 1973). Utilizing multiple methods to study a population is a major strength of qualitative case study research (Merriam, 1988).

The raw data were reviewed with an eye toward various possible interpretations. Patterns in the data were searched for (Stake, 1995). Open and axial coding were used to analyze the interviews. A history and chronological analysis was performed to describe the implementation of SLL.

Analysis consisted of explicitly stating my research concern and theoretical framework, selecting relevant data for analysis through open and axial coding of interviews, discovering repeating ideas and organizing the repeating ideas into themes through axial coding, developing theoretical constructs from organized themes, and creating a theoretical narrative – positioning
the study for further research. The next chapter describes the findings of this qualitative case study analysis.
CHAPTER 5

FINDINGS

The schools above us are the schools that need to...be teaching the hands-on approach. I don’t care what degree it is. Chemical engineering, mechanical engineering, whatever it is, they need to adopt a systems approach, to whatever level they can afford or whatever time they’ve got to do [it]. (Faculty Elias)

This chapter presents the findings of a qualitative case study of a community college’s implementation of systems-level learning. The following themes resulted from the qualitative analysis described in the last chapter: beginnings, implementation, instruction, challenges, best practices, outcomes, and future. The findings are organized into a chronological narrative of SLL implementation at this college.

Findings on the Beginnings of SLL at the College

This section delves into how the mechatronics program incorporating the SLL pedagogy came into being at the site college. The history of the growth of the college mechatronics program is shared, including the initial support, the initial funding, and participant beliefs on why the SLL approach was chosen as the pedagogy to be used throughout the department.

Initial Support

Professor Elias began the description of the initial support for a SLL-based mechatronics department with the recent history of the manufacturing industries in this community. He spent
32 years with a local large manufacturing company before the company decided to move its manufacturing facility to another country 15 years ago. He described the local job situation at that time:

We live in a somewhat depressed, rural area. And so, there just wasn’t any [skilled] labor [force] here. In 2002 to 2005, we lost 16 major manufacturing facilities within 30 miles of us. [One major manufacturer] alone closed, and 2,000 people lost their jobs.

Without a skilled labor force from which to draw as people retired, Faculty Elias explained that the concern in the community was the remaining manufacturing industries would also either shut down or move away, taking the good-paying jobs with them. (The mean wage in manufacturing positions is approximately $25/hour, according to the Bureau of Labor Statistics [n.d.]). Keeping manufacturing jobs in the area was a critical issue.

Administrator Bates elaborated on the previous conditions in the local area. He described the conversations he had with local industry about what was (and still is) happening in the advanced manufacturing areas:

We need a good, sound, trained work force to help us get through the next 20 years. We have people retiring, that when they retire, those baby boomers, you know, there’s no one coming … to back fill them. That’s a big issue. The other issue is, all the technology that’s coming to industry to be more efficient [and] productive, is higher [end] technology.

Administrator Bates described a situation in which not only was it very difficult to find skilled workers, but those workers had to be highly skilled to be able to work on the cutting edge automation machinery of contemporary industry.

Before there was a mechatronics department at this college, according to Administrator Bates, the president of the college was very active in talking to local manufacturing industries about their needs for skilled workers. Administrator Bates said,
They [local industry] came to [us] and said, “We need somebody that is skilled in all of these aspects.” They need to know electronics, they need to know mechanics, they need to know fluid power, they need to know PLC’s and programming and ladder logic. They didn’t say we want a mechatronics [technician]. They just said we want someone who knows all these things. At first, we called that the millennial worker.

The college president was committed to addressing the needs of the local industries. Administrator Bates described that she told him she saw a seminar by a Siemens Technik Academie (STA) representative in the late 2000s on their SLL curriculum. She described it to him as being very hands-on and coupled to theory, a very different pedagogy from what was being traditionally taught in engineering education. It seemed to her to be the type of training local industry told her they wanted. Administrator Bates continued,

So, she came to me and I… was brought in to help develop it and get it going and to get this program started to support industry. The impetus came from industry in our area to do this.

Administrator Bates said the president then initiated conversations with a STA representative on how to implement the SLL approach and then hired him to continue those talks in order to build a new mechatronics department using SLL pedagogy.

**Funding the Idea**

Administrator Bates described how he was hired in 2009 to develop and teach the mechatronics program. He is now the Dean of Career and Technical Programs at this college. At the beginning of the process of developing a mechatronics department, Administrator Bates recalled:

We did a cost analysis and knew that it was going to take anywhere from $400,000 to $500,000 to facilitate purchasing this training equipment. It’s very advanced equipment… it’s a complete system. When [the college president] found this new type of approach and understood it’s going to cost some money to get the equipment, much less
the instructors, she talked to industry, we talked to industry then, and industry said, in collaboration with [the college], [the college] would put up $150,000 if the industry would put up $150,000.

To give the reader a general idea of how much money $400,000 to $500,000 is to a community college, I can describe my experience with department budgets. I am the chair of the mechatronics department in a community college in a relatively affluent area of the country. My entire budget for the academic year for supplies and repairs to equipment was $1300. If a single one of my PLCs on my automation cell were to need replacing, it would cost approximately $800 for a rebuilt one or about $1300 for a new one. One replacement item could practically wipe out my funding for anything else. The reader can see that $400,000 to $500,000 for a smaller community college in a depressed area of the country is a very significant amount of money.

Administrator Bates recalled how county businesses and industries led the drive for funding. They needed more skilled workers for their plants in order to keep the plants in the local community. They promised to raise $150,000 if the college would match that amount. In the end, stated Administrator Bates, the business round table raised $170,000 and the college contributed $150,000.

At this point, the college still needed about $80,000 to $180,000 to fund the program, so Administrator Bates applied for and received another grant through a state industrial development board. This grant mandated the requester invest $250,000 and the grant would match those funds. Since the college already raised $320,000, the grant was awarded to the college for $250,000, resulting in a grand total of $570,000 to build a brand new mechatronics program.
Once funding was secured, Administrator Bates described how he traveled to the STA in Berlin, Germany and took the Level 1 and Level 2 instructor courses. Then he developed his department’s curriculum in partnership with the STA. He continued working with the STA in ordering equipment for the lab and then started the arduous task of recruiting students.

From my experience, this high-level support for a new department helped pave the way significantly for obtaining resources (both in personnel and in funding) needed for the endeavor. The new department could have been built in other ways, depending on the structure of the higher education institution. One option would have been for an administrator or faculty member at the college to see a need for a new department. That administrator or faculty member would have to sell the idea to higher-level administrators. Even if the higher-level administrators were open to the idea, the administrator or faculty member with the original idea would have to do the majority of the hard work of raising money and getting additional support for the department primarily by themselves. Yet, before he was even hired, Administrator Bates’s college president was committed to helping the community and local industry by creating a mechatronics department that could produce graduates who could fill high-tech manufacturing jobs. She made funds available to help build this new department and, as will be described later, she supported the department as it continued to grow.

Advantages of the SLL Pedagogy from the Participant’s Viewpoints

The new department was now funded. The question becomes, why did the college president push for the SLL pedagogy to be implemented in this new department? Administrator Bates described earlier that the college president saw a presentation by the STA and believed the
SLL pedagogy produced graduates with the skills local industry said they needed. Labor gaps existed for maintaining high-tech automated equipment. She sent Administrator Bates to the STA in Berlin for both Level 1 and Level 2 SLL training in how to implement SLL pedagogy. He described the SLL pedagogy as follows:

It’s different in the fact that you start with the system and you explain the purpose of systems, the purpose of what you’re teaching, and how it belongs to a system, so that it gives reason or rationale for why… [They are] learning this. How will [they] apply this to work? So they understand… if you’re studying electronics, you don’t just study circuits. You study how circuits are applied in an overall complete system, because that’s the way it is in the industry.

As the participants in this study were hired, they were all sent to the Level 1 and Level 2 training. Each of the participants believed that the SLL pedagogy is far superior to the way they were taught in engineering school. The following descriptions illustrate the benefits of the SLL pedagogy from the participants’ viewpoints.

Administrator Bates emphasized that it does not matter whether a person is developing a product or a process, it all involves mechanical, electrical, fluid power, and controls. A person must understand the complete system. According to Administrator Bates: “When you start learning, and you see, at the very beginning, the application, you start understanding roles. That approach helps immensely with the training and the mentality of learning.”

Administrator Roberts described what he liked most about the SLL approach; that is, getting the instructors out of subject matter silos. He described how he can talk about mechanical systems in the electrical class, for example. He will bring other types of systems to the class and will show students how they integrate with the electrical systems. In the electrical class, they will dive deeper into the electrical systems while also looking at mechanical, fluid power, and controls.
Faculty Austin had experience teaching electronics in a traditional setting. He described how one faculty would be lecturing in a subject field and a different faculty member would be working with students in the lab for that subject field. When he taught in the university setting, his assigned classes were the lab classes. He described the situation as follows:

There’s a whole semester just taking electronics in theory. The [students] don’t even see a transistor. And then they take a lab in electronics by a different instructor who might teach them different [topics]. So this was a challenge, it was really a big challenge, you know. Because a lot of times… I would have students who don’t [know] about [different types of] transistors...I mean, it was difficult. There’s a disconnection between the theory and the practical things. The students…study things, they know the details of the mathematics, but they never saw a transistor in their life.

Two problems occurred in the experience described above. The first was a lack of communication between what the students learned in lecture and what they were supposed to learn in lab that week. Faculty Austin depicted how often the topics for the lab did not emphasize the topic in the lectures.

The second problem involved the disconnect between what the students were learning theoretically and what they were seeing and using in the lab. Faculty Austin explained how the students may be theoretically and mathematically learning about transistors in the classroom, but they could not identify a transistor in the lab. Part of that problem related to how the class topics and the lab assignments did not sync together. But another part of that issue was the inability of the theory instructor to link what they were teaching to real-world applications. The classroom instructors did not teach students how to look at things as a systemic whole.

Faculty Taylor described how learning the SLL approach changed the way he taught. He believed that once you understand the SLL approach, it “opens the door for all the other tools to
be used.” He described how it is possible to cover more information in the SLL approach because he is not adhering to a prescribed sequence of book chapters. He went on to say:

With the systems approach, you will be able to cover more [topics]. So you’ll be able to teach the students more [about] what they’re going to see or learn in Level Two, for example. So we would be able to cover more chapters in an easy way…. [The] system approach shows you the big picture of what you’re going to learn, what you’re going to do. How is it going to benefit you from the beginning? And then you build on that.

Administrator Roberts described the systems approach as something you learn when you work with equipment in industry. An experienced technician knows how the equipment works as a system and is able to troubleshoot it when problems arise. They have learned the systems approach on the job, but they don’t realize it. He explained:

So from a troubleshooting standpoint, going through industry, working with equipment, you have it, but subconsciously you don’t have it. Troubleshooting the [SLL] approach was just so much what our industry needed…and I became passionate about it. Just how they look at stuff from the standpoint of, “We’re not going to just think about it from electrical. We think of it as [an] entire system and how it’s networked.”

On being asked what the difference is between a traditional approach to troubleshooting and an SLL approach, Faculty Michaels gave this analogy:

If someone [came from] a traditional approach, strictly [they] went [into industry] as an electrician, a mechanic or a computer programmer. If they would have to go to a system and troubleshoot something, they would be just looking at their own level of expertise. In order to [do] the same type of troubleshooting [as an SLL-taught graduate], all three of them [electrical, mechanical, and controls technicians] would have to work collaboratively and look at each individual section that they’d been trained in as opposed to [a graduate] of our systems level approach that has that broad brush of knowledge that they would be able to focus on all aspects of what makes the machine run.

When Faculty Taylor was asked what the differences were in troubleshooting between traditionally taught students and SLL taught students, he had this to say:

[The] first thing is the time. Traditional [students] might take a lot of time to find the problem and fix it. We had, actually, quite a few [traditionally-taught] students…like that. They [were] all smart, but they never saw [a] PLC before. They know how to
program PLC[s] professionally. They know what [a] PLC [is], how a CPU works, but they…never even kn[e]w how to connect a sensor to it.

Faculty Austin explained how students who have only been taught theory can be given a simple contactor or an overload relay and will not know what it is. [Note: both a relay and a contactor are basic electromagnetic switches activated by a current in one circuit to open or close another circuit. The difference is that a relay is intended for low voltage applications and a contactor is used for high voltage applications.] Faculty Austin said he did not know the difference between a relay and a contactor when he first worked in industry. He continued:

One of the first things I saw [in industry] was the contactor. And it was for me, a new graduate, it was something I didn’t know. Of course, I knew how a relay works, but the contactor…I didn’t know them. It was [the same] for all people who graduated from engineering….So I think the mechatronics [SLL] from Siemens, it actually addresses this point strongly…Because students, they graduate from here, they’re ready from day one.

Faculty Taylor contributed to that viewpoint: “There’s a disconnection between the theory and the practical things. The students…they know the details of the mathematics, but they never saw a transistor in their life.”

Faculty Elias described the four-year engineering graduates and how important it is that when something goes wrong on a system, the graduate is not just performing a component swap. He explained,

If I hired an electrical engineer out of my alma mater, the love of my life, that electrical engineer [in industry]…would not do anything for two years, unless they had co-oped and already knew how to do systems. We put them with a senior maintenance person. We put them with a senior engineer. Because, they didn’t know a…relay from a contactor, or a switch from a transformer. And so, we took two years to get them up to speed and then they could go out and start doing stuff. So, I’ve always been about teaching systems and hands on. And not just the motor fails so let’s put another one in. I want to know why it fails, so I don’t burn up a $4,000 motor the second time.

Administrator Bates had this to say about graduates of four-year engineering schools:
Those [graduates] that have never worked on a system are timid. They (meaning the industrial employers) found a lot of the four-year [graduates] are timid. They soon learn, but it is something that I wish four-year education would focus on....They tend to really focus purely theoretical and that may work for someone wanting to go get a PhD, but someone leaving with a Bachelor’s or even a Master’s, wishing to go out and work in industry, if you’re going to start designing things like I did, you need to know how it’s made. You need to know the processes that are included and why things are designed a certain way. Typically right now, a four-year student learns that on the job. They don’t learn that in school.

Administrator Roberts discussed how the traditional approach brings in some applications. However, he believed that the general consensus of those who teach using the theoretical approach is that if you know the theory behind how something works, you will understand how to apply it. In his opinion, this assumption is flawed,

As United States instructors, I think we can do great on the theory... And we can even apply it to a system. But we go halfway, and we stop, and then we say, “Okay, if our student truly understands the theory, then they can apply it”...But that’s not the truth. In my four years of engineering classes, I didn’t touch hardly anything. I didn’t develop [those] skills. I developed the theory, but I didn’t develop how to apply it.

I did a lot of engineering hiring over the years. And I would tell [you], when I’d hire the young guys coming out of school, I would tell them, “Really, the first year, you’re not a benefit to me. I’m not saying that as a bad thing, but I want you to learn. And what I want to do is, I’m going to put you with a maintenance guy. And you’re going to go out for a year, and you’re not going to be in the engineering office. You’re going to be in maintenance. And then I’ll bring you back in.” Because they had to get that hands-on...application. And that, to me, is what the Siemens approach, really, the systems approach, brings.

Faculty Elias discussed how the four-year colleges are turning out people who cannot apply knowledge. He said,

Well, my take on it is, that the traditional student may be able to demonstrate theoretical knowledge and application, but in many cases cannot demonstrate competency in application of that knowledge. So therefore, the reinforcement of why and why not, and what would I do different, is much different than the traditional theoretical approach. The stumbling block is the four year schools that have a propensity to say this is a grease monkey program. And it’s not. I’d put my students up against any of their freshman or sophomore level students.
Administrators Bates and Roberts, along with Faculty Taylor all concurred and added that their two-year mechatronics graduates could out-perform junior and senior level engineering students on the job. They based their opinions on their experiences of hiring new engineering graduates.

**Summary of Beginnings**

Implementing a new cutting-edge program like mechatronics in an institution of higher education is not easy, nor is it cheap. Local industry was desperate for employees with mechatronics skills, so the college performed a cost analysis and found it would take between $400,000 and $500,000 to fund equipment for the program. Local industry was willing to help fund this new program. The college was able to raise $570,000 through a combination of grants, help from local industry, and funds from the college.

All participants were eager to describe the advantages of the SLL pedagogy. Participants described a disconnect that traditional engineering education creates by not strongly tying theory to practice. The end result, according to participants, are four-year traditionally-educated engineering graduates who need a year of on-the-job training before they are productive. Conversely, two-year SLL-educated mechatronics engineering graduates can be productive from their initial starting points.

**Findings about SLL Implementation**

This implementation section describes the curriculum development along with the faculty training in the SLL pedagogy. Descriptions and examples by participants of how SLL was implemented are included. Discussion is also found here regarding administrators’ viewpoints of
Curriculum Development

This research site had no mechatronics program or mechatronics curriculum in the beginning. This situation was advantageous because no history had to be overcome in order to start teaching the SLL method. Administrator Bates described the development of the curriculum as:

A blessing, I guess. I did not have to revamp anything. I had a clean sheet of paper. We developed the curriculum from scratch in collaboration with Siemens. They had an outline of what they wanted to be taught, to make sure that, in the systems approach and to get a Siemens Level 2 Certificate, or Level 1, you had to teach these certain things. We developed it from scratch with that in mind. I did not have to change any curriculum because there was no program. This was the first.

The Siemens outline Administrator Bates described above is a set of course outcomes and skills a mechatronics graduate should possess upon graduation, according to the STA. Administrator Bates took the course outlines and built the core courses from them with the help and guidance of the STA. These course outlines are located in Appendix F.

Once the initial courses were built and Administrator Bates taught the first few cohorts, Faculty Austin, Elias, and Michaels were hired to handle the increased demand for the program. Now the new faculty had to be trained in the SLL pedagogy.

Training the Faculty

Administrator Bates believed it is absolutely imperative to have the entire full-time faculty trained in the SLL pedagogy. This college has five full-time faculty members, all of
whom were formally trained in Level 1 and Level 2 SLL pedagogy. He also had most adjunct faculty formally trained at Siemens. This financial commitment is rather large on the part of the college, but the college president was in support of making sure the faculty had the training they needed. Each training event cost $6000 per person per level, not including travel costs for four weeks of training (two weeks for each level). The college currently has six faculty members trained at both Level 1 and Level 2, an investment of $66,000, not to mention the adjunct faculty members who were also trained in Level 1, according to Administrator Bates. The primary role of four adjunct faculty is to teach high school dual-credit mechatronics courses, and they also teach the first-year college mechatronics students at night. These four adjunct faculty members were sent to Siemens Level 1 training.

Administrator Bates attempted to have all adjuncts trained, but due to the $6000 price tag, that was not always possible. He explained,

It’s not mandatory that adjuncts be trained officially, but it is mandatory they work with trained instructors. All of our instructors are certified. We work with our adjuncts in telling them about the system approach, going over it. We spend a lot of time with that, making sure that they’re trained.

None of the faculty members was trained in the SLL approach before any of them started at the college. Administrator Bates implemented a process for new faculty which involved close mentoring. Faculty Elias described the process as follows:

I take those individuals after they get hired and I’ll spend two or three days with them. I’ll go through the [SLL] concept. We’ll walk through the lab. We’ll talk about it. I give them my PowerPoints. I give them my quizzes. So I try to supply them with everything they need not to have to reinvent the wheel. They can just focus on how [to] teach [using] the systems approach.

Faculty Austin added,
We tell them how to implement [the] systems approach, because a lot of instructors, they come in the beginning, they want to basically spend the time on paper and pencil and on the board. So we tell them to implement the systems approach, to concentrate on troubleshooting using the system here, the techniques we have learned in Siemens.

Faculty Taylor recalled his first days on the job. “All the instructors here were very helpful. They showed me how they implement it. How they teach it.” Yet, although the instructors are given the SLL curriculum and they have mentors, Faculty Taylor described how the SLL approach still did not make complete sense to him until he went to the Siemens training. The Siemens training allowed him to reach the insights needed to teach using the SLL approach efficiently and effectively.

Faculty Taylor became a believer in the SLL approach. He realized that a person could cover more material than someone using the traditional teaching approach because the instructor is continually building on similar concepts from other courses. He said it makes learning much faster and easier to comprehend for the student.

**Is SLL Actually Being Implemented After the Training?**

The old adage of you can lead a horse to water but you can’t make them drink could be applied here. One question to the administrators was how they knew SLL was being implemented by faculty in light of all the training that faculty were given. It is, of course, possible that all the money and time spent training the faculty would result in faculty just going back to the old chalk-and-talk ways of teaching anyway. The answer to this question was that it was possible but unlikely that faculty were going back to the old methods.

The faculty and the administrators interviewed found the following practices to be very helpful to administrators and instructors wanting to implement SLL. First, faculty members must
be hired with industry experience. Administrator Bates emphasized, “The success of any program is based upon the quality of your instructors. You can have the best equipment whatsoever, but if you don’t have good instructors, it will suffer.” Instructors hired with industry experience can see the advantages of the SLL approach since, as described earlier by Administrator Roberts, it is aligned with the way people learn troubleshooting on the job. The entire faculty spoke about how they all believed in the superiority of the SLL curriculum compared to the traditional way they were taught. They could see that relationship from having worked in industry. They explained how having industry experience enables faculty to describe to students how topics relate to actual automation systems with which they worked in industry.

An example of this relevance is a story Faculty Elias told his students when he was covering the topic of sensors in one of the mechatronics classes. He described how a machine in his company was malfunctioning only during certain times of the day at certain times of the year. He described how he analyzed the entire system to see how it worked (the systems approach) and then isolated the problem to a particular type of sensor that did not read inputs it was supposed to read. The problem continued intermittently even after the sensor was replaced. Eventually, he discovered that the problem occurred only when the sun was in a particular location when it would shine into the building’s windows at exactly the same spot as the sensing position of this sensor. Once he found the problem, it was an easy fix to cover that window to ensure the problem would not happen again.

This example depicts the richness instructors with industry experience can bring to the classroom. These stories and their outcomes are typically easy to remember. Instructors who describe industry experiences like this one tend to remember the situations and the outcomes
from these stories. Faculty who have worked in industry and who can talk about their industrial experiences give students a richer classroom experience than those who have never worked in the industry and can only talk about theory. Instructors who have worked in industry can illustrate concepts by tying concepts into the systems with which they worked in the past.

The second recommendation to help faculty adopt the SLL pedagogy was to assign an experienced SLL instructor to mentor every new faculty member. New faculty should also be encouraged to talk to others in the department when they have questions about implementing the SLL approach. Administrator Bates stated that it was mandatory that adjunct faculty work closely with trained instructors. The trained instructors spent a lot of time telling new faculty about the systems approach and going over it. Administrator Roberts described what he does:

I’d do a two or three day [workshop where]…[the adjuncts] would come in [and] we would actually do the systems diagramming. We would do several of the exercises that we learned in Siemens, but it was very condensed. And [we] just really talk more about the troubleshooting, and do some of the troubleshooting exercises where you take [components] off, have them put [them back] on. That sort of stuff.

The third recommendation to help faculty adopt the SLL pedagogy was to touch base with faculty regularly. Administrator Bates kept up with faculty on a regular basis. He explained that he talks with them and checks in with them often to make sure things are running smoothly. This approach has the added benefit of making sure a strong connection exists with faculty in case they have questions about how to approach a topic using SLL, according to Administrator Bates. In fact, every faculty, except Administrator Bates, since he was the only faculty member in mechatronics when hired, independently spoke about how they were supported by every other faculty member in the department when they had questions about how to implement the SLL approach. In addition, Administrator Bates spoke about the support he had from the STA when
he began to implement the new curriculum, since he was alone in implementing it. Administrator Roberts emphasized that he works one-on-one with instructors to make sure they have the support they need.

The fourth recommendation to help faculty adopt the SLL pedagogy was to give SLL curriculum to all new faculty – the lesson plans, PowerPoints, labs, quizzes – everything they needed to implement the SLL approach. Faculty can choose to ignore the curriculum, but they do so at their own peril of having to create the entire curriculum on their own. By giving new faculty the curriculum, all they need to do is to focus on implementing the SLL approach. As explained by Administrator Roberts:

The direction from the top is, “You need to use this.”...But, as you know, every instructor has academic freedom. So the biggest incentive that we give is.. We provide all the material. If you’re coming in as an instructor, and you say, “Oh, I’m going to teach this. I haven’t taught this fluid power class yet,” we’re going to go, “Here…I can give you the PowerPoints.” If they don’t want to follow the systems approach, guess what they got to do? They got to develop it all. So that, to me, is the incentive, is the workload that they’ve got to do if they don’t follow it.

The fifth recommendation to help faculty adopt the SLL pedagogy was to give full-time instructors and adjuncts time to immerse themselves in the method, to get to understand the equipment, and to get familiar with the labs during their first few months. Many of the faculty commented on the value of understanding and practicing the SLL approach before they had to teach it in front of a class. Experienced faculty members also traveled to the other campuses to help the less-experienced instructors run the equipment initially.

The last recommendation to help faculty adopt the SLL pedagogy was to have the new SLL instructors sit in on classes taught by faculty experienced in the SLL pedagogy to get a better understanding of how it is applied.
Administrator Roberts summarized the six practices described above as a very collaborative approach – one that they foster every day with each other. He said faculty members Austin and Taylor are very good with theory. He told me that when he needs help understanding some of the electronics theory, he immediately seeks out these two faculty members for help because that is their strength. He told me they often co-teach, since his own strength is the hands-on applications.

Faculty Austin emphasized that every instructor has done his best to teach using the SLL method. The first semester is difficult, he stated, but once they fully understand the system and are shown how to implement it, the SLL approach is the preferred approach.

Faculty Taylor told me about how he received the notes and the lectures and the help from all the other instructors. The lecture notes were different between instructors and what they chose to emphasize in class was different, so he had multiple examples of the SLL pedagogy he could choose from for his own classes. Overall, almost every instructor stated that it was a difficult transition in the beginning, but once they had time to assimilate the pedagogy, it became their preferred approach.

Summary of Implementation

Administrator Bates was trained at Level 1 and Level 2 at the STA. He worked closely with the STA to develop his mechatronics curriculum using the SLL pedagogy. I think it is important to note that all the faculty members were trained at least at the Level 1 after they had been at the college for about one semester. This training included adjunct faculty, in which they were immersed for two weeks in how to apply the SLL approach. In addition, the faculty were
given the curriculum, time to work closely with a mentor on the SLL technique, and time to become proficient in using the laboratory equipment. This commitment on the part of the college was substantial. The SLL implementation included the time and money invested by the college in training faculty, the help from faculty mentors, and the development of the existing curriculum. Implementing this new pedagogy of teaching mechatronics was greatly enhanced by this support.

Findings about Instruction

In this section, faculty discuss their experiences of implementing the SLL pedagogy in the classroom and the mind-shift they had to make. They discuss teaching using the SLL approach, class projects, the adaptive expertise resulting from the SLL pedagogy, and the assessments utilized in the SLL approach.

Mind-Shift

According to participants, teaching the systems approach is a mind-shift because they were unused to focusing on and teaching about an entire automation system at the start of all classes. They were used to starting the subject field with theory and the details of the smallest components. However, many faculty noted how similar the pedagogy was to what they unconsciously did when they were working with and troubleshooting equipment in industry, which they described as always starting with an understanding of how the system is supposed to operate. They explained that once they saw the analogies between how they learned the system in industry and how they could present the instruction to students using the SLL pedagogy, the faculty stated the SLL approach became very clear.
One of the newest instructors, Faculty Michaels, is a retired military officer who did not have teaching experience prior to coming to the college. He described his first few classes:

I chuckle because it was going from the frying pan into the fire...[I have] a bachelor degree and an aerospace background, a lot of fluid dynamics, math, physics. I had a good physics background, but I did not know what a PLC was to save my life when I got hired. It was a very, very steep learning curve to understand the equipment and the programming from it and the material as well as keep in mind the overall systems approach.

Sometimes...you get wrapped up into the theoretical side of things that you forget...how it goes back to the overall system. In the time I have in the class, I try to...always...incorporate how this relates to the overall system or the machine that we're focusing on.

[The SLL method is] more [of] an outcomes-based approach. With the systems approach, you try to keep in mind you got input, process and output. Linking all three of those together in a total systems area is...something I try to do. Sometimes I have more success [than] at other [times].

Administrator Roberts also did not have teaching experience prior to being hired at the college. I asked him to describe his first year of teaching:

Oh, wow, the first year....It was a lot of fun. I’ll be honest with you. Because I was able to get in the summer before I really started teaching....(They hired me in February, and I did not have to teach my class until the summer). Because I was really at a place of disconnect. I knew what I’d learned in industry, but I did not know how to connect it with academia.

This is our textbook for electrical class...it reminded me exactly what I went [through] in college...I mean, I went through Circuits I and II. And being a mechanical engineer, I was scared to death of electrical. So I was really trying to learn this, but I was trying to learn it from a traditional [approach]...Trying to go back and remember what I’d learned in Circuits. How to do the parallel circuit, and all that stuff. Went to the [Siemens] training, and all of sudden it was...a total release, because it was like, “Wait a minute, I’m getting caught up here. I can go back to what I’ve learned in industry.”

And I know how to connect it. I know how to take those troubleshooting things, how to use an ohmmeter, how to bring all that stuff back into it. And how to really make it relevant.

The [SLL] hands-on approach was just so much what our industry needed in this area, and I just became passionate about it. Just how they look at stuff from the standpoint of,
“We’re not going to just think about it from electrical.” “We’re not just going to think about it....” We think of it as entire system, and how it’s networked.

So it helped connect...how to apply the troubleshooting into more of the theory side of it....I liked how you lead-in with the system, and then the component, and then work down.

In industry, you’re taught that, but you don’t realize you’re taught it. So, from a troubleshooting standpoint, going through industry, working with equipment, you have it, but subconsciously you don’t have it. Does that make sense? So it’s always funny....When you’re teaching Mechatronics II, especially some of the seasoned maintenance guys who come into the course, who are getting their certificate or their degree, they’re already thinking about that side of it. But they don’t know how to vocalize it.

In other words, the seasoned maintenance workers know they need to understand what a system is supposed to do and how it operates before they can troubleshoot it. This understanding is what SLL brings to the classroom. The SLL pedagogy starts with the system in order for students to understand what the system does and how it operates before the instructor discusses the details of what the various components of that system are and the theory of how the components work. The seasoned maintenance workers who are in the SLL classes see the correspondence to how they approach their jobs and they can relate to the SLL approach.

The other instructors had teaching experience prior to being hired at this college and had an easier time shifting to the SLL approach. Administrator Bates stated: “It works for the student. It’s a different way. It’s not a harder way. It’s just a little different. It’s not like you have to put more time in versus the classical, it’s just a different way.”

Faculty Taylor described how it changed the way he teaches. “[The] system[s] approach show[s] you the big picture of what you’re going to learn. What you’re going to do. How is it going to benefit you from the beginning? And then you build on that.” He described how he teaches the PLC class differently now. Initially, he followed the textbook sequentially through
the first eight to ten chapters. After learning the SLL approach, he first starts with how the PLC is used in the system. He shows them a PLC in a working system. Then he re-arranges all the chapters to suit how a person would learn the concepts on the job – always focusing on how it is utilized in an actual system. In the traditional model, Faculty Taylor continued, an instructor would start with teaching about the CPU, the numbering systems, the logic combinations – essentially the theory first – and would be able to only cover about eight chapters in the textbook in a semester. With the SLL approach, the instructor can cover so much more “in an easy way,” said Faculty Taylor, including delving into the second year coursework, by tying everything back to the system.

It is well known by those of us who have studied engineering and who have taught engineering using the traditional approach (and of course those in other subject fields know this as well) that the layout of a textbook is often used as the structure of the course. Administrator Roberts described how this is not the case in SLL. He explained that the textbook is “not the structure of the material. It’s just a guideline to pull resources from….Really, the systems approach is the way I lay out my classes, now,” according to Administrator Roberts. Faculty Taylor added to that concept. He described how the textbook is kept “in my back pocket. It is a reference. It is the system that is the instructional material, not the textbook.”

Traditional textbooks, in my experience, tend to isolate components from the system and students learn about how the system operates only after they learn the theory of how the components work. The students learn the theory of how components work without first seeing the components in action. As described earlier in this research, the strength of the SLL pedagogy is the way the system is always at the forefront of learning. All participants experienced how
students comprehend the concepts so much easier and faster using the SLL method since everything is related back to how a system works and since students are given experience with the system from the first day in the classroom. When students learn about components, they learn about them only after they have learned how the system works, which is different from the way traditional textbooks are structured.

**Teaching Using the SLL Pedagogy**

Part of the requirements to becoming a Siemens Partner School is to have a fully functioning automation cell. It becomes the lynchpin in applying the SLL pedagogy. In a common automation-training cell, the cell as a whole “manufactures” an object such as a pneumatic valve. The process starts on one end with a parts retrieval station and then processes the parts differently at each station – indexing, gauging, sorting, torqueing, and so on until the valve is completely assembled. Each individual station, or module, is a complete system. Each module of the cell can be separated from the whole and can be operated on its own as a substation. Breaking the process down further, each substation can be broken down into third-tier subsystems (a sub-subsystem), including electrical systems, mechanical systems, and control systems. The final stage is to break each of the third-tier subsystems into individual components – sensors, bearings, valves, and other piece-parts.

In the SLL pedagogy, the system must always be the starting point in teaching about mechatronics. Faculty Austin described how the instructor starts with the system, then goes down to the theory, and then comes back to the system again. They then focus on
troubleshooting techniques. The key to the SLL approach is to always start with the system and keep the system in focus.

During the first and second week of his classes, Faculty Taylor said he familiarizes his students with the complete system, and he has the students operate the system. They see the sequence of operations to understand what the whole systems does. He says he then breaks the automation cell down in to modules and again has the students operate the modules to see the sequence of operations particular to that module to understand what the modules do. Then he discusses why those systems are used with other systems – how you can leverage the synergy of each sub-system as part of the whole.

I can show you a…ten-minute lecture, before we take them to the stations. I can show…you how we break it down into systems and then generally…talk about each system. And then after that….we take a system and we break it into components. So that will be in the third week. If I’m teaching, let’s say, electric, I will take the electric system, break it into components, like what we have in station one, what we have in station two. Break it into components, and then talk about the function of each component.

During the third week, students will be able to describe the functions of each of the sensors and other components. Faculty Taylor went on to say,

They’re not going to memorize the name [of the objects] in the third week, so I’ll talk about the functions. This is a height measurement sensor [for example]. This is [a] puck-present sensor. This is [a] position sensor. [I talk about] their functions. And then we…break it into components. And then [into] the functions of those components. And then how those components work and what malfunction we can have in that system. [Then we]…trace the flow of electricity, for example, if it’s an electric system. And then troubleshoot. Techniques for troubleshoot[ing]. All of it in general, or basic explanation[s].

And then after they troubleshoot, they should be able to run the system completely. So we tell them...go back to the system, as a whole, and…make sure you found the mistake. Make sure you troubleshoot it correctly. You [need to] run the system correct[ly], and let me see if it runs correctly or not.
The fourth week, we take one of those components and then we talk about its operation...more in depth. Malfunction[s], how it’s being connected in the system, [and] to the PLC. If it’s a sensor, how many wires it has. Some seem to have three wires and [are] color coated. Like a brown, black and blue. What are they, what is the symbol? And we [have] two different systems for the symbol. There’s the NEMA symbol, there’s the IEC symbol. So we show them both systems...If we have, let’s say, [an] electronic reed switch, we try to build one.

We take each component...[and] we talk about [its] operation and we talk [about] troubleshooting...We also print...the pictorial diagram [of] the components. So if I’m talking about read switch[s], I will print a pictorial diagram for them. The [students] will cut it [out]...on a piece of paper, stick it [on another clean piece of paper] and then try to draw lines [to demonstrate] how it’s connected to a PLC. [They] will have many different sensors, but they need to see the pictorial diagram also, so they can memorize it.

What Faculty Taylor described above is the SLL pedagogy – he first starts with the system, then shows students what the subsystems do and has them operate the subsystems, then shows students the components that make up the subsystems. He covers the design function of the component in the system, its physical properties and characteristics, causes of malfunctions, tracing the signal flow, and on to system troubleshooting strategies.

Faculty Taylor also described the fluidity of the SLL pedagogy – how he lectures for a short time, then moves to the lab to apply the lecture points, then goes back to the lecture to cover more ground, then back to the lab. He said sometimes his class goes to the lab two or three times in the course of a single class. It is a flexible teaching system, utilizing the actual systems and components to drive the learning. He also takes advantage of system animations and simulations to demonstrate concepts in the lecture and in the lab.

The Siemens STA developed simulations and animations to use in class for those who went to the instructor training. The simulations demonstrate and simulate a properly functioning system with all inputs and outputs. The same system is then simulated with operating problems so that the students can analyze what is not functioning. The students are able to hone their
troubleshooting skills online. These simulations are not high-end, expensive software. Some simulations are video-based, showing an actual system running with written dialog alongside the video to describe the actual system and the malfunctioning system. Other simulations are PowerPoint-based using the animation feature of PowerPoint to make various parts of the animation move. They can be created by any instructor with some PowerPoint technical savvy. They have been very effective in my classes to teach students how to approach troubleshooting mechatronic equipment.

Faculty Austin explained how he also likes to use the simulations in class. He made the analogy of an airplane pilot using simulation for training purposes: “I like…the simulator….Imagine…me learning [how to] pilot…a plane. The first thing they do, they put you in a flight simulator to simulate the plane….You’re on a plane from day one.” In other words, the simulations combined with the SLL pedagogy can get students troubleshooting equipment, at least virtually, from the very first day.

The site college offers some mechatronics classes in a fast-tracked schedule. Administrator Roberts described how the setup of the accelerated mechatronics schedule aids the SLL pedagogy. Students are working in a single class from 8:00-1:00 pm every day for four weeks. Once the students are in the second course, the instructors incorporate material from the first four-week course into the subject matter of the second four weeks. The third four-week class incorporates material from the first and second four-week classes. By the time the students reach the fourth, and last, class in the semester, they have integrated all the knowledge from the entire semester. Administrator Roberts explains:

What’s nice about it, [is that] I’m constantly pulling other stuff out of other classes. Because in the end, you should know the system….And I hear some students say, “Well,
it’s not fair.” But by the time they get through the two years, they know it’s fair, because this is life. This is what you’re going to do in the industry.

Faculty Elias described how he also likes their accelerated schedule of classes because the students are immersed in mechatronics courses for five hours every day. Their attention is not divided between other subjects they are required to take, like general education coursework.

One of the difficulties the college has learned to overcome is the lack of adequate trainers to serve all the students in a class at the same time. One would think it becomes hard not to lean on the theoretical aspects of the subject matter – the chalk-and-talk method – more heavily if there are few trainers. However, Administrator Roberts stated that this is where the SLL approach really shines because an instructor can bring in different exercises from a variety of subject matter areas to supplement learning in the main subject matter. He gave an example of working on the section on gears for the mechanical systems class. Group A will be performing a troubleshooting exercise on the main mechanical trainer on the principle covered in class that day. Group B will be using conveyors on the automation cell to figure out the gear ratios. Group C is orchestrating a gear system setup. Group D is performing an electrical exercise related to the mechanical system. The fluid power station can be used to perform a relay logic exercise that pertains to how the mechanical system integrates with the PLCs.

Finally, since the department wanted all students to know something about CAD, but it is not a course requirement, Professor Elias described how he has the remaining students working on a CAD project utilizing a basic Solid Works textbook designed for a quick overview of how to make CAD drawings. He explained that the students work on different parts of a system for a specified period of time, and then they move around as the main subject matter trainer becomes available.
Faculty Elias described how the trainers come with lab curriculum, but those labs are “cookie cutter labs. Take wire one and put it in port A, and plug it into port B, and read instrument C.” He took the trainer labs and expanded on them:

For instance, in the motor lab this semester, I had them [build] a compound wound motor, and I had them vary field winding voltage and the armature winding voltage and plot it out. Then they had to get up in front of the class and explain the curve and what the differences were. We did that with the series and shunt. But specifically the compound wound guys had to explain why this curve looked different than [the series and shunt] curve[s]. So I think that’s much different than a traditional [engineering] lab, where you just collect data and hand in your lab report. Some graduate student grades it, and you move on.

The [engineering] schools need to…be teaching the hands-on approach. I don’t care what degree it is. Chemical engineering, mechanical engineering, whatever it is, they need to adopt a systems approach, to whatever level they can afford or whatever time they’ve got to do.

Faculty Elias gave an example of how he teaches using the hands-on approach. He described his class session on motors. Students first learn how to wire a series-wound, compound-wound, and shunt-wound motors (These windings are different types of internal motor designs). Then they run those motors and collect data using a tachometer and clamp-on meter and plot the data. Then when Faculty Elias talks about the series wound curve, the students can see that their data fits the theoretical model of that kind of motor.

The Level 2 coursework is different than the Level 1 training in that it veers toward the theoretical, as can be seen from the course descriptions in Appendix F. Faculty Michaels described his experience with Level 2 coursework:

With Level 2, it’s a lot more technical, a lot more physics intensive with the math, so I try to quickly go down deep into how that component or what I’m teaching them relates to a certain component in the actual system. Sometimes, again, it gets lost in the weeds. You get wrapped up into the theoretical side of things that you forget sometimes how it goes back to the overall system. In the time I have in the class, I try to somehow always try to incorporate how this relates to the overall system or the machine that we’re focusing on.
In other words, by the time the students are taking Level 2 coursework, they have seen how all the components work and how they are melded into a system. Level 2 courses bring that training forward by incorporating higher-level math and physics into the topics of the Level 2 courses. Even so, the system is still the focus of the Level 2 courses.

**Class Projects**

Most traditional class projects are usually reserved for the middle to end of a course. This college has implemented projects into every week of class in some of the classes. Faculty Elias explained that the students have a number of projects they need to complete in a certain timeframe. They are given the list and description of projects. He explained how this project work arrangement helps when there are not enough equipment trainers to have everyone working with the trainers at the same time. While one group works with the trainers, the other groups work on other projects.

An example of a class project is the project assigned in Administrator Roberts’ Level 2 manufacturing class. He described how this works: The students organize themselves into teams, and then they pick their own project manager. The team is given $2000 to $3000 (real money) and a real engineering problem to solve. The students have ten weeks and the mechatronics knowledge they gained over two years to build a piece of equipment and run it.

The student project managers meet with Administrator Roberts 30 minutes before class every week to discuss what they are going to do that day. Then the students run the class. Administrator Roberts acts as a consultant. The students work from a Gantt chart showing who will be doing what every week. Administrator Roberts critiques the students and wants them to
work on their weaknesses during the project. If a student is a hands-on learner, that student is
given tasks that are less hands-on, and vise versa. At the end of the class, the students summarize
what they have accomplished and what they need to work on during the next session.

At the end of ten weeks, engineering managers from area industries are invited to a two-
hour presentation. The graduating students show the visiting engineering managers what they are
able to do. Administrator Roberts goes on to describe the results of this presentation.

The real key is, it’s opened up jobs. Because what we have is, we bring in these
engineering managers. [The students] give that two-hour presentation to them, and I tell
the students who are still looking [for a job], I say, “Have your resumes ready.”

And so, at the end, I say, “This student here, this student here, this student here, still
looking for a job.”… And then I have certain engineering managers saying, “I want that
student.” And I’ll say, “Well, they’re already working there.” They say, “I don’t care. I
want to talk to them.”

The engineering managers get competitive in trying to hire students in the group.

Administrator Roberts explained that some of the $2000 to $3000 to invest in the
students’ projects comes out of the budget and some comes from local industry donations.
However, the college is doing some “train-the-trainer” work in mechatronics. He convinced the
college to reinvest the money the college receives for train-the-trainer into the mechatronics
program. The train-the-trainer money funds the majority of the cost.

Administrator Roberts described how this project is in actuality a Level 3 (third- to
fourth-year) engineering project. It is what the local engineering university is doing after the
third and fourth years of study. This community college has trained students using SLL
pedagogy to enable them to perform this complex design project at the end of only two years of
study.
Handlungskompetenz

Handlungskompetenz is the ability to learn about a topic and apply that learning to similar systems, even if the systems look quite different. It is adaptive expertise. For example, if a student understands how a pneumatic system works, it should not make a difference whether that student sees one manufacturer’s pneumatic system or another manufacturer’s system. They may look quite different due to the manufacturer’s design. The components of a particular system are the same. If students have Handlungskompetenz, they will be able to apply the theory and hands-on knowledge of troubleshooting to any pneumatic system no matter what the components physically look like or how the system is designed. Likewise, a pneumatic system has many parallels to electrical systems. Faculty Elias stated:

Well, in the systems lab, we’re always going back to previous learnings or projecting forward to new learnings. We’re always talking about one is equal to the other. The wiring in the electrical is the same as the plumbing conduit in fluid power.

Faculty Austin added, “You need to know the theory, how it works in the background, how it works in detail, and you need to see more applications. The more applications you see, the better. So really it needs both [theory and hands-on applications] to work together.” The emphasis among faculty members was that SLL graduates would go into their first jobs knowing, for example, control systems are control systems, no matter who manufactured them or what they physically look like. Faculty Michaels explained that they see “a gear is a gear, a belt’s a belt, a motor’s a motor. Even if it’s making a different item…there should be no difference in [our graduates’] troubleshooting skills from one system to another.”

Faculty Michael’s point is very important. Handlungskompetenz is the primary outcome of the SLL pedagogy. Students learn the function of components and how they work in a system
as a whole. It does not matter whether one gear looks different from another gear or that one motor is different from another motor. They still perform the same function in a system. Knowing the function of a system and the role of a component in the system, a knowledge that SLL develops in a student, enables the student to develop a high degree of Handlungskompetenz.

Assessment

Faculty Elias discussed the assessments in the pneumatics and hydraulics class. He stated that in one exam, students are given four fluid power schematics. They have 25 minutes to physically construct the fluid power circuits and collect the data on the system by observation, reading gauges, reading how quickly actuators move, and recording when motors turn and stop, along with other data. Students have to understand how and why they are performing objectives in the labs in order to do well on the assessments.

Written assessments are also conducted. Faculty Elias described the assessments in the PLC class. Students are given a description of a process. They have to construct the step diagram and a process flowchart, program the ladder logic, and demonstrate the program works. “It intimidates them, as does anything that is new or challenging” said Faculty Elias. Faculty Austin said the systems approach is overwhelming for students initially. But by the end of the year, they know the systems well, and they find it easy to understand and troubleshoot.

Faculty Taylor gave an example of the assessments he uses in his class. The lab portion of the assessment relates to troubleshooting. The lecture portion covers the related theory. He may give them a picture of a PLC and tell them that one of the outputs from the PLC was
measured, and it is zero volts. In addition, the actuator is not actuating. He asks them what the probable causes are and what the recommended actions are to solve the problem.

Faculty Michaels described how his assessments are all-encompassing systems exams that bring in other subject matter knowledge. He goes on to say,

All these courses that we teach here, probably more so than engineering, build on each other…There’s a lot of overlapping with our courses, and I think our assessments, especially with the Level 1 and Level 2 Siemens exams, builds on that. [The assessments are] a lot more computerized and very comprehensive, mixing up the electronics and mechanics and sensors, trying to put them all together. I would just say…the assessments [are] comprehensive, focusing on the subject we’re trying to teach but overlapping in some other areas, too.

Faculty Michaels mentioned that there are a number of external assessments to ensure the students are learning what they need to know for engineering jobs. The first one he mentioned was the students passing the world-renowned Siemens mechatronics test. Faculty Michaels stated the college uses their students’ results of that worldwide exam as part of the assessment of student learning. He describes other external assessments that students take, which are the entrance tests that Nissan and Bridgestone use for potential new employees. Faculty Michaels explained that the department meets with the hiring managers of those companies to see how their students did on the entrance exams as a check on the knowledge and skills their students should have at the time of graduation. The department uses that feedback to hone the coursework.

Administrator Roberts added, “What’s really nice about that is my mechanical final. It…has electrical questions on it, because I know they’ve already [gone] through it. Because, as I tell them, you’re a mechatronics guy [sic]. You should know it all.”
Summary of Instruction

Participants described their initiation into the SLL pedagogy as a mind-shift because they were unaccustomed to focusing on teaching about the entire system at the beginning of every topic. As described earlier, the way the system worked as a whole was traditionally taught at the end of a semester. However, many participants noted how similar SLL was to what they unconsciously did when they were troubleshooting equipment in industry. Once they saw the analogies, many participants stated the SLL pedagogy became very clear. The students are able to build on their knowledge every day; the mechanical knowledge builds on the electrical, the electrical knowledge builds on the fluid power knowledge, and the fluid power builds on the controls knowledge. In this section, Faculty Taylor described how this buildup enabled instructors to cover many more topics than they could if they were using the traditional approach to teach the class. Numerous examples of how the participants taught using SLL pedagogy were described in this section so that the reader can get a better grasp of what it means to teach using SLL pedagogy.

The college overcame the lack of enough of the same trainers for all students by utilizing the systems approach to have them working on different trainers in each class. Class projects were incorporated into the training with an actual cash fund students could use to physically build the systems they designed. Towards the end of each year, the results of those class projects were presented to local employers who often offered the graduates jobs within their companies right on the spot due to mechatronics skills the graduates demonstrate in their project designs.

Instructors described the students’ adaptive expertise resulting from the SLL approach in which students have the flexibility to quickly adapt to new and different systems and situations.
in a self-directed way. Finally, faculty explained the type of assessments they use in the classroom for the SLL instruction.

Findings about Challenges

Getting the new mechatronics program up and running involved several challenges, such as the initial cost to start a new technology-intensive lab program, getting the word out about the new mechatronics program, having enough training equipment and space for the labs, hiring qualified faculty, recruiting and admitting students with higher pre-requisites into the associate degree program, the initial opposition from the State Board of Regents (a governing body that oversees public education in a state), the opposition from higher education, and keeping up with changing technology. Each one of these challenges will be addressed in order.

Cost

As mentioned in the section, Findings about Beginnings, a cost analysis to create a mechatronics department was performed by the college in 2009. At that time, it was determined that between $400,000 and $500,000 would be needed to develop the curriculum and purchase necessary lab equipment to run the new mechatronics program. The college was able to raise a total of $570,000. The college invested 25%, local industry invested 30%, and an industrial development board awarded the college 45% of the $570,000.

The specialized SLL training at the STA was a separate cost. The college invested $84,000 to train faculty there. The training cost $6000 for each faculty member at each level. All full-time faculty members were trained in Levels 1 and 2 and adjuncts were trained in Level 1, because adjuncts were only teaching Level 1 coursework. In addition to training costs, an annual
A $3500 fee was charged to continue as a Siemens Partner College. The Level 1 and Level 2 student certification exams cost $150 each. This site college was convinced of the superiority of the SLL approach in training mechatronics graduates; thus, they were willing to pay this cost. The majority of mechatronics graduates have a job at the end of their program – or even before they graduate. These financial burdens are substantial for a college to assume.

**Getting the Word Out**

In my experience, one of the most difficult challenges in getting a new program off the ground is the task of recruiting students. I found that the skill set academics have is typically different from the skill set needed to be successful recruiters. Successful recruiters tend to have extrovert skill sets that academics may not possess. In addition, the amount of time needed to recruit students is significant. This time spent is in addition to the time needed for all the other responsibilities of department chairs, such as maintaining laboratories, ordering supplies and equipment, hiring and mentoring full-time and adjunct faculty, scheduling classes, ordering textbooks, and so forth. Administrator Bates concurred. He stated,

> Well, the biggest challenge…is getting the word out that you have this new program. So, I went to talk to a lot of companies since I have a lot of contacts with industry already, having worked in industry, I knew a lot of these folks already. I would talk to the industries, explain the new program that we have, I would do radio shows, TV shows talking about the program. I was invited to a lot of radio talk shows and to talk about it because they had heard about it and it was interesting to the radio station to pass the word, and I did a lot of TV shows.

> As indicated from the quote above, he spent a great deal of time advertising the program through radio and television. This access to radio and television for this type of recruiting may not be so easy in other parts of the country. It may also be expensive and be out of reach for many institutions of higher education.
Administrator Roberts described the situation when some industries heard the program was a Siemens-certified training program. He described how some industries did not see the need for the Siemens certification because they said they did not use Siemens equipment. He recalled:

First and foremost, we said, “Okay, we’re using the systems approach. We’re using Siemens certification.”…What Siemens is known for is PLCs. So [industry’s] response was, “We don’t use Siemens PLCs. Why do we need this?” And…it took us about three, three and a half years to get industry to understand it’s not Siemens PLCs. We learn Siemens PLCs, but a PLC is a PLC. It doesn’t matter if it’s on Allen Bradley, Siemens ... The principles are there. [The term PLC stands for Programmable Logic Controller. These are the small industrial computers that control machinery and processes.]

But the key is the systems approach, and understanding that troubleshooting and all those sorts of things. So it took us a while for industry to start realizing what it was, and seeing the need that they could use. But then, once they realized it, and they got a few of the students in, then it’s like, “Oh, this is what we want.”

Administrator Roberts had to get industry to understand that it is the SLL pedagogy – training for the Siemens certification – that creates graduates who are familiar with all kinds and brands of systems, not just Siemens. As Faculty Michaels said in the section on Findings On Instruction: “a gear is a gear, a belt’s a belt, a motor’s a motor. Even if it’s making a different item…there should be no difference in [our graduates’] troubleshooting skills from one system to another.”

I show students in my classes that a PLC is a PLC just like an Apple computer and a Windows computer are computers. A person who knows how to use computers can use either one. The operating systems may be different, but in general, a personal computer is still a familiar device that most people can jump right in and use, no matter whether it is Windows-based or Apple-based. This adaptive expertise in the mechatronics area was exactly what industrial representatives said they were looking for in employees.
Another challenge, according to Administrator Bates, was convincing counselors, potential students, and their parents that this curriculum was not just another vocational-technical program. Administrator Bates described the misunderstanding counselors, students, and parents initially had about the mechatronics program:

The biggest stumbling block was trying to convey this isn’t just a vo-tech kind of education. This is a much more technical, intense, ‘cause it is. It really gets into the theory heavily. You learn a lot more about how systems work from the analytical aspect and so, in the very beginning, some people thought it was just, you go in and just take a shop class, if you will, or something like that. But, they soon learned it was a lot more than that.

We have issues with trying to convey to high schools because it was in the Career and Technical Education. It wasn’t just a program for someone, well, they can’t go to college, so you go here. A lot of them looked at it that way. You got to have sound math skills to get through mechatronics, pre-calculus, I mean, it’s analytically challenging. Trying to convey to them that it’s something that you really want to do. It’s not a alternative path. I don’t want to go to college, or I can’t go here, therefore this is my second, third choice. It should be a first choice for a lot of them if you really, you want to get a good, sound education, and get a real good paying job.

As described in Chapter 1, the Level 1 certification is designed for students who have completed their first year of mechatronics education. The Level 1 curriculum is designed to take someone with no background in mechanical, electrical, and controls subject matter and make them into an “intelligent operator,” according to the Siemens Level 1 Job Profile (Siemens, n.d.a).

A student going into engineering and graduating from the first-year Level 1 coursework will be employable in industry as someone who can understand and explain the principal operations of the mechatronic subsystems in a complex system; who can operate a manufacturing machine efficiently; who can localize, identify causes, and correct malfunctions of the machinery; and who can perform routine preventive maintenance. The first-year SLL
curriculum helps students become proficient at these skills. The first year is designed to help students gain employment in a high-tech manufacturing facility after one year of study (see Appendix G).

Administrator Bates described how he had to change the mindset of the high schools, which originally looked at this mechatronics program as a fit for someone who could not go to college because of low academic achievement. He had to convince counselors that potential students needed sound math skills such as pre-calculus to succeed in the associate degree program because it is analytically challenging. He emphasized to the high school counselors that this program should be the first choice for talented students to get a sound education and a good paying job. It was not a program to which students should default if they could not succeed at their first or second choice of careers.

The Level 2 certification is for second year, associate’s degree mechatronics graduates. This level requires a background in college algebra or pre-calculus and physics. This person has all the skills of the Level 1 intelligent operator, but at the end of their second year becomes a highly skilled technician who can, according to the Siemens Level 2 Job Profile (Siemens, n.d.b),

Work with modules and components in complex mechatronic systems as well as be able to assess and analyze the system as a whole. A certified Associate can manage, investigate, repair and troubleshoot mechatronic systems, with the aim of operational efficiency and cost and process control.

Faculty Michaels described the difficulty he had when a student’s grade point average is not high enough for the second year of study. He explained that he would like to see students come into the second year of study with C or better in math and in the first-year core mechatronics courses. He struggled spending 80% of his time with the 20% of students whose academic background was not strong enough. Since the demand for the program is high, Faculty
Michaels would like to see more stringent academic accomplishment before students are allowed to continue in Level 2. He believed by restricting enrollment to students who have a C or better in the prior coursework, the students would be better able to master the Level 2 courses and beyond.

Administrator Roberts stated that his second-year graduates have been hired as engineers instead of four-year engineering graduates, because the Level 2 graduates have the hands-on engineering skills that industry employers are seeking. They can be productive immediately, whereas four-year traditional engineering students commonly need at least a year on the job before they are productive.

The Level 3 certification means a graduate can design and project manage complex mechatronic systems. This person is usually a four-year engineering graduate from a SLL approach mechatronics program. This level was not covered in this study.

The radio, TV, industry, and student marketing efforts were successful for this site college. Their mechatronics department is saturated with students trying to get admitted, described Faculty Austin. As soon as registration opens, the mechatronics classes are filled. As mentioned earlier in this chapter by Administrator Bates, the first classes began in 2010 with a cohort of 12 and one faculty member, which was Administrator Bates. At the time of this research, this college had over 250 mechatronics students and seven full-time faculty members instructing them, stated Administrator Bates.

**Laboratory Training Equipment and Space**

Not having enough equipment or laboratory space is a challenge, according to some of the participants. Faculty Austin stated he could not have more than one type of equipment trainer
in his lab because of the space limitation. The college started out with six students per class and now they have 16. Administrator Roberts described how he accommodates the hands-on training for 16 students in a mechanical systems class when there is only one trainer:

That’s where the systems approach is really nice…. So what we try to do is we’ll have one group doing a troubleshooting exercise for that principle…[Another] group doing, let’s say… gears. If you look at Station 2, that one, or Station 4, the conveyors, those are good ones. So you can talk a little bit about… gear ratios…We’ll [say], “Okay, we want you to watch this. We want you to calculate and figure out how many turns this is doing, how many turns is this doing.” So one group’s [working on gear ratios]. One group’s on the main trainer, and they may be doing a whole gear setup there….So just because that day I’m learning gears, doesn’t mean I can’t go back and pick up electrical exercise…So we incorporate one of the…relay logic trainers …because it sets us up for PLCs. So they’ll have the relay logic [lab exercise].

We’ve embedded Solid Works. We want our students to have CAD. So we will have literally a group working on CAD project. And we’ve also added our 3D printing in there. So we’re also teaching 3D. So we’ve added certain things. So you [are] here for an hour. You move to here for an hour. Or today, you’re on Solid Works. Tomorrow you’ll be here.

This approach requires faculty to be flexible and be completely familiar with all the systems covered in the first and second years. This method works because the SLL approach brings all subsystems together. The subsystems cannot operate unless they are a part of the whole. Yet with more of the same lab equipment, the instructors can have more students working on the same thing at the same time, which is advantageous for the instructors rather than having to help students on different equipment during every lab period. From my experience, it is very tiresome and not ideal for faculty members to have students work on different laboratory objectives on different equipment in the same lab period because it requires constantly shifting gears mentally. If everyone is working on the same equipment at the same time, faculty know problem areas for students, and it takes less time and energy on the part of the faculty member to get students back on track when they run into difficulties.
Working with less equipment than is optimal and still keeping students working on various labs and projects during the hands-on lab periods is an important strategy that this college implemented out of necessity. This site has demonstrated that having a room full of equipment in order to implement SLL is not necessary. The SLL approach is a very adaptive approach and can accommodate a program that does not have the funding or the space for multiples of each type of trainer. In fact, a number of grants are available to colleges and universities who are developing low cost trainers. High schools and colleges can offer mechatronics courses without spending enormous amounts on expensive lab equipment from commercial vendors. For example, I am the Principle Investigator of National Science Foundation Grant Award number 1601172 in which one of the deliverables is the design of low-cost mechatronics trainers that utilize industrial components. Each of the trainers costs less than $1000. Drawings of those trainers are in Appendix H. The trainers incorporate electrical, mechanical, and controls systems and subsystems. I use those trainers in addition to the expensive lab equipment to continually immerse students in the application of the mechatronics concepts. The trainers are portable and they easily fit within the classroom space to demonstrate concepts that students would normally have to go into the lab to see.

Getting and Retaining Faculty

Administrator Bates, who does the hiring of instructors, stated that one of the problems he has is getting qualified faculty to teach mechatronics. At the time of these interviews, he had five instructors: four full-time faculty members and one administrator who also teaches. In addition, he had seven adjuncts who help teach the mechatronics load. Administrator Bates stated,
I really could use a whole bunch more [faculty]. Our program is growing substantially. We’re at capacity now with the faculty that we have. I have one, two, three, four, five, six, seven adjuncts that help. That’s a challenge getting good adjuncts and good faculty. The faculty that we have now are stellar.

Despite the demand for the courses, he continued, he does not have the number of faculty he needs in order to offer more classes to match the demand for them. Part of the difficulty, the administrators explained, lies in the fact that salaries for good, qualified, full-time faculty fall way below what industry would offer them.

Keeping Up with Technology

One of Faculty Austin’s concerns was the challenge of being able to keep up with the latest manufacturing technology. Technology is becoming more sophisticated. The Internet of Things has expanded to manufacturing and is called Industry 4.0 – Fourth Generation Manufacturing. He explained:

The main thing that concerns me is not the changes in the teaching. Because I think the systems approach actually addresses that. But the thing is to keep them updated with the current technologies. [For example], industry 4.0 is a standard. It started in Germany. It basically means fourth generation manufacturing. So basically it says that now all the industries evolve around networks, connecting things to the network. It’s called the Internet of Things. In other words, like for example, everything’s gonna connect with [the] internet. Like the fridge is now connected with internet. Even the light bulbs…I actually bought a light bulb for my house, you can actually turn it on in your smartphone, with an app. So right now, it’s called [the] Internet of Things. There’s also for example additive manufacturing, to incorporate additive manufacturing basically in everything. For example, high definition subtractive manufacturing, or high accuracy, it’s like laser, subtractive manufacturing, building machines but with a laser, for example. 3D scanning, rather than have to make a CAD of something, you just scan it, it generated a CAD file for you. So in other words, this is basically the fourth generation industry standard.

So the thing is, my concern is to keep the students and the faculty updated about the recent technologies.
Faculty Austin was concerned about keeping up with advanced manufacturing even within the Siemens Level 2 coursework. He stated,

I noticed in the Siemens curriculum for Level 2, in the third course that basically you need to teach the students about computer integrated manufacturing, about computer aided production, computer aided design, you know what I mean? These terms, I learned them actually when I was a sophomore back in 2002. Now things are changing. Now I need to teach them about Industry 4.0. So the thing is there, the main thing that I’m concerned with is not the way of teaching, but to incorporate the cutting-edge technologies, the recent standards in the teaching.

The Siemens Level Two coursework was developed to teach interconnectivity through networks, but has not evolved to Industry 4.0 yet (see Level Two coursework descriptions in Appendix F). Faculty Elias was concerned that it is difficult to keep instructors up to date in cutting edge technology their graduates will see in industry. It is difficult to constantly update and evolve curriculum to reflect the new technology. Finally, advanced equipment is continually needed to train students as the latest technology evolves, and the changes the latest technology bring to manufacturing never ceases.

About eight years ago, my department purchased what was then a state-of-the-art automation cell which would assemble a pneumatic valve using seven or eight stations. Each station could operate independently of the others to perform a task, enabling the instructor to have groups of students working on different stations. Once the students could operate and troubleshoot all the individual stations, the entire set of stations would be reassembled for the students to operate and troubleshoot the entire system. This equipment was among the best automation cell a learning institution could purchase for training students. Now automation cells for training students are being built with the capability of embedding microchips and “smart
labels” into each part that is being assembled. Many of us have seen these smart labels on products we have purchased (see Figure 3).

![Figure 3. Smart Label.](image)

Barcodes are becoming a thing of the past. The smart labels are called RFID (radio frequency identification) labels and are used to communicate with a networked system to track each individual item. Eventually people will be able to walk out the door of a merchandiser and not have to go through a checkout line because the item will be recorded through a networked system connected to financial institutions enabling them to be charged for the item directly out of their bank account (Bonsor & Fenlon, n.d.). Faculty member Austin and Elias voiced their concerns about staying abreast of this type of high-tech Internet of Things, Industry 4.0 manufacturing. Higher education typically struggles to afford these forms of technology advances. Keeping up with new technology is one of the challenges with which mechatronics departments must contend.

**Academia as a Stumbling Block**

Administrator Roberts described how the State Board of Regents, the governing body that oversees public education within this particular state, was under the impression the mechatronics program at this college was overlapping into the category of trade schools, or career tech centers, as they are called in his state. He explains,
We fought a lot of the academia within our Board of Regents. So through the [state] governor, we have a governing body. And then that governing body governs all state schools, depending on [the education level]. So the four-year universities have their own governing bodies. All [their state’s] community colleges report to the same Board of Regents. And then also…that same group is over all of our career tech centers. And they’ve just renamed them to colleges. We were getting into their area. They’re industrial maintenance. That’s what they train....There were a lot of issues there, because a lot of the stuff they would do is, “This is the problem, change the component.” “This is the problem,” you change the component. We [train students to] get more into the theory of why. “Why?” So there was a lot of resistance there. And then the whole thought of what Siemens was. “What is that? You’re just making up something” [was the feedback they received from the State Board of Regents].

So there was a lot of resistance in that. And it took us a while...because we were the first in the area, and it took a long time to get that relationship smoother.

As Administrator Roberts explained, what the college was doing in mechatronics was far different from what the trade schools were doing. According to Administrator Roberts, his school was delving deep into mechatronics theory as part of troubleshooting, whereas the career tech centers were concentrating on identifying the faulty component in troubleshooting and replacing the component instead of teaching the theory of why the component malfunctioned. He stated that the State Board of Regents also did not realize the Siemens certification was a worldwide certification test. Eventually, Administrator Bates explained, the State Board of Regents came to understand what he was trying to do in this new mechatronics program and approved it.

Building a relationship with the local colleges and universities took time in order to fully articulate coursework into the state’s upper division colleges’ and universities’ engineering degree, says Administrator Roberts. Faculty Elias spoke about how the local colleges and universities thought this mechatronics program was just a “grease monkey” program or a technology center program. He believes the colleges and universities have too many PhDs who
Administrators Bates and Roberts described how they both tried to set up articulation agreements with state colleges and universities, but initially the colleges and universities were not interested. However, according to Administrators Bates and Roberts, recently the tide seems to be turning, and these same colleges and universities are now trying to catch up to what this community college is doing because they are trying to become Siemens Partner Colleges, too. Administrators Bates and Roberts explained that they both are finally noting a change in the receptiveness of the state colleges and universities to the idea of a college/university partnership with their community college. Administrators Bates and Roberts have now worked out a complete articulation agreement with a large state university. At this time, Administrator Bates said, students are able to transfer approximately 45 credit hours to this university.

Administrator Bates described how the STA is using this site college as a benchmark because they have been able to work with major colleges and universities to have students complete a four-year mechatronics engineering degree (not to be confused with a mechatronics engineering technology degree). Engineering educators are beginning to see the benefits of training students with hands-on knowledge in their first two years so that when they transfer to a four-year college, they have the application background that makes the theory more valuable, he explained.

Summary of Challenges

One of the biggest hurdles that had to be overcome was raising the money to put the new mechatronics program in place. The college raised $570,000 mainly due to the realization by
local industry that the local population of potential employees did not have the skill set necessary to replace the baby boomers who were retiring. Industry invested in the community college, believing the college could deliver graduates who could walk into employment and be productive from day one on the job.

Once the curriculum was developed and laboratory training equipment was in place, the college spent a great deal of time and effort getting the word out to industry, guidance counselors, and to potential students and their parents. The message was that this was a program of study that would set a graduate up with a good paying job at the end of both the first and second years of study. They also had to spend time and energy convincing counselors and students and their parents that the mechatronics program should be the first choice for students who are strong in mathematics and analytics rather than the choice made when a student is not suited for other programs.

Laboratory training equipment is expensive and the space to house the equipment is fairly significant. The college still struggles with not having enough of the same equipment to train all the students on the same lab equipment at the same time. However, the beauty of the SLL approach allows the faculty to have students working on a variety of equipment from different classes in order to get around the lack of enough trainers of the same type. Since the training is always systems-based, trainers from all courses can be used in every class to provide a systems-approach lab period. Students in the electronics class can also work on the fluid power trainers, the mechanical systems trainers, the electrical trainers, and can work on learning CAD. The students rotate through labs on different equipment. This tactic works because the SLL approach brings all these fields, or subsystems, together as part of the whole system approach.
Administrator Bates remarked that finding qualified faculty and retaining them is a challenge for the college since the pay for instructors is low compared to the pay the faculty would receive in industry. At the time of this study, he stated that the program was at full capacity, and it was offering as many courses in mechatronics as possible based on the number of available instructors.

Staying abreast of industry trends is a big hurdle. Keeping up as technology moves into the Internet of Things is a challenge both for faculty knowledge updates and for having the laboratory training equipment to train students in this new advancement in technology.

Finally, although the upper division colleges and universities and the State Board of Regents are now supportive of the value of the new SLL-approach mechatronics degree, initially it was a struggle to get them to understand the caliber of the graduates the college was producing through the SLL approach. The college has been able to set up articulation agreements with the local university to have their two-year associate degree coursework fully articulate into the university’s four-year engineering program.

Findings about Best Practices

This section covers some of the best practices recommended by the participants for colleges wanting to develop an SLL-approach mechatronics program and include hiring the right faculty, faculty development, getting the word out about the program, having a strong laboratory curriculum, and having enough training equipment and laboratory space to run the program. It also covers what to do in case equipment or laboratory space is at a minimum.
Hiring the Right Faculty

The common theme among all participants is how important it is to have instructors who have knowledge of the systems approach and/or have had field experience in industry. Faculty Elias stated that some of the very best instructors he had in engineering school were the ones who had industry experience and could bring that experience into the classroom to augment topics.

Administrator Bates recalled, “It’s very important to have faculty that have industry experience so they can relate both the systems approach to…what’s going on in the real world.” He also believes in training the full-time faculty in the SLL pedagogy in both Levels 1 and 2 and training the adjunct faculty in Level 1. Administrator Bates discussed three attributes the best instructors have in general:

The success of any program is based upon the quality of your instructors. You can have the best equipment whatsoever, but if you don’t have good instructors, it will suffer. The best attributes are number one, sound education. We mandate that they have either an engineering or engineering technology degree. The second thing is all of them have great industry experience. They are able to apply their knowledge of industry to the classroom. They can talk real world to the students. I think that’s very important. The third is the willing or wanting to impart the knowledge and working with those students. They care about their students. They spend a lot of time with the students, not just in the classroom, but also outside. They go above and beyond helping the students understand the material if they struggle and working that plan out. They’re very diligent about their profession and want students to succeed. They spend a lot of time above and beyond working with a student. They spend a lot of time understanding the equipment. Being able to learn the equipment so that they can impart that knowledge to the student.

Based on my experience as an educator, I concur with Administrator Bates’s perspective that the quality of instructors can make or break a program. Word gets out about the quality of instructors in a department. If the instructors are really good, students talk about the class and the instructor, recommending them to others. And if the instructors are not so good, students talk
about the class and the instructor, recommending to avoid those classes and instructors. In other words, Administrator Bates believes that the word will get out about the program, and that the word should be laudatory. He contends that a department head can help ensure the reputation of the department by hiring exceptional faculty. Exceptional faculty, he believes, have the attributes of a rigorous engineering education, great industry experience and the ability to impart that experience with students, and a dedication to helping students be the best they can be.

Administrator Bates hires the faculty for the department. The participants at this college all had a strong engineering education background, as was described in Chapter 4. From the interactions between students and the faculty that I saw while I visited the campus, the faculty all seem to be very much committed to student success. As a result, the word had gotten out about the mechatronics department at this college, and that word was that the college is a model of SLL implementation. Other colleges and universities can emulate this model, according to discussions I had with Lauren von Steuben, the Product Manager of Factory Automation and Industrial Communication at Siemens AG.

What if faculty members do not have industry experience? Faculty Elias answered this question by stating the department should reach out to industry so those faculty can get industry experience. He suggested the department build relationships with industry so that if instructors only have theoretical knowledge, the college can support these faculty members to work in industry over the summer in order to add practical knowledge to their subject matter expertise.

**Faculty Development**

Another best practice mentioned by a number of the participants was faculty development. Examples of such development include sending faculty to SLL pedagogy training,
mentoring new faculty and giving them the SLL curriculum, giving newly-hired instructors time to become familiar with the training equipment, giving them time to run through and possibly tweak the labs, and providing troubleshooting practice on the training equipment.

When the faculty have been with the college for a semester, Administrator Bates said he sends the faculty to Siemens SLL training: “I think it’s important to understand the pedagogy of teaching this. All of the [full-time faculty] have been trained in Level 1 and Level 2.” Faculty Taylor stated how the mentoring and receiving curriculum from other faculty members were critical to his success as an instructor. However, it wasn’t until he went to the SLL training that it all came together for him. He explained the situation as follows:

Before Siemens [training, my colleagues …showed me the…system[s] approach. But I was missing something. So you told me to cover the system. I’m missing something. I couldn’t find it....When I went to Siemens [training], for [the] system[s] approach, they explained it more. And this is where I said, oh no, I’m missing that [aspect]…right [t]here.

All participants mentioned how important it was to receive the training in order to understand the pedagogy and adopt it into their classrooms. They noted a link between their training and how their graduates gained employment advantages compared to four-year engineering graduates. This latter point will be discussed further in the Findings about Outcomes section.

Because the SLL approach is focused on hands-on learning, Faculty Elias emphasized the importance of working with new instructors. He described this issue as follows:

What we traditionally do is, I take those individuals after they get hired and I’ll spend two or three days with them. I’ll go through the concept. We’ll walk through the lab, we’ll talk about it. I give them my PowerPoints. I give them my quizzes. So I try to supply them with everything they need not to have to reinvent the wheel. They can just focus on how do I teach the systems approach. If you don’t have to write your own
quizzes and other kind of things, obviously, they’re going to modify them as they get their feet on the ground.

So, we bring them in, we mentor them, they’re assigned to me kind of as that mentoring person. But they can also go to Administrator Bates or Administrator Roberts, or any other instructor if they need to ask questions and I’m not available or whatever. They don’t have to just deal exclusively with me. We just realized that we didn’t have a kind of a train the trainer approach. So, that’s what we’re doing. Then if they get hired full-time, then at some point they will go to Siemens certification.

The time given to new faculty to acquire skill and knowledge on the equipment in the class is vital because students in the mechatronics department will be working on most of the trainers in a single class period (as was described in the Challenges section of this chapter). An instructor needs to be fluent in using the equipment in order to help students when they are having problems in the lab. Faculty Elias described the importance of this fluency for new faculty:

You can’t walk into a mechatronic system with labs, and do it in two days. You need at least a semester, half minimum, probably a full semester to get up to speed. So that you are smarter than the students, and can outthink the students. They’re always going to ask you a question you haven’t thought about. That as a practice would be a best practice that I would tell everybody you need to do.

A third best practice, according to Administrator Roberts, was to set aside a day in the summer when all the faculty members, adjuncts as well as full-time faculty, would meet and talk about what is working and what is not in their SLL approach. They would also go over the curriculum and share how they made improvements to the SLL curriculum over the course of the year. This focus on continuous improvement contributes to the instructors’ success in the classroom.
Getting the Word Out

As was covered in the section on Challenges, Administrator Bates was interviewed on radio and TV regarding the new mechatronics program. His consistent message was that the program can help a person start a well-paying career with many opportunities for advancement. He took the time to also talk with high school counselors and potential students and their parents about the program. He talked about what the program is, what it does, how it does it; in general, how the program is an improvement over the traditional approach of training engineers and how it is an academically challenging program. Completing the program has to be something a student really wants to do, explained Administrator Bates.

Administrator Bates emphasized that a significant amount of time was spent on this type of marketing to the public. He suggested continually talking to counselors and advisors throughout the year. This communication was done by going to the high schools, talking to the counselors and advisors individually, and by inviting the counselors to personally observe the program.

Administrator Bates was adamant about the importance of developing partnerships with local industry. He cautioned that the SLL program should accommodate all the industries in the area, not just the dominant industry. He described that his college has a very large industrial automotive sector in their area along with casket manufacturers, food manufacturers, and other smaller industries. Administrator Bates said this is “one of the beauties of mechatronics. It’s very general on automation and how systems work so you can go to work in many different industries.”
Another way that helped get the word out to industry, states Faculty Austin, was the invitation to local engineering managers to attend the capstone presentations. This feature was described in more detail in the section on Instruction – Class Projects. The engineering managers had the chance to see the skills graduates developed as a result of this mechatronics program. Faculty Austin described how many of the managers were so impressed with the final projects that they wanted to hire the students immediately.

Need for Good Training Equipment, Laboratory Curriculum, and Laboratory Space

Faculty Michaels described the criticality of having the correct lab equipment that is understandable and easy to implement for the students. He explained that the lab curriculum from the equipment supplier helped him tremendously during his first year in teaching both Level 1 and Level 2 material. The lab curriculum was tightly paired with the essential theoretical base the students needed to be successful.

Faculty Elias, an experienced instructor, mentioned how he modified the equipment supplier lab curriculum. This refinement required students to think more instead of having the instructions laid out for them step-by-step. “I’ve taken those and tweaked them, and made various assignments that are not so cookbook-like.” He elaborated:

My observation [is] those labs, the traditional approach labs are going to be what I call cookie cutter labs. Take wire one and put it in port A, and plug it into port B, and read instrument C. As opposed to what we do. There is some of that in the [equipment supplier] labs, but then we take that and expand upon it, of why didn’t you get the answer. Or, what answer would you get if you did this differently?

According to Faculty Elias, their students don’t just collect data, write up labs, and hand it in to a graduate student, as is so often done in the traditional approach to labs. Faculty Elias
explained that his students have to think about what they are doing, and they need to apply concepts they learned in class to design projects in lab.

Other faculty, such as Faculty Austin, emphasized the need to have enough space in the lab for the mechatronics trainers. This college had a severe space limitation and was only able to fit one mechatronics trainer of each type in the lab. But as was mentioned in the section on Challenges, he used the SLL approach to design different lab activities using trainers in other subject fields. This strategy worked because of the SLL pedagogy. Not having enough equipment trainers or enough space for equipment trainers is not a roadblock to offering mechatronics, but it makes teaching the course content more challenging when groups of students are working on many different laboratory exercises during the same instructional hours, according to Faculty Austin.

**Summary of Best Practices**

One best practice, according to Administrator Bates, was to hire exceptional faculty. He sought out faculty who have a sound engineering education, who have significant industry experience, and have the passion to spend time with students. He wanted faculty members who would go above and beyond the ordinary to help students understand the material.

A second best practice, according to the participants, was the time and money invested in faculty development to help them thoroughly understand the SLL pedagogy. This development was done by sending new faculty to Siemens SLL training so they fully understood how to implement SLL pedagogy, by mentoring new faculty and giving them the curriculum, by giving faculty time to get familiar with lab equipment prior to having to teach the lab classes, and by
getting all faculty together at the end of the term to share experiences and best practices they came up with during the term.

A third best practice, according to Administrator Bates, was to market the mechatronics program through radio and TV advertising spots. He also advertised the program to high school counselors and potential students and their parents. He stated how these marketing endeavors were time-consuming, but a critical job in order to get the word out to the general public about the program.

A fourth best practice, recommended by Administrator Bates, was to make contacts in industry. Getting the word out to potential employers about the program was very important, and these efforts contributed to recruiting students to his department.

A fifth best practice was to invite industry representatives to the graduating students’ capstone project presentations. These interactions showcased the quality of their graduates and often resulted in graduates receiving job offers from the industry representatives at the presentations.

Finally, the sixth best practice involved having good training equipment and adequate space for its use. Administrator Bates demonstrated that colleges can run the labs with a shortage of equipment and a lack of space, but such conditions are not ideal. Although the faculty at this college were short in equipment and in space, they were able to overcome these obstacles. They creatively employed the SLL approach by having students work on a variety of laboratory exercises in each laboratory class. This strategy required flexible faculty who possessed deep knowledge of the systems covered in the first and second years.
Findings about Outcomes

The outcomes in this section include student feedback the college received on a regular basis and the feedback from industry. Collectively, this feedback informs the administrators and faculty members about their goal of producing graduates with the mechatronics skills that are in demand. Administrator Bates recalled that his first classes in the mechatronics department began in 2010 with a cohort of 12. He was the lone faculty member. Through his leadership and expertise, the mechatronics department grew exponentially and, at the time of this research, the department had over 250 mechatronics students and seven full-time faculty teaching the mechatronics students.

Student Feedback

Faculty from the STA described how they talk with the students about how the program is going for them. The STA is committed to receiving constructive feedback from students, and they request this feedback from students at the end of every week in the semester. The STA faculty meet with the student cohorts on Fridays with all the faculty members present and together they review how the week went. This same concept is used at this site college at the end of every semester, according to Administrator Roberts. Administrator Roberts described how he assembled the students and has an open dialog with them about the program. He asks questions of them such as “What did you like about the program?” “What things did you struggle with the most?” “What were the things you found easiest?” and “Were there ways this could have been done better?” The aim is to continuously improve the program. Administrator Roberts found that
one common response was the students wanted more and more hands-on opportunities. He said he continues to find hands-on opportunities for them as much as possible.

Faculty Taylor described the feedback he received from the older students who are coming back to college after being away for many years. Some told him they never liked math or physics, but that the SLL approach helped make traditionally difficult to understand subjects easier to understand once they understood how it is applied to mechatronics. Faculty Taylor described his experience with these older students:

We have many students...they’ve been out of college for many years….They have no idea what electricity [is], what mechanical [systems are]. With [the] system[s] approach, they learned fast, quickly. Some people that [didn’t used to like] math, now with the system approach, when you show them how this work[s] and why, and what the basic equation[s] for that [are], it just clicks in their mind.

Faculty Taylor concluded that once these nontraditional students were able to see how math, physics, and other challenging subjects were directly applicable to mechatronic systems, they were better able to understand how the math, physics, and the mechatronics topics fit together.

Faculty Taylor talked about the nonverbal feedback he got from students in a traditional class as opposed to the nonverbal feedback he gets from students in the class using SLL pedagogy: “Students give you their full attention when they are in their first week of the traditional program, and maybe even to the third week,” said Faculty Taylor. Eventually the excitement of a new class wears off. This is not the case with the SLL approach, he said. Faculty Taylor believed the students are more motivated to learn the material and consequently he can cover more chapters in a semester because he has their continued attention because of the SLL approach. He explained:
I would say system approach is a tool that we use…to teach and this tool opens the door for all the other tools to be used. [The] first thing [is that] it changed the way I teach… n many courses, you just only need to cover, let’s say, six chapters or seven chapters. Like if you take Chemistry one, they only cover eight chapters. With [the] systems approach, you will be able to cover more. So we would be able to cover more chapters in an easy way. The systems approach show[s] you the big picture of what you’re going to learn, what you’re going to do, [and] how it is going to benefit you from the beginning. And then you build on that.

On the other hand, Faculty Michaels was not sure it was the SLL approach that motivates the students. He believed that some students realize “the great potential that their future has by completing our program,” and that potential is the motivating factor for them.

Faculty Michaels described one of his biggest stumbling blocks with some students is motivation. Some students are in the program because their parents told them they have to be in class. Some of the students have all their college academic expenses paid at a community or technical college if they are 18 years old and a graduate of high school with the right prerequisites. Faculty Michaels tries to encourage them to see the opportunities available to them when they graduate with a certificate or degree in the mechatronics program. According to Faculty Michaels, most of the students, however, have a strong desire to complete the program because they see that:

To live the quality of life they want to live, they need some credentials. And so, they’re here for a reason. And again, you get a few just here because mama said go. But for the most part they’re here because they want to have a better life, a better quality of life. Some are obviously more skilled than others. Some struggle more. Some are just innately able to do the work, or had a good high school class, or had a good experience in high school.

A source of motivation for many students is the SLL approach with the hours of hands-on applications. As mentioned by Administrator Bates, the feedback from many students about the program is they wanted to have even more hands-on experiences with the equipment. They enjoy
it, and it captures their attention, adds Faculty Austin. He believes that starting with a working system and then breaking it down into smaller components is the critical component of the program.

Faculty Elias described the feedback he gets from his students: “Almost every semester my students say, ‘We get a lot more out of your class than we pay for.’ And they do!” he exclaimed.

Industry Feedback

When asked how they know the program is successful, participants mentioned feedback from industry. Administrator Bates discussed how their Association of Technology Management and Applied Engineering (ATME) accreditation is used as part of student success. In order to maintain their accreditation, they need to keep track of their graduates. They poll their graduates to find out how they are doing after graduation. Administrator Bates stated that almost all the graduates get positions in mechatronics. The department also gets feedback from industry telling them the graduates are doing well; so well in fact, that industry keeps knocking on the department’s door asking for more graduates: “To me, that’s a great gauge of success on how well the program works,” said Administrator Bates.

Faculty Elias concurred and elaborated on that point:

One of the issues that we’re having is that our graduates get gobbled up almost as quickly as we can produce them, almost 100% placement rate. Very few employers have come back and say, “These guys aren’t meeting our needs.” All of the employers…come to us directly, and say, “Hey, we [have] this opening for a maintenance tech. Please send us your best and brightest or anyone who’s graduating,” and [they] say, “Have them send us a resume.” I think that’s our biggest indication of success.
Administrator Roberts described the feedback he received from an engineering manager that hires the second-year graduates over the traditional four-year engineering students. Here is what this manager had to say, according to Administrator Roberts:

Here’s what I see. The first year, the first day when your students walk...into our plant, if I’ve got a robot down they were willing to grab the teach pendant. And they jump right in...they literally will get dirty. They will literally start touching things the first day, and they’re not intimidated by anything they see. The engineering degree people that come out of the four-year universities ...that first year...they don’t want to touch anything. They want to sit more in the office. They want to draw it. But they don’t touch anything. After a year it’s hard for me to tell the difference. The [second-year SLL graduates and the four-year engineering graduates] look about the same. It takes me a year to get their [the four-year engineering graduates’] confidence up to do that. But in the overall, they’re all about the same level. But that first year, that first moment, the [two-year graduates are] ready to jump in.

Administrator Roberts described the importance of obtaining a certificate or a degree. But in the end, it is all about the job they get after graduation. Administrator Roberts said his two-year graduates are being hired over four-year engineering graduates. In fact, he emphasized, some of the two-year graduates are being hired directly as engineering, not engineering technicians: “They come in with that higher skill level, and they have the hands-on skills that companies are looking for....I mean, those guys are coming in at $60,000 a year, straight, with a two-year degree....That’s impressive. And one of our individuals came in at $85,000,” he said.

Yet another one of his students told Administrator Roberts that after earning just a one-year certificate in mechatronics and by working overtime for a large food manufacturer, he is going to exceed a six-figure salary this year. Administrator Roberts celebrated that fact by stating, “You know, that shows he’s in his fit. He loves what he’s doing, and so, that, to me, is the success of the program.” Administrator Roberts described how companies are coming in to the college to recruit the mechatronics students, but the students are so much in demand,
according to Administrator Roberts, “the [companies] cannot hire the [new graduates] after two years, because they’re already gone. So they’re having to hire them at the first-year certificate level [because] they’ll be gone by the [second] year.”

Faculty Austin stated that industry monitors the students and tells him how the students are doing. In addition, in order to become an employee of the large manufacturers, the graduates have to take an entrance exam. The feedback from the graduates, according to Faculty Michaels, is that the mechatronics coursework prepares them very well for those employment tests.

The college mechatronics program graduates were in such demand that Administrator Bates expanded the program to the local high schools. According to him, all high school mechatronics instructors have been formally trained in the Siemens Level 1 SLL approach. He said the high schools are offering the first four courses in the certificate program so that once students graduate high school, they will have earned 16 college credits in mechatronics that can be used towards the associate degree in mechatronics.

Summary of Outcomes

Part of why the mechatronics program produces graduates who are in demand is that they listen to their students. They take the time to get honest feedback and make continuous improvements to the curriculum based on the feedback from the students in the program. This practice is also what the STA in Berlin does every week.

Administrators Roberts and Faculty Elias described how the faculty and administrators actively listened to the employers of their graduates. That feedback has been overwhelmingly positive, with students earning salaries significantly above the median salary for the region with
only one year of study. Industry employers were so highly satisfied with the quality of the graduates, according to Administrators Roberts and Faculty Elias, that there is almost a 100% placement rate. Employers told the participants that the two-year graduates of their mechatronics program are often hired above four-year engineering graduates because their two-year graduates were able to leverage their learning to such a degree that they could earn the company money on their first day of employment, whereas the four-year engineering graduates needed at least a year to become productive. The four-year engineering graduates could not relate the theory they learned to actual systems in the field. Some two-year graduates of the SLL program at this college were hired as engineers, not engineering technicians, due to the skill they developed in the college’s SLL mechatronics training, according to Administrator Roberts and Faculty Elias. Students were making $50,000 to $60,000 to start in a geographic area where the median income was $36,000, they said.

Findings about the Future

This section on the future delves into improvements in the SLL mechatronics program the administrators and faculty would like to see. Additionally, this section touches on how well the SLL approach produces graduates that answer the call for change in engineering education.

Improvements to SLL

I asked all participants what they would modify in their curriculum and changes they would make to the way SLL is implemented in the classroom and received a variety of responses. Many participants mentioned improvements that were already in progress. Administrator Bates would like to see more robotics in the curriculum since “robots [are] vital to
automation and mechatronics. Right now…we’re creating new classes to put into the program…. I’m looking at making an associate [degree] in mechatronics with an emphasis in robotics."

Administrator Roberts taught the second-year manufacturing processes class, which teaches students about continuous improvement and quality using a simulated factory that the Siemens training refers to as their Pen Factory. The Pen Factory has students simulate manufacturing pens – red pens, blue pens, black pens – according to orders placed by a customer. The customer is the instructor. Students act as suppliers, assemblers, and purchasers of pen parts. During the first week(s) of class, the students are left to their own devices to come up with a plan for how to meet the demands of the customer. They inevitably soon discover it is not easy. In fact, teams of students compete with each other to meet the customer’s demands. Soon they all find out that manufacturing a simple pen and supplying the demand is much more complicated and difficult than they expected. Each week, the instructor teaches them about a new lean manufacturing technique to apply to their team’s ability to supply the correct order to the customer. The next week they apply the technique and get better at manufacturing and supplying the pens, but they discover the process still has many rough edges. Again, they learn new techniques to apply to the following week’s manufacturing process. Eventually, they learn the basic manufacturing techniques to become a money-making, rather than a money-losing, manufacturer. Of course, these techniques will help students on the job when they are engineering managers.

Administrator Roberts wanted to see more application in the Level 2 classes, so he added the design and building of an actual pen-manufacturing cell into the factory simulation. He describes what he did:
We said, “Okay, instead of doing the pen factory for 15 weeks,” kaizen, we took their exact pen factory and everything and put it in about four weeks. And then what we said is...the students create their own teams. Pick their own program manager, and we give them $2000 to $3,000 real money. And we basically give them a Grainger book, and we give them a real-life problem, and they have ten weeks to build it and do everything. This is basically, pull everything they’ve learned over the two years, and build a piece of equipment, and then actually run it. And then we bring engineering managers from all over the area, and they give a two-hour presentation, at a technical management level, to those presenters. And then that’s the project. And that’s their project. And that’s their final grade. It’s a capstone class.

I asked Administrator Roberts where they got the money to give the students. He said,

Initially, we were doing it out of our budget, which was tough. And we had some components. But, also, too, we’ve had companies give us some stuff. So that helps. But also, the other thing is, being now Train the Trainer, there’s some benefit to that financially. And so we’ve been able to work that out that the college doesn’t take that money. They put it back into our department. So we’ve been able to take that little bit of money and say, “This is our project money.”

And what is nice is, the students...They have to learn program management. When I teach the class, and I’m the main one...The [student] program managers meet with me 30 minutes before class. They tell me what they’re going to accomplish that day. Then they go in, and they run the class. I just become a member. I become a consultant to them. So if they hit a really hard problem, I’m there. But I’m in the classroom. But then they have a person ordering parts. We order it through Grainger. So they have to look at time.

So at the beginning of class, they have, every day, the beginning of class, they have a timeline. A Gantt chart...they develop that. And they show, “This is where we’re at.” They assign responsibilities. Who’s going to be doing what? And then they have a concerns list at the end of class. They do a wrap-up. I mean, they run it just like a real, live project.

But... it’s really not about the project. I tell them it’s a pass/fail. If the project doesn’t work, then... But the real key is, it’s opened up jobs. Because what we have is, we bring in these engineering managers. They give that two-hour presentation to them, and I tell the students who are still looking, I say, “Have your resumés ready.”

And so, at the end, I say, “This student here, this student here, this student here, still looking for a job.” And I’ll have them...And then I have certain engineering managers saying, “I want that student.” And I’ll say, “Well, they’re already working there.” They say, “I don’t care. I want to talk to them.” So you get that competitive.
Administrator Roberts stated that Siemens liked this approach so much that they have incorporated it into their own train-the-trainer instructor training. This approach has become a Level 3 project, not just a Level 2 simulation (Level 3 is the bachelor degree SLL).

Faculty Austin wanted to see the mathematics requirements strengthened. The college did this by having students take pre-calculus. Those students who want to go into mechatronics engineering are advised to go on to take Calculus I, calculus-based physics, and engineering statics, which covers how to determine the forces on the members of an object given forces applied to the object at certain points. They are typical second-semester engineering courses.

Faculty Taylor would like students to incorporate the non-calculus-based physics as a prerequisite for the second-year mechatronics program because the second-year curriculum is more in-depth with more theory. He believes the physics course would give them the background they need to be successful in the coursework. Faculty Michaels concurred by saying students coming into the second year need stronger math skills. He mentioned that he seems to spend 80% of his time on the 20% of the students who have a weak mathematics background, especially with the demand they have for the courses now. Faculty Michaels’s suggested improvement would be to have students attain a 2.0 grade point average in the first-year core classes and a C or better in college algebra. He stated, “Those are the students that will be successful in the level 2 and beyond.”

Faculty Elias would like to see more internships and co-op programs with industry. He mentioned that Administrator Bates was working diligently to make that happen. However, many students already work at a non-mechatronics job while they are going to school, so it is difficult
for them to add an internship or co-op opportunity since those jobs are typically not paid positions.

**Changes to Engineering Education**

I asked all the participants how the SLL approach answers the call for a change to engineering education. Administrator Bates emphasized the importance of America’s colleges and universities graduating engineers that have had hands-on experience during their educational years. He felt it was important that students have some basic hands-on work to support their theoretical studies. He lamented that four-year engineering graduates typically do not know how to make a part on a milling machine. The problem with not knowing how to do something that basic is they cannot talk to the machinists intelligently. A person has to understand how parts are made to design parts that can be manufactured. Administrator Bates stated:

If you’re going to start designing things like I did, you need to know how it’s made. You need to know the processes that are included and why things are designed a certain way….Typically right now, a four-year student learns that on the job. They don’t learn that in school.

I’ve had many businesses and industries come and tell me that our two year degree, for the first two or three years are much more adapted to working than a four year engineering [graduate] because they have already touched stuff and so when you come in and you start working on systems, our graduates aren’t afraid to touch it and change it….Those that have never worked on a system are timid. They found a lot of the four-year are timid. They soon learn, but it is something that I wish four-year education would focus on. I really do. They tend to really focus purely theoretical and that may work for someone wanting to go get a PhD, but someone leaving with a Bachelor’s or even a Master’s, wishing to go out and work in industry, if you’re going to start designing things like I did, you need to know how it’s made. You need to know the processes that are included and why things are designed a certain way.

What would make for an “absolutely wonderful engineer,” according to Administrator Bates, is a student who took their first two years at his college, where they can get hundreds of
hours of hands-on experience, and then transfer to the local four-year engineering university where they can get the theoretical and analytical engineering knowledge to build upon the hands-on experience. When they graduate with their four-year engineering degree, those students would be able to “walk-the-talk,” said Administrator Bates.

When talking to young people about their future, Faculty Elias described how robots will take over the unskilled, mundane jobs:

If I’m flipping hamburgers at McDonald’s, do you think they’re going to pay me $20 an hour to flip a hamburger? McDonald’s can’t sell a hamburger for $1 and pay you $20. So, sometime you’re going to walk into McDonald’s, there’s going to be a kiosk. You’re going to plug in what you want, mayonnaise, lettuce, pickles. And somebody back there called a robot is going to cook that hamburger, put the bread down, squirt the ketchup on it, wrap it up, and send it out to you. There might be one or two people there to handle any problems. The…people [who will have the real job] are the people that are going to be back there working on the robots. And they’re going to be making $20 or $30 an hour. So, yeah, are they going to take the mundane jobs? It’s going to happen. But is it going to put more money in the pocket of the skilled people that we ought to be teaching today? Yes.

Administrator Bates and Faculty Elias described how the college realized how important it is going to be to teach the skills related to robotic technology and artificial intelligence, and they are trying to get on that cutting edge. They have received a $5.5 million grant to create a 15,000 square foot building to hold six robotics bays and five classrooms. They plan to hire two to three faculty members to start and build that number to ten in four to five years from now. They will offer a concentration in robotics and, as part of their SLL curriculum, they will offer SLL classes in robotics, artificial intelligence, and advanced PLCs. They will offer training classes to industry and will modify their curriculum to have several pathways for the students who want to earn college credit: the traditional mechatronics path, which they are currently providing, and a mechatronics path with a specialty in robotics.
Administrator Roberts also talked about how he advises students. Administrator Roberts said he will ask students what they want to be doing once they graduate:

When a student comes in, and they [tell] me... They want to do mechatronics or engineering/mechanical….or electrical. My question always comes as ...What does that job look like? What job do you want?

The student tells me, “I want to do R&D research for NASA.” I’m not going to tell them mechatronics is the place they need to go in. I’m going to tell them, “You need to specialize into that field.” So I think the electrical/mechanical degrees, the way colleges do those, are great for the research side. Because your theory has to be... Because you’re taking and you’re doing something nobody else has ever done. So I think that’s really good.

But if a student comes to me and they say, “You know, I really want to work in a plant. I want to build cars.” If they’re talking about taking existing technology or modifying existing technology, that still can be research, but it’s still taking existing technology and taking it one little step further. And I’ll tell them mechatronics and the systems approach is dead on from that standpoint. Does that make sense?

To summarize, Administrator Roberts said he takes the time to understand what the students see themselves doing once they graduate. By understanding that vision, he can then advise students whether to go to a college or university that teaches engineering using the traditional engineering education pedagogy or to those that utilize SLL pedagogy. The issue, he said, is that four-year engineering colleges and universities will not advise students in that way.

Administrator Roberts related this dilemma to the changes he thinks need to happen in engineering education. He goes on to say,

I think the changes that we’re doing...[that] even the four-years are looking at, I think they have to really begin to ask themselves, “What is our student’s career [path]? What is it they really want to do?” And that really should determine how we teach them. And I think the problem is we’ve tried to put everybody in a box, and we say, “You got to do it this way” [the traditional way of teaching and learning].

Matter of fact, two weeks ago the State Board of Regents [are] doing a big push right now to two-year and four-year colleges. And it’s about career. In-game career. And they’re asking everybody to begin to ask, how is that course relevant to what the
student’s going to do? And how do they make it more relevant to what they’re going to do? And I think that’s the same thing. I think that’s what’s going on in engineering.

I think that’s what mechatronics is really talking about. What do you want to do, and how can we make sure that we’re giving you the skills to that? And right now the traditional college does not train ...If you’re going into plant engineering, I’ll be honest with you, they’re teaching you to think, but they’re not teaching you how to do it. And I think they’ve realizing they’re missing the boat.

The traditional way of teaching engineering should not be the only way of teaching engineering, emphasized Administrator Roberts. The problem with the way engineering is taught today, he said, is that we are not asking students what job they envision for themselves once they graduate. The four-year engineering colleges and universities are training all engineering students for research-based careers when many want to work in a hands-on engineering career. Engineering educators need to ask students what they want to do once they graduate and then come up with a plan to give those students the skills to do that upon graduation.

One of the keys to being able to make the coursework more relevant to the student that wants to work in areas other than research is to have more faculty who have worked in industry teach the upper level engineering coursework using the SLL approach, according to Faculty Elias. He would like to see either more faculty who come from industry into academia to teach the engineering students or have the faculty members with only research experience be paid for working in industry over the summer to get them that experience. Faculty Elias’ explained, “There’s a 30% shortage of qualified individuals to work at the levels they need to work, in order to make companies want to come back to the United States and be viable in the United States.”

Faculty Michaels made a recommendation to engineering students in colleges that are using the traditional approach to engineering education:
Become multidisciplinary. If you’re going to become a mechanical engineer, have some understanding of what electrical engineers do or have some basic understanding of electricity and how that works…so you…[are] able to understand how…traditional mechanics incorporates electronics and electricity. Likewise, have a good understanding of computer programs and how the computer processors integrate with your system. Everything’s interconnected nowadays when you’re talking about machines and manufacturing, and having that as a background, in my opinion, I think is very critical nowadays.

The participants viewed the engineering education pathway as one that should be based on what students sees themselves doing in their careers. An engineering education focusing on producing only research engineering graduates is not an education that serves engineering graduates or American industries well. Participants see the need for an alternative approach designed for engineers who see themselves designing products and working on automated manufacturing machinery as opposed to those who conduct pure research.

**Summary of the Future**

All of the faculty had ideas about how to improve the mechatronics program in their department. The interesting and exciting thing about their suggestions is that they are all taking action on their ideas for improvement. They are building a brand new robotics program; they are infusing Level 2 classes, which are more theoretical than Level 1, with systems design work; they are increasing the mathematics, physics, and grade point average requirements for students entering the second year coursework; and they are working on getting more industry partners to offer internship and co-op opportunities.

As far as the changes to engineering education, all of the participants believed the SLL approach creates a much stronger engineering graduate who can work in industry; so strong in fact, that some students just completing their associate degree from this mechatronics department
are being hired over four-year engineering graduates as engineers in the engineering department. The participants believe there should be an alternative to the traditional engineering education, and that alternative should produce good hands-on engineers who can be immediately successful in a high-tech manufacturing engineering job. That alternative is a college that can deliver training in mechatronics using the SLL pedagogy.

Chapter Summary

This chapter provided the results of the case study of a community college’s implementation of SLL. This chapter covered the beginnings of SLL at the college, how SLL was implemented, details on SLL instruction, the challenges of implementing SLL, best practices recommended for implemented SLL, the outcomes reported, and the future of the program at the college. The final chapter summarizes the research, discusses the findings, describes implications for practice and research, and makes recommendations for future research.
CHAPTER 6
SUMMARY, DISCUSSION, AND RECOMMENDATIONS

“Today in America, we are trying to prepare students for a high tech world of constant change, but we are doing so by putting them through a school system designed in the early 20th century that has not seen substantial change in 30 years.”
Janet Napolitano (2004)

The purpose of this study was to produce a qualitative case study on the design and implementation of a systems-level inductive learning approach in a community college. The primary sources of data were interviews with administrators and instructors who played key roles in the implementation of this program.

The Problem

Researchers have identified several concerns regarding engineering education. Renovation suggestions in the literature included the need for a systems-level, inductive pedagogy, the need for interdisciplinary courses, and the need to excite students in engineering practice.

This qualitative case study investigated a mechatronics department in a pioneering community college in the United States that adopted an inductive SLL pedagogy in its curricula. Stakeholders of this engineering program were key sources of data for this study. The purpose of this inquiry was to produce a thick description (Schwandt, 2007) of why and how the SLL
inductive learning approach was implemented in a community college context. Findings of the study pertain to and provide insights for renovating engineering education.

Methods and Procedures

The community college I chose for this study is known for its historical implementation of SLL. The site is known and respected as a Siemens partner college with Siemens-certified instructors; thus, the site has implemented the SLL concept throughout the mechatronics department’s curricula. Note that this case study was not about the content of Siemens SLL training. It was about implementing an SLL curriculum in an American community college. The site name is not important because it is an example of a model adoption of SLL. This assertion means the SLL curriculum was designed from scratch with the help of the STA. An existing traditional curriculum was not in place that had to be changed. Faculty were hired and trained in SLL before or soon after starting teaching at the college.

The faculty and the administrators who were a part of the history and development of SLL at this college were selected for semi-structured interviews. Interviews were recorded using digital audio recorders. The data were transcribed and stored in MS Word files.

Chronological, descriptive, and inductive analyses were performed on the results of the interviews with the help of NVivo software. Axial and open-coding were used to develop free nodes including beginnings, implementation, instruction, challenges, best practices, outcomes, and future. Axial coding was then used in each of these instances to develop free nodes into tree nodes with the resulting children.
The question of trustworthiness was addressed by having participants review the transcript of their interviews to give them the opportunity to rephrase or retract statements. To mitigate bias, I triangulated the data by using field notes, a reflective journal, and documentation in addition to the interviews.

Findings

The overarching question that guided this study was how SLL was implemented in a community college mechatronics department. Data analysis used for the responses to interview questions resulted in seven free nodes which were synthesized into the four research questions below.

Research Question 1: How Did This Programmatic Innovation Emerge, Grow, and Develop at This Case Study Site?

Administrator Bates, Administrator Roberts, and Faculty Elias described a history of major manufacturing job loss in the early 2000s within a 30-mile radius of the college. A shortage of skilled workers contributed to the departure of industries. Remaining local industry leaders started a dialog with the college and raised funds to start a new college program that was intended to produce potential industrial employees with the needed skills.

Administrator Bates went through the Siemens Level 1 and Level 2 training at the STA. He developed the mechatronics curriculum using the SLL pedagogy with help from the STA. He taught the initial mechatronics courses himself at this college, so he has been through the challenges of teaching new curriculum using a different pedagogy. He had been in the trenches so to speak, both in industry and in academia.
People matter to Administrator Bates. He has great respect for the people he hired in this department and they have a deep respect for his leadership and for him as a person. A person can ascertain this from listening to Administrator Bates describe and talk to the people in his department and by the way the people in his department describe and talk to him. Many participants reported he is also generous with his time in helping others and easily shares the resources he developed. I believe his leadership qualities are part of why all the instructors work well as a team to deliver mechatronics content using the SLL pedagogy.

The faculty in Administrator Bates’ department are given the curricula, time to work closely with a mentor on the SLL technique, and time to become proficient in using the laboratory equipment. They are also sent to Siemens training for two weeks where they are immersed in how to apply the SLL pedagogy. I believe the leadership from Administrator Bates, the SLL training at the Siemens Technik Academie, the help from mentors, and the curriculum that was in place was critical to enable faculty to adopt the new pedagogy.

**Research Question 2: What Practices Were Most Effective and Helpful in Designing and Delivering Systems-Level Learning at This Case Study Site?**

Administrator Bates discussed the importance of hiring faculty who have a sound engineering education, who have significant industry experience, who have the passion to spend time with students, and who excel at helping students understand the material. He believed faculty need to thoroughly understand the SLL pedagogy in order to be successful in the SLL classroom.

Faculty described their initiation into the SLL pedagogy as a mind shift because they were not used to focusing on an entire automation system at the beginning of each class.
However, many faculty noted how similar the pedagogy was to what they unconsciously did when they were working with and troubleshooting equipment in industry. The faculty stated the SLL approach became very clear after they recognized the similarities between applying troubleshooting skills industry and training students using the SLL pedagogy. The faculty members construct the students’ knowledge every day with the mechanical knowledge building on the electrical, fluid power, and controls knowledge; the electrical knowledge building on the mechanical, fluid power, and controls knowledge; the fluid power knowledge building on the mechanical, fluid power, and controls knowledge; and the controls knowledge building on the mechanical, electrical, and fluid power systems knowledge. Faculty Taylor described this buildup as enabling instructors to cover many more topics than they could if they were using the traditional approach to teach the class.

Faculty described how class projects involving automation system design were incorporated into the training – in some of the classes projects were completed every week. Administrator Roberts established a cash fund students could use to physically build the automation systems they designed. These financial resources were accrued from contractual work provided by the mechatronics department to local industry.

The student projects were strategically used to ease the problems associated with not having enough trainers for each group of students. If a group was waiting to gain access to a piece of training equipment, they could continue with one of a few projects on which they were working for various mechatronics classes. Administrator Roberts explained that many of the projects were on the advanced level of projects 4-year engineering students usually complete.
Projects in Level Two were important to the graduating students because they culminated in presentations to hiring managers of local industry. Many of the graduates were able to obtain their first mechatronics jobs as a result of these presentations. The hiring managers were impressed with the results of the projects and they would get competitive amongst themselves to try to hire students for mechatronics positions in their companies.

Research Question 3: What Caveats, Stumbling Blocks, and Lessons Learned Were Identified According to the Stakeholders with Regard to Their Goal(s) for the Program?

One of the biggest hurdles that had to be overcome was raising the money to put the new mechatronics program in place. The college raised $570,000, mainly due to the realization by local industry that the local population of potential employees did not have the skill set necessary to replace retiring workers, nor did they have requisite knowledge regarding the new technology that was being implemented. Industry invested in the community college, believing the college could deliver graduates that could be productive from day one on the job.

After the curriculum was developed and laboratory training equipment was in place, Administrator Bates spent a great deal of time and effort promoting the program to industry, guidance counselors, and to potential students and their parents. His consistent message was that this program of study would prepare graduates for good paying jobs at the end of both the first and second years of study. He spent time and energy convincing counselors and students and their parents that the mechatronics program should be the first choice for students who are strong in mathematics and analytics rather than the choice made when a student was not suited for other programs.
Laboratory training equipment was expensive and the facilities required to house the equipment was fairly significant. At the time of this research the college continued to struggle with not having enough of the same equipment to train all the students at the same skill set at the same time. However, the beauty of the SLL approach allowed the faculty to have students working on a variety of equipment from different subject matter classes in order to get around the lack of trainers of the same type. Because the training is systems based, trainers from all courses can be used in every class to provide a systems approach lab experience. Students in the electronics class can work on the fluid power equipment, the mechanical systems equipment, the electrical equipment, and can work on learning CAD. This rotation works because the SLL approach brings all these fields together as part of the whole system approach.

Finding qualified faculty and retaining them was a challenge for the college because the pay for instructors was low compared to the pay the faculty would receive in industry. At the time of this writing, the program was at full capacity based upon the number of instructors. Keeping up as technology moves into the “Internet of Things” was a challenge both for updating faculty knowledge and the laboratory equipment to train students in this new advancement in technology. The “Internet of Things” involves embedding electronics – sensors and microchips, for example – into physical objects such as appliances and vehicles, in order to connect them to the internet and with each other to collect and exchange data (Morgan, 2014).

Finally, although the colleges and universities with four-year engineering degree programs and the State Board of Regents eventually became supportive of the value of the new SLL-approach mechatronics degree, initially it was a struggle to get them to understand that the college was not duplicating what the trade schools were doing and that they were producing a
much higher caliber of graduates through the SLL approach. The college has been able to set up articulation agreements with the local university to have their two year associate degree coursework fully articulate into the university’s four year engineering program.

Research Question 4: How do Stakeholders Address the Call for Change to Engineering Education at the Community College Level?

Part of why the mechatronics program produced graduates that are skilled and in demand was because the faculty and administrators listened to their students. They took the time to get honest feedback and make continuous improvements to the curriculum based upon the feedback from the students in the program.

The faculty and administrators also actively listened to the employers of their graduates. That feedback has been overwhelmingly positive. Students with only one year of study were earning salaries significantly above the median salary for the region. Industry employers were so highly satisfied with the quality of the graduates, that there was almost a 100% placement rate. Employers told the administrators and faculty that the graduates are often hired above four-year engineering school graduates because the graduates of the mechatronics program can be productive immediately whereas the four-year engineering school graduates need at least a year before they can earn the company any money. If the employers wait for second year graduates, they find others already hired them before their studies concluded because their skills are in demand.

The faculty all had ideas about how to improve the mechatronics program. The interesting and exciting thing about their suggestions was that they were all taking action on their ideas for improvement. They were building a new robotics program; they were infusing the
more theoretical Level 2 classes with systems design work; they were increasing the mathematics, physics, and grade-point average requirements for students entering the second year coursework; and they were working on getting more industry partners to offer internship and co-op opportunities.

Findings Related to the Literature

Researchers have identified several concerns regarding engineering education. Renovation suggestions include the need for a systems-level, inductive pedagogy; the need for interdisciplinary courses and integrated knowledge; and the need to excite students in engineering practice.

The Need for Systems-Level, Inductive Pedagogy

Research into engineering education has indicated that inductive, systems-level pedagogy should be an important aspect of engineering curricula. Supporters of inductive pedagogy claim that it leads to better engagement, deeper learning, and enhanced intellectual development for students (Felder & Brent, 2004). In inductive pedagogy, the student is an active part of teaching and learning (Prince & Felder, 2007). Such an approach helps engineering graduates apply their new learning to new systems, something with which traditionally-taught engineering graduates struggle (King, 2007). Inductive pedagogy is the base upon which SLL curriculum is developed.

Preparing future engineers for technologies that do not yet exist is a challenge. Boud and Feletti (1991) asked: “If learning occurs best in context, how do we prepare ourselves for future contexts which are unknowable?” (p. 19). The answer to that question for engineering students
may very well be the development of Handlungskompetenz through the application of SLL pedagogy. (Recall that Handlungskompetenz results in graduates who have the flexibility to quickly adapt to new systems and situations in a self-directed way). If a student can be trained to analyze any system holistically prior to delving into the subsystem and component levels, that student has Handlungskompetenz – adaptive expertise. Handlungskompetenz is necessary for future contexts that are unknowable (Boud & Feletti, 1991).

Interviews with administrators and with faculty have indicated that SLL graduates are hired and are productive from their first day of employment. Thus, they are being prepared to be productive on systems on which they did not have prior experience. They have developed Handlungskompetenz.

Interdisciplinary Coursework and Integrated Knowledge

According to existing literature, technician/engineering education needs a new pedagogical strategy to enable students to develop an integrated understanding of all their coursework. King (2007) stated “...there is widespread agreement on the need to develop engineering graduates with the multidisciplinary approach required for successful systems integration” (p. 31). This goal is difficult to accomplish when courses in mechanical systems, electrical systems, and computerized control are taught as separate entities (King, 2007). As noted in the research, the traditional silos of technical subject matter and the “chalk and talk” method of traditional engineering instruction has changed very little since the 1950s. Wulf and Fisher (2002) summarized the issue: “many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real world
engineered systems. Although there are isolated ‘points of light’ in engineering schools, it is only a slight exaggeration to say that students are being prepared to practice engineering for their parents’ era, not the 21st century.”

This qualitative case study found that the SLL pedagogy implemented at this college brought in knowledge from a wide spectrum of subject fields in each course. The main emphasis for a particular course was the subject field, but analogies between that subject field and other fields were a part of the curriculum. The focus remains on the system and the system represents a diverse conglomeration of many different subject fields. As stated above, the faculty construct the students’ knowledge with the mechanical, electrical, fluid power, and controls knowledge all building on each other.

Recommendations in the existing literature also called on colleges and universities to provide students with more practical applications so engineering graduates can better understand and solve real problems (King, 2007). Although some college educators have integrated practical applications through capstone coursework, junior and senior level design courses, and PBL projects within classes, these examples tend to be isolated curricular experiences. Rarely are these approaches integrated throughout the entire curriculum, according to King. This current study documented the SLL approach of integrating entire systems in every course. Students saw practical applications every day at this case study site.

The general assumption by faculty in traditional colleges is that if you teach students theory, students should be able to apply it, stated Administrator Roberts. The college under study and the industries that hire traditionally taught engineers have data to show that this assumption is flawed. The National Academy of Engineering issued their report Educating the
Engineer of 2020: Adapting Engineering Education to the New Century because they were very concerned that current engineering students “…may not be appropriately educated to meet the demands that will be placed on the engineer of 2020 and that, without refocusing and reshaping the undergraduate engineering learning experience, America’s engineering preeminence could be lost” (p xi).

Faculty from this college and their industry partners have experience with four-year, traditionally taught engineering graduates that all needed at least a year to become productive on the job. Whereas these traditionally taught students could not relate the theory they learned to actual systems in the field, the two-year SLL graduates were able to leverage their learning to such a degree that they could be productive on their first day of employment. Some graduates of the SLL approach were hired as engineers and not engineering technicians. Engineering graduates need to be able to integrate and apply their knowledge. Thus, engineering graduates should have Handlungskompetenz.

The Need to Excite Students about Engineering Education

As noted in the literature review, problems exist within engineering education beyond the lack of fluid competence and the lack of integrated coursework. Low engineering student retention is a concern, specifically among women and minorities (Beering, 2007). Reasons for these problems include students’ perceptions that coursework is unrelated to the excitement of “real” engineering work and the coursework seemingly too restrictive for students’ varied interests (Beering, 2007). Furthermore, students struggle to apply the first and second year coursework to later engineering coursework (Streveler & Smith, 2006).
Faculty participants in my study agreed that most students in the engineering programs like more of the hands-on practical work. Lab time and hands-on training is crucial to SLL. Another strategy that faculty found beneficial is to start students on a fully functioning automation system. Faculty start their instruction with the overall system and then break the system down into smaller and smaller modules. This approach attracts the students’ attention and keeps them engaged. Faculty Taylor described what typically happens in a traditional class during the first few weeks of class; the students give the faculty their attention for those first few weeks, then they disengage. That disengagement does not happen with the SLL approach, according to Faculty Taylor. Students are engaged throughout the semester, which means more content can be taught – more integrated content.

This section has made connections between findings of this case study and relevant existing literature. The following section discusses the boundaries of this case study.

The Limited and Unique Parameters of this Case Study

A qualitative case study approach was used to study a historical implementation of the SLL pedagogical approach to teaching mechatronics. The college under study had an advantage in that it was able to start the mechatronics department from scratch utilizing the SLL approach. By building the program in this way, curricula were developed before faculty were hired and then each new faculty member was trained in the SLL approach and given the time to integrate the knowledge of SLL into learning how the equipment trainers worked. This situation was an ideal way to set up a brand new department with a new pedagogy. However, the majority of colleges who have implemented the SLL pedagogy into an existing department face different
challenges because of the existing beliefs and culture of the institution. Converting an existing mechatronics department that uses the traditional approach to teaching would be quite dissimilar compared to this case study because it would involve different implementation strategies, challenges, and best practices. Those challenges were not covered in my research.

Implications for Practice

Engineering education has been the target of renovation for decades. Felder, Stice, and Rugarcia (2000) acknowledged that understanding what needs to be changed in engineering education is the easy part: “The real challenge is to create a favorable climate for these changes…a climate that motivates faculty members to improve their teaching and the quality of instruction in their departments, supports their efforts to do so, and rewards their successes” (p. 208).

This qualitative case study opens a window to what a “favorable climate for changes” might look like. It gives the practitioner in-depth knowledge of how a SLL pedagogy was implemented and how it functions in practice. This qualitative study is an opportunity to see how faculty members approached class curriculum and what the challenges were with implementation. Moreover, it uncovered a model of departmental change that can be used in creating a favorable climate for innovation at other institutions. Along these lines, the Froyd et al. (2006) seven-element framework for curricular change is a useful tool for discussing the implementation of SLL pedagogy in this case study. The seven elements are: goals for change, objects for change, barriers to change, change mechanisms, models of change, change agents, and the role of faculty development. These elements are described in the sections below.
Goals for Change

Some of the overall goals for change in engineering education were increased Handlungskompetenz in graduates (which results from systems level, inductive pedagogy, and integrated coursework and knowledge) and a student population excited about working in the field of mechatronics. The degree to which students persisted and graduated, and to which graduates were placed into industry at an engineer level after only two years of study are good indicators of the SLL pedagogy contributing to those goals.

Objects for Change

The objects for change were the means by which the goals were met. The college under study had an advantage in that the curriculum was developed from scratch using SLL pedagogy. The new faculty were given the curricula and were trained and mentored in the pedagogy. Every faculty member saw the advantages of these curricula and realized how closely they mirrored the process of on the job learning.

Among systemic influences that affect the way faculty teach are student resistance, departmental norms, expectations of content coverage, and lack of discretionary time to implement change (Dancy & Henderson, 2005). As discussed in the chapter on ‘Findings’, the department norm at the college under study was SLL pedagogy, the expectation was that all courses were to be taught from a systems framework, and curricula were given to all the new faculty (and all faculty were new) so there was no need to change the way they were teaching. These faculty members did not want to go back to the chalk and talk pedagogy in which they had
been taught. They saw the benefits in student engagement and in the job placement of the graduates of the system.

**Barriers to Change**

The college under study was fortunate in that the original department faculty member was able to start the program from scratch and not have to try to persuade people out of an entrenched, traditional way of educating students. However, the great challenge at the beginning was obtaining funding to equip the laboratory. Ample support from local and state industry emerged and grants were secured to enable the purchase of training equipment. However, at the time of this writing the college still needed a larger facility to house the department and its labs. In order to have all the students working on the same skill set at the same time, they needed a greater number of the same type of training equipment. Although the college had scant equipment (in some cases, only one trainer of a particular type), they were able to conduct mechatronics classes due to the nature of SLL. With few pieces of equipment, students were rotated through the equipment from other subject fields during each lab period. For example, in the mechanical systems class, a few students were working on the mechanical trainers, a few on the pneumatic trainers, a few on the electrical trainers, and so on, during a single lab period. This approach required all fields to be integrated, as they are in SLL pedagogy. Thus, the lack of sufficient trainers for a class was overcome by having students work on projects from the integrated subject fields in every lab period.
Change Mechanisms

Froyd et al. (2006) described change mechanisms as tools that promote change such as model curricula and faculty development. The Siemens Technik Academie developed the model curricula that are used by this college. The STA refined the curricula over the years. The STA model came from the 100-year-old German technical education tradition. Their pedagogy focuses on the holistic system. The overriding goal of this innovative pedagogy is to produce graduates with Handlungskompetenz -- graduates who have the flexibility to quickly adapt to new systems and situations in a self-directed way. In every class, the STA systems-level model melds theoretical and practical learning with the goal of improving an industry’s bottom line.

Siemens has been teaching the SLL pedagogy to instructors worldwide. Siemens charges a fee to train instructors and as part of the fee, the curriculum is shared, instructors are trained on how to implement the curriculum, and at the end of the training, the instructors are observed and critiqued in using SLL to teach a class.

Model for Change and Change Agent

Froyd et al. (2006) asserted that how change will be adopted is a key component of a model for change. This case was an ideal situation where the program did not exist prior to 2009. The president of the college was the original change agent. She decided to implement the change process by employing the first faculty member/chair, Administrator Bates, to develop the program using the SLL approach. He was directed to look at the STA curricula as a solution to the training needs of local industry. Administrator Bates spent a lot of time at the STA and was able to develop curriculum with the help of the STA.
Role of Faculty Development

Froyd et al. (2006) stated that in order for systemic change to be implemented and become adapted, faculty must have appropriate and timely training along with planned follow-up. At this college, investing in the faculty to learn the SLL pedagogy played a critical role in the program’s evolution. Faculty Taylor stated that even though he was given the curriculum and was mentored, the whole SLL pedagogy did not make complete sense to him until he attended the Siemens SLL training. The college made a substantial investment in every faculty member in the department to attend the training. The cost to train a single faculty member was $6000 for two weeks, not including room and board. The college was committed to making the faculty members successful in this new pedagogy. The faculty members also received the complete curriculum and were provided with ongoing mentorship from the more experienced mechatronics faculty once they returned from training. They were also given time to assimilate the new pedagogy within the lab classes to ensure their success. They were given time before teaching their first class, to learn how the lab equipment worked and how it was integrated into the SLL pedagogy.

Rugarcia, Felder, Woods, and Stice (2000) discussed how engineering administrators and professors question the way engineering has been taught but they are unsure of the alternatives to traditional pedagogy. They fear that significant curricula changes would take too much time out of an already busy schedule. This case study provides administrators and faculty members a window to a historical alternative and describes how the alternative was implemented. Felder et al. (2000) stated if faculty “…try to implement every new technique they hear about, they will
probably be overwhelmed by the time they find themselves spending and the student resistance they encounter, get discouraged, and go back to old ways of doing things” (p 210).

Programmatic changes are typically not part of a coherent whole systemic change; instead, more commonly they are techniques learned here or there in faculty/administrator research into engineering education.

However, the SLL pedagogy is a whole system change – a change in the entire approach to engineering education. The pedagogy applies to each class and is an approach to teaching rather than a faddish technique. It is essentially a practical mindset that can be applied to any class without the need for special techniques or costly class time. It applies what cognitive scientists have known for years – that watching and listening to lectures is much less effective in the accumulation of skills and knowledge than doing and reflecting. The results in terms of employability of graduates of this case study site have been impressive.

In order for the SLL approach to be fully implemented, however, administrators need the time to get the message out about the new pedagogy. The administrators of the department need to champion the advantages of the pedagogy in order to support faculty training and mentoring. Faculty must believe the SLL pedagogy to be superior to the traditional pedagogy in order to expend the effort to teach subject matter differently than the way that they were taught.

The absence of thousands of dollars to equip laboratories with equipment trainers can be overcome in the development of a SLL mechatronics program. As previously discussed, the SLL approach can be used even if students are working on a variety of systems at the same time. In addition, there are a number of National Science Foundation grants that have been recently
awarded to design low-cost mechatronics trainers and lab curricula. These low-cost trainers also open the door to high school dual credit using the SLL pedagogy.

Implications for Research

Felder et al. (2000) summarized four changes in engineering education that are crucial: (1) revision of curriculum and courses, (2) implementation of new teaching methods and effective assessment of those methods, (3) faculty development in instructional development, and (4) status increases of teaching not only in society but also in academia with reward policies for great teaching. The first three recommended changes are addressed in this case study. This qualitative case study fills a void in the research – that of the study of a historical program which incorporates the first three recommended changes and has produced a systemic change in how engineers are trained.

The findings of this qualitative case study show an example of making reform happen. The prescriptive changes to engineering education recommended by the research, including inductive pedagogy (Sheppard et al., 2008), interdisciplinary coursework (King, 2007), and exciting students in the subject matter (Clough, 2004) have been effectively implemented at this college by building curricula with SLL pedagogy. Research into SLL curriculum is sparse. This qualitative case study illuminates SLL pedagogy and how a department developed and implemented this pedagogy.

Inductive teaching is a considerably different approach compared to the traditional deductive methods of teaching engineering. Prince and Felder (2006) compared deductive methods of teaching engineering students to inductive methods as follows:
The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things on exams. Little or no attention is initially paid to the question of why any of that is being done. What real-world phenomena can the models explain? What practical problems can they be used to solve, and why should the students care about any of it? The only motivation that students get—if any—is that the material will be important later in the curriculum or in their careers.

A well-established precept of educational psychology is that people are most strongly motivated to learn things they clearly perceive a need to know. Simply telling students that they will need certain knowledge and skills some day is not a particularly effective motivator. A preferable alternative is inductive teaching and learning. Instead of beginning with general principles and eventually getting to applications, the instruction begins with specifics—a set of observations or experimental data to interpret, a case study to analyze, or a complex real-world problem to solve. As the students attempt to analyze the data or scenario and solve the problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either presented with the needed information or helped to discover it for themselves (p. 123).

Inductive pedagogy is learner-centered. It works on the premise that students learn better when they can build new material into their own existing knowledge structures. Common types of inductive teaching and learning include problem- and project-based learning, discovery learning, and just-in-time learning. Prince and Felder (2006) explained further:

> Induction is supported by widely accepted educational theories such as cognitive and social constructivism, by brain research, and by empirical studies of teaching and learning. Inductive methods promote students’ adoption of a deep… approach to learning, as opposed to a surface… approach. It also promotes intellectual development; challenging the dualistic type of thinking that characterizes many entering college students…and helping the students acquire the critical thinking and self-directed learning skills that characterize expert scientists and engineers.

Systems level learning is a newer instructional method and a type of inductive learning that has garnered scant research.
Hartle, Baviskar, and Smith (2012) described four criteria that are essential to constructivism: (1) eliciting prior knowledge, (2) creating cognitive dissonance, (3) applying new knowledge with feedback, and (4) developing metacognition. The following paragraphs examine these four criteria in conjunction with this case study.

**Eliciting Prior Knowledge**

The role of prior knowledge is a key element in constructivist SLL mechatronics curricula. One of the Level 1 courses will be mechanical systems. In my experience of teaching the mechanical systems class for years, students in the mechanical systems class will run the gamut of students who have previously worked on mechanical systems, to those who do not know a bearing from a shim, and the rest of the students who fall in between on that continuum. The students who have previously worked on mechanical systems most often have operated mechanical systems, taken them apart, and put them back together. Those students started with a system, worked with sub-systems, and then took apart the sub-systems to the component level. The best students have been able to put the components back together into correctly operating sub-systems and an improved fully functioning system.

In a community college setting, the percentage of each type of student in a class will primarily depend on the area of the country in which the school is located. Quite often, rural areas with students who grew up on farms will have more students with systems knowledge. Colleges in cities and often suburbs will often have higher percentages of students who have never taken apart mechanical systems larger than a simple toy-sized system. Aptitude and
The development of practitioner skills can be greatly influenced by the context in which youth grow and develop.

If we look at the classroom from a constructivist perspective, those students with the mechanical systems background tend to take the traditionally taught theoretical knowledge and apply it to mechanical systems they have seen in the field. They have an advantage over the students who never worked with mechanical systems. The other students have little to no experience upon which to apply the theoretical knowledge.

With the SLL approach, students can be exposed to the same experience level on the first day. Chances are, none of the students have seen the automation cell the college has in the lab. On the first day, all students see how the automation cell works and are given the opportunity to operate the machine themselves. With guidance, even the students who have no mechanical background begin to see the various sub-systems that make up the working system. The SLL pedagogy gives all students the ability to start from the highest level – the understanding of a working system. All of the students begin with knowledge upon which they can build all other knowledge of the system.

As Norton, Richardson, Hartley, Newstead, and Mayes (2005) described, the students need to know where the lessons fit into their mental constructs. If the constructs do not fit, students are apt to memorize terms and definitions and will forget the knowledge after the quiz or exam. When constructs do fit, students are more likely to be engaged with the content. Students will be positioned to relate what they are observing and operating to machinery with which they have worked in their past.
Creating Cognitive Dissonance

Cognitive dissonance occurs when students realize their prior knowledge is insufficient to understand how the system works as a whole. Part of cognitive dissonance is discovering missing information in their understanding. In the observation of how an optimal system works, students are motivated to understand what input in a system causes which output. They are encouraged to operate the system over and over to see connections.

This SLL constructivist perspective is similar to building the whole base of a knowledge pyramid at the onset of learning. Layers above the base are more firmly cemented in place every week because the new knowledge is tied to the large base. As knowledge accumulates, smaller and smaller parts are infused; that is, the knowledge of the small individual components are integrated into the whole. Every week the knowledge is tied to the knowledge of the large pyramid base – the system. Eventually an entire, stable pyramid is built with every part cemented and tied to the base.

Extending the analogy to the traditionally taught class, the instructor starts with the smallest components, the smallest piece of the pyramid and builds that in the air. A larger base of knowledge is not acknowledged and established. Eventually, towards the end of the course, the faculty may get to the large stable pyramid base, but usually not much time is spent on that structure because the end of the semester is near. Little knowledge is tied into the previous week’s lecture let alone to the knowledge from week one. Each topic is treated in isolation. The pyramid may or may not be stable, depending on how much of the base is built during the last weeks of the class. Very little time is put into the base, and so all the levels above the base are not solidly tied to the base.
The viewpoint of starting all students with a broad background of the system provides a different look at how constructivism can be enhanced for all students by giving all students the knowledge of the system with which to start. The students with experience are no longer the only ones who have a knowledge base on which new constructs can be built.

Application of New Knowledge with Feedback

Troubleshooting techniques integrate the new knowledge into a system that is not operating correctly. Students must take the new knowledge they learned in class and integrate it into what they know about the system to make the system operate correctly. The feedback is whether or not the system operates as expected. If it does not, the students must continue their work until the system operates correctly.

Metacognition

Hartle et al. (2012) described metacognition and students:

Metacognition can often be recognized when students are required to explain what they have done, how they did it, and why it was important…. Look for questions or objectives that ask the students to explain a logical sequence or derive a conclusion from evidence, rather than to simply report what they have seen or done (p. 34).

SLL pedagogy requires that students continually communicate how the sub-system fits into the big picture of how the system works. Students are routinely asked questions about the function of a subsystem, how it is supposed to operate, and what it is not doing that it should be doing.

Students are routinely expected to present to their fellow students descriptions such as how different parts of a system fit into an integrated whole and their results of a troubleshooting
exercise. This approach is an important aspect of integrating SLL into the classroom because it gives students practice in a safe setting to become more conversant with others and to sharpen their communication skills.

Recommendations for Future Research

Since there is scant research on the SLL pedagogy, numerous avenues exist for continued research, both qualitative and quantitative. This case study explored a college that implemented the SLL pedagogy from scratch in a newly formed department of mechatronics in a rural community college. As mentioned earlier, few colleges and universities have implemented the SLL pedagogy into an existing traditionally taught mechatronics program. The numbers of these colleges and universities are growing every year, as can be seen in the Siemens Partner School website (Appendix A). The partner schools which have changed pedagogy from the traditional to the SLL pedagogy can be examined to ascertain how the existing pedagogy was transformed, the challenges that occurred in doing so, and recommendations for best practices.

Unique dynamics existed among the faculty members at this site college. From my perspective, the participants had a great deal of respect for each other and were committed to working as a team to deliver SLL pedagogy. These elements require talent on the part of the person leading the team. Therefore, another theme for further study in the area of higher education innovation is research around the unique dynamics and leadership that made the implementation of SLL thrive throughout a department. This type of research would provide useful findings for educators who are planning to integrate innovative pedagogies into a department.
Further opportunities for research can include how the SLL pedagogy is implemented into existing curricula in various types of higher education institutions and in different subject fields. The findings from such research could help to introduce SLL as an alternative approach to higher education as a whole.

This research did not include direct quotes from the people in industry who hired the graduates of the SLL pedagogy. I included anecdotal stories relayed from study participants regarding the impressions of industry representatives. Industry partners are stakeholders of these kinds of programs. Talking with them directly about the Handlungskompetenz of engineering graduates would be a worthy inquiry. They could provide insights regarding various schools with different teaching pedagogies and offer their perspectives concerning work readiness of graduates.

Suggestions for improvements to the education of future engineers were made in the literature, such as making hours spent in the lab more effective to support integration and synthesis of knowledge. Truax (2007) stated,

Observing physical demonstrations of textbook and lecture information can enhance a student’s perception of a concept and produce clarity of key issues. Unfortunately, limitations often exist that constrain the developing laboratories and sometimes reducing the student’s experience to little more than performing “cookbook” experiments and copying previous lab reports; an exercise that benefits neither the instructor nor the student.

Faculty Elias also stated how he thought the traditional labs tended to follow a cookbook model. He explained how he changed the labs in the mechatronics area to make them less so. Student surveys can be conducted with classes that implemented traditional laboratory teaching methods for a few weeks and then switched over to SLL techniques for another few weeks.
Research can also be designed and compared to gain an understanding of the Handlungskompetenz attained by students taught using different pedagogy.

Another suggestion from the literature to improve engineering education is for faculty to better connect the initial math and science courses to the following engineering courses. The SLL approach is designed to eliminate silos between subject fields as much as possible. Research would be needed to discover how the SLL pedagogy addresses or does not address that suggestion for improvement.

In the literature review, researchers such as Wulf (1998) urged that there should be gender and cultural diversity in engineering. Wulf stated, “As a creative field, without diversity, engineering cannot take advantage of life experiences that bear directly on good engineering design” (p.29). The effects of a SLL pedagogy on retention, especially women and minorities would be a prime research topic. If it is shown that SLL pedagogy helps to increase retention, the finding could lead to SLL making inroads into institutions that would not have otherwise considered implementing it.

Not mentioned in the findings is the part of Handlungskompetenz that involves working effectively as a team member. Employees in every industry need to be able to work effectively on cross-cultural and multi-disciplinary teams. The student training in the Siemens Technik Academie (STA) in Berlin incorporates some training in teamwork, which I discovered from my talks with STA faculty. In those talks, I discovered the STA put students into teams based on the results of Meyers-Briggs – like evaluations. STA instructors also work with students on strategies for effective teamwork. I believe most faculty members place students into teams without any consideration on how to help them become effective team members. Problems are
likely to occur for both faculty and students when students are not compatible with other team members, and when team members do not have the tools to resolve the incompatibility problems. I believe this practice only courts failure of the student team to attain the desired educational outcomes.

I incorporate Meyers-Briggs assessments and instruction in teamwork in my classes every week. This instruction takes approximately 15 -20 minutes and I found, informally, that tolerance between students increases when they are given tools to resolve conflicts. I believe the results of a study revolving around the practice of training students to be effective team members would be beneficial to every faculty member who uses teamwork or group assignments. Specifically, research on such training in conjunction with SLL pedagogy would be enlightening. In my experience, this instruction on teamwork does not take a lot of time, but for those students who learn from and internalize the lessons and strategies, the benefits can last a lifetime.

In summary, little research exists on SLL, yet future studies may take several avenues, including research into problem solving capabilities and design abilities of students taught using SLL pedagogy, along with research into the retention of women and minorities when a Handlungskompetenz approach is used in engineering education. These studies would lead to a better understanding of how to implement SLL along with more details on the strengths and weaknesses of SLL pedagogy. This recommended research may provide a further understanding of the link between SLL and constructivist learning theory.

Concluding Thoughts
Call for change in engineering education has been going on for over 100 years. When funding became plentiful from the federal government in the 1950s and 1960s, emphasis on teaching to produce research engineers led to the current traditional approach to teaching engineering. Obtaining government funding to the extent that occurred in the 1960s to change engineering education to meet current industry needs is unlikely.

Some instructors are sporadically trying out the latest constructivist pedagogy, including flipped classrooms, problem- or project-based learning, discovery learning, and so forth. Those changes in technique are piecemeal and “…rarely extend to ever-expanding spheres of influence inclusive of different cultures, institutional missions, and policies, types of leadership and values, and economic and political factors” (McKenna et al., 2014). These techniques usually do not lead to the systemic change that is needed in engineering education. If a few instructors implement the flipped classroom or problem-based learning, for example, these changes have little effect on how students learn in other classes. However, one instructor can very well make a difference with SLL. SLL has the potential to create a systemic transformation in engineering education because once students are trained in seeing how new learning fits into an overall system, they can apply that thinking to classes that are not using SLL. It is a method of looking at learning that transcends whether other instructors are using it. An instructor who enables students to operate a complete system at the beginning of the term and then uses the system as the basis for further learning in that class will help learners incorporate knowledge from other subject areas. If several instructors incorporate SLL into their classes, then the magnitude of systemic change in engineering education is enhanced. Training students to look at the system rather than a small part of the system may transform engineering education from the inside out.
When students are asking how the new information applies to the systems with which they are working, then the students have become the change agents.

**Insights to Professional Improvements**

I believe that the SLL method of engineering education is a far superior method to the traditional approach for the majority of students. This study has improved my own implementation of SLL. I have learned about more classroom implementation techniques from other faculty members who have been able to do a great deal with less equipment in their labs than what I have. This research has given me insight into how to increase the adoption of SLL with adjunct instructors who will not be able to attend Siemens SLL training due to cost barriers.

I have noticed in my own classes that students are engaged in refining their own understanding and learning, and they stay in the lab for an hour or more after class ends every day because they want to learn more. They are working independently or in small groups. They are ‘in the zone’ and do not want to leave yet. They have become what we want all our students to become – self-directed learners. They find it challenging to draw in the knowledge from other courses they have taken or are taking into their work in this class - they were not used to doing that in their former studies. They were used to the traditional model of teaching subjects in which each subject field is isolated from the others and the ability to do well in a class meant mastering the concepts of that particular class.

My background working for years as an engineer in research and development with the quantitative mindset that goes along with it made this qualitative study a challenge. It is indeed a mind shift to focus on understanding reasons, opinions, and motivations, rather than focusing on
data comparisons. This mind shift is analogous to the mind shift that occurs when a person shifts to the SLL pedagogy from the traditional engineering education pedagogy. Learners need to train themselves to think in a manner that is not familiar, habitual, or natural. With regard to this case study, the opportunity to take that journey has enabled me to become a much stronger researcher than I would have been had I only concentrated on quantitative studies in my career.

**Insights About Future Directions**

As I see it, engineering education is still entrenched in an almost arrogant mindset by many colleges and faculty about the ‘prestige’ of teaching traditional chalk and talk, theoretical-based engineering, rather than industry-based engineering curriculum. I do not believe that this predominant mindset will change much over the next few decades.

Engineering educators should take a step back from this predominant mindset and consider what is best for this country as well as for the majority of students. My viewpoint is that students should start with operating and troubleshooting systems, then understanding the theory behind what they are operating, and finally designing systems. This learning sequence educates engineers in a more comprehensive manner. In the mechatronics field, students can complete the first year of the program to become an intelligent operator of automated systems and have employable skills. Employers benefit by gaining intelligent operators and students benefit by gaining experience and securing a living wage. The second year of the mechatronics program should be spent learning theory about the automation with which they are gaining familiarity. The theoretical learning can lead to a new and higher career level with increased responsibilities and pay. Finally, the last two years of a four-year engineering education can be
spent in design, with hands-on learning and a solid background in automation, culminating in a higher paying position in industry. This sequence of learning and experience would help the vast majority of engineering students obtain a good paying and challenging industry position. Students who are inclined to conduct research can pursue the traditional engineering degree and will have many opportunities to select a college of their choice that maintains the traditional approach.

Administrator Bates made a comment which I originally mentioned in Findings on the Future. He said,

What would make for an “absolutely wonderful engineer” is a student who took their first two years at his college, where they can get hundreds of hours of hands-on experience, and then transfer to the local four-year engineering university where they can get the theoretical and analytical engineering knowledge to build upon the hands-on experience. When they graduate with their four-year engineering degree, those students would be able to “walk-the-talk.

As an educator who has been teaching for 17 years, I have seen many creative and talented young people come through our programs. They start with such energy and enthusiasm in their initial courses, but the system beats them down. As the literature showed, and my experience bears out, they simply cannot bear to sit in math class after math class and all the theoretical classes before they even get the chance to work with “real” engineering systems. They are the ones who can change the world. They have so many great ideas. But we throw two to three years of theoretical courses at them and slowly the fire leaves their eyes – often after only one year of traditional engineering education. These people would make excellent engineers. It is the imagination and talent of these students we need to foster. The great thing about systems level learning is that we can capture and direct that enthusiasm so that they can see how to utilize the concepts taught to them to build the systems they see in their minds eye –
the systems they dream about creating. Instead, we lose them to other non-STEM-related fields; they never realize their full potential as engineers. The country loses the implementation of their concepts that may solve some of the world’s most pressing problems. Let’s get them into systems level learning coursework so they can connect the dots to full implementation of their ideas. Let them work in industry after their first year of SLL to continue to look at how systems work. They will be paid a living wage and can further their studies with financial help from their employers. Or let them come to us in a full-time SLL program. They can work on their innovations while working and furthering their education. I am convinced we will capture the hearts of these talented students and give them a bright future in engineering rather than dissuading them with an elitist view that only those who can survive the theoretical rigor of years of equation solving should be allowed to become engineers.

In a related side note: I have often been in the company of fellow engineers when the topic of education came up. Inevitably, there would be one or two in the group who would exclaim that after all the years of calculus, linear algebra, and differential equations, they never used any of that math in practice. Without exception, they received knowing nods of agreement from the others in the group. I never heard anyone argue in favor of the amount of mathematics that was required for a traditional engineering degree.

I did exceptionally well in my studies in mechanical engineering. I loved the math and the engineering theory. However, I was extremely overtrained for the majority of jobs in engineering. I used very little, if any, calculus even when I was working in a research and development capacity for the Buell Motorcycle Company, designing motorcycles, where one would think all that mathematical training would come in handy. I would “re-study” calculus
and differential equations during my weekend mornings over the course of my career, eventually running through my textbooks from section-to-section, cover-to-cover twice over the years. I state “re-study” rather than “review” to emphasize that I solved thousands and thousands of problems to keep up my math skills rather than simply just reading over the calculus and differential textbooks, which reviewing implies. Since I did not use those topics in my practice, I was fearful of losing my knowledge of them. I was bored in my engineering jobs, even though I worked in research and development and also headed up multimillion dollar jobs as a project engineer.

There is an argument that those students who cannot be successful in a traditional engineering curriculum should move into an engineering technology program. I would like to remind the reader that we would still be graduating traditionally trained engineers who need months of on-the-job experience before they start earning money for the company. Those graduates cannot apply their knowledge to industrial systems. When we move to an SLL approach, the students who are good at the math and theoretical courses will increase their ability to apply the knowledge, and we will not forever lose the students who are talented and creative engineering thinkers.

In summary, this case study explored one rural community college’s path of implementing the SLL approach to learning. The interviews with the participants revealed the path to this new approach, highlighting participants’ insights and challenges as well as descriptions of how they implemented SLL in their classrooms. My hope with this research is that other faculty and researchers who are interested in SLL and its implementation will be given
a foothold into adopting this method. The SLL method is not intended to be a piecemeal approach to change; rather, SLL changes the whole approach to engineering education.
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APPENDIX A

INSTITUTES OF HIGHER EDUCATION THAT ARE SIEMENS PARTNER COLLEGES
According to the Siemens Partner School website (http://www.siemens-certifications.com/content/0/9131/9147/9163/9167/), the institutes of higher education that have adopted SLL are:

Anne Arundel Community College
Blue Ridge Community and Technical College
Bossier Parish Community College
Calhoun Community College
California University of Pennsylvania
Central Piedmont Community College
Cochise College
College of Lake County
Canville Community College
Greenville Technical College
Ivy Tech Community College
Kentucky Community and Technical College
Lansing Community College
Macomb Community College
Motlow State Community College
Mott Community College
Nashville State Community College
Patrick Henry Community College
Peidmont Technical College
Perdue University
Spartanburg Community College
Thomas Nelson Community College
Virginia Western Community College
Western Nevada College
Westmoreland County Community College
APPENDIX B

ATTRIBUTES OF A SIEMENS PARTNER COLLEGE
Attributes of a Siemens Partner College

A college must meet the following four attributes in order to be accepted by Siemens as a Partner College:

1. Must have at least two SMSCP Certified Instructors on staff (defined in Appendix C).
2. The instructional language must be English.
3. The college must have a mechatronic training lab system on site.
4. There must be a written agreement with Siemens on program implementation.
APPENDIX C

ATTRIBUTES OF A SIEMENS-CERTIFIED INSTRUCTOR
Attributes of a Siemens-certified Instructor

The Siemens Corporation has a “Siemens Cooperates with Education” initiative in which instructors can be trained in the SLL methodology in the area of mechatronics. The attributes of a Siemens Mechatronics Systems Certification Program (SMSCP)-certified instructor is described on their certification process webpage (http://www.siemens-certifications.com/content/0/6/7/4215/5920/) These attributes are described as follows:

A Siemens-certified SMSCP instructor is an instructor that has completed all the Siemens certification requirements to teach SMSCP curriculum at one or more of the three levels. In order for an instructor to become certified, he/she must complete the Siemens System Approach Paradigm Week training and the course content/curriculum training that corresponds to his/her desired Certification Level. During the Instructor certification process, participants are expected to actively participate in all training activities, demonstrate an openness to [the] System Approach, as well as design and teach a sample lesson for that Level’s curriculum.

SMSCP Instructors come from a variety of technical backgrounds. Typically, instructors have an educational and teaching background in one or more of the related subject areas of Mechatronics. These include electrical engineering, mechanical engineering, or software and computer engineering.

The three levels mentioned in the paragraphs above are described in the Siemens Student level brochure as follows (http://www.siemens-certifications.com/content/0/9131/9147/9180/3138_SMSCP_Students_mit%20mail_ohne_web.pdf):
The SMSCP has three qualification levels that correspond to specific job profiles. The job profiles clearly define the certified qualification and skills of the graduates. The three levels are as follows:

Level 1:
Siemens-certified Mechatronic Systems Assistant. Emphasis is placed on efficiently operating complex mechatronic systems, troubleshooting and foreseeing problems.

Level 2:
Siemens-certified Mechatronic Systems Associate. The focus in Level 2 is on systems management, investigation, repair and troubleshooting.

Level 3:
Siemens-certified Mechatronic Systems Designer. Corresponds to university-level engineering education. Emphasis is placed on systems design and project management.
APPENDIX D

INFORMED CONSENT FORM
Informed Consent Form - Interview

I ________________________ agree to participate in the research project titled “Implementation of Systems-Level Learning Within a Community College Mechatronics Program” being conducted by Margie Porter a graduate student at Northern Illinois University. I have been informed that the purpose of the study is to provide a description of the current practices of systems-level learning (SLL) within a community college level mechatronics program. The focus of my research is on implementation of SLL and not on evaluation of that program. My study examines the ‘how’ and ‘why’ of long-term implementation of a SLL pedagogy throughout a curriculum in a department.

I understand that if I agree to participate in this study I will be interviewed about my experiences implementing a systems-level learning pedagogy. This interview will take approximately 90 minutes and will be conducted in person at the college.

I am aware that my participation is voluntary and may be withdrawn at any time without penalty or prejudice and that if I have any additional questions concerning this study I may contact:
Margie Porter Dr. Gene Roth
(847) 543-2904 NIU Faculty Advisor
margieporter@clcillinois.edu groth@niu.edu

I understand that if I wish further information regarding my rights as a research subject I may contact the Office of Research Compliance at Northern Illinois University at (815) 753-8588.

I understand that the intended benefits of this study include research findings which will be available to faculty and administrators that can help to inform them as they consider changes to a SLL pedagogy as they seek to implement pedagogical innovation and which can help them to learn from others who have made the journey before them.

I have been informed that potential risks and/or discomforts I could experience during this study include possible loss of confidentiality. I understand that all information gathered during this experiment will be kept confidential and no names of individuals nor the name of the college will be used or mentioned specifically in the results of this study.

I understand that my consent to participate in this project does not constitute a waiver of any legal rights or redress I might have as a result of my participation and I acknowledge that I have received a copy of this consent form.

_____________________________________   _____________________________ Signature of Subject         Date

I consent to have my interview audio taped.

_____________________________________   _____________________________ Signature of Subject         Date
**Interview Questions**

The semi-structured interview questions for the faculty teaching SLL and who have a history with implementing SLL are as follows:

1. Please speak briefly about your background – your industry experience, how long you have been with the college, and your current role at the college.

2. How were you introduced to SLL?

3. How were you trained in SLL?

4. How is SLL different than other ways you have taught engineering curriculum?

5. Why did the college look at implementing the SLL?

6. Please describe what the first year of implementation was like.

7. What changes were made to the curriculum as a result of becoming a Siemens partner school? Pedagogy (PBL, SDL, ETC), teaching strategy, etc.?

8. How was the training passed on to other instructors who did not attend Siemens training?

9. How was the change to SLL disseminated?

10. What makes a class a good example of systems-level learning?

11. What do you do in the classroom that is unique to SLL?

12. If teamwork is taught, how is it being taught – how is it being integrated into the curriculum?

13. How do you know that SLL is successful?

14. Describe what differences there are, if any, in the way students are assessed in SLL as compared with other ways contemporary classes are assessed?
15. How do the students trained using SLL perform in troubleshooting and problems encountered in the lab work compared with other ways troubleshooting is taught to students?

16. How do the students trained using SLL perform in the fluidity of knowledge – being able to apply it to situations that are new, compared with the performance of students that are taught using other pedagogy?

17. How does content knowledge compare between the students trained using SLL versus that of students that are taught using other pedagogy?

18. Describe the motivation to succeed of students in SLL versus the motivation of students that are taught using other pedagogy.

19. What were the stumbling blocks, if any, in implementing SLL, with students or with the academic community with respect to your goals for the program?

20. What would you modify if you could, to the curriculum or to the SLL you are performing in the classroom?

21. Describe what practices were most effective and helpful in implementing SLL in the classroom.

22. There has been a lot of talk in the engineering education community about the need for change in engineering education. Your college has implemented the first and second levels of systems-level learning. What are your thoughts about how the SLL addresses or does not address the call for changes to an engineering degree (not to an engineering technician degree)?
Interview questions for the chair of the department will be as follows:

1. Please speak briefly about your background – your industry experience, how long you have been with the college, and your current role at the college.

2. How were you introduced to SLL?

3. How were you trained in SLL?

4. How many people were trained in SLL?

5. How is SLL different than other ways you have taught engineering curriculum?

6. Why did the college look at implementing SLL?

7. How long has the college incorporated SLL in the mechatronics department?

8. Please describe what the first year of implementation was like.

9. What changes were made to the curriculum as a result of becoming a Siemens partner school? Pedagogy (PBL, SDL, ETC), teaching strategy, etc.?

10. How was the training passed on to other instructors who did not attend?

11. How was the change disseminated?

12. What are the characteristics and attributes of successful SLL instructors in general?

13. How do you know that SLL is successful?

14. How do you know it is being implemented throughout the curriculum? Are there any incentives to do so?

15. Were there stumbling blocks in implementing SLL, with students or with the academic community?

16. What would you modify if you could, to the curriculum or to the way SLL is implemented in the classroom?
17. Please describe some effective and helpful practices that were used to implement SLL in the department.

18. There has been a lot of talk in the engineering education community about the need for change in the engineering education. Your college has implemented the first and second levels of systems-level learning. What are your thoughts about how SLL addresses or does not address the call for changes to an engineering degree (not to an engineering technician degree)?
APPENDIX F

SIEMENS PARTNER COLLEGE COURSE DESCRIPTIONS
LEVEL 1 COURSES

Level 1 Course 1: Electrical Components

Course Description
This course covers the basics of electrical components in a complex mechatronic system. Based upon a physical system students will learn the basic functions and physical properties of electrical components and the roles they play within the system. Technical documentation such as data sheets schematics timing diagrams and system specifications will also be covered. By understanding the complete system the flow of energy through it and measurements on the components students will learn and apply troubleshooting strategies to identify localize and (where possible) correct malfunctions. Preventive maintenance and safety issues for electrical components within the system will be discussed.

Level 1 Course 2: Mechanical Components and Electrical Drives

Course Description
This course covers the basics of mechanical components and electrical drives in a complex mechatronic system. Based upon a physical system students will learn the basic functions and physical properties of mechanical components as well as electrical drives (AC and DC) and the roles they play within the system. They will also learn about mechanical components which lead and support the energy through a mechanical system to increase efficiency and to reduce wear.
and tear. Materials lubrication requirements and surface properties will be examined. Technical
documentation such as data sheets and specifications of mechanical elements and electrical
drives will also be covered. By understanding the interworkings of the complete system students
will learn and apply troubleshooting strategies to identify localize and (where possible) correct
malfunctions. Preventive maintenance of mechanical elements and electrical drives as well as
safety issues within the system will be discussed.

**Level 1 Course 3: (Electro) Pneumatic and Hydraulic Control Circuits**

**Course Description**

This course covers the basics of pneumatic electropneumatic and hydraulic control circuits in a
complex mechatronic system. Students will learn the functions and properties of control
elements based upon physical principles and the roles they play within the system. Technical
documentation such as data sheets circuit diagrams displacement step diagrams and function
charts will also be covered. By understanding and performing measurements on the pneumatic
and hydraulic control circuits students will learn and apply troubleshooting strategies to identify,
localize and (where possible) correct malfunctions. Preventive maintenance of (electro)
pneumatic and hydraulic components as well as safety issues within the system will be
discussed.

**Level 1 Course 4: Digital Fundamentals and Programmable Logic Controllers**

**Course Description**

This course covers the fundamentals of digital logic and an introduction to programmable logic
controllers (PLCs) in a complex mechatronic system with a focus on the automation system
SIMATIC S7-300 and the appropriate programming software STEP7. Using computer
simulation students will learn the role PLCs play within a mechatronic system or subsystem. They will also learn basic elements of PLC functions by writing small programs and testing these programs on an actual system. Students will learn to identify malfunctioning PLCs as well as to apply troubleshooting strategies to identify and localize problems caused by PLC hardware.

**LEVEL 2 COURSES**

**Level 2 Course 1 - Process Control Technologies**

**Course Description**

This course covers topics in Closed Loop Control and technologies used in Process Control in the context of a complex mechatronic system. Based on a real system students will learn the basic functions related to obtaining knowledge of plant documentation and manuals making suggestions for use in future analysis creating sets of suggestions for future analysis and creating diagrams that show the interaction between controller sensors and actuators. The course focuses in helping students to be able to characterize a system by its step response function and creating and interpreting charts with diagrams for time-based changes of measured values. Students will learn how to establish controller operating parameters and learn the difference between the types of controllers that are typically used in mechatronic systems. PID controllers will be introduced and discussed along with strategies for optimizing them. Based on the step response functions mentioned above students will learn how to determine which controller is the best one to use. The advantages and disadvantages of ON/OFF and PID controllers are covered in certain systems. Finally, optimization and troubleshooting of industry controllers is covered.
Level 2 Course 2 - Introduction to Totally Integrated Automation

Course Description

This course introduces the Siemens concept Totally Integrated Automation by looking at the automation pyramid. Students will start at the field level with analogue sensors and actuators and later on go up to the control level with programming and networking PLCs.

The course begins with connecting different analogue sensors (for example voltage, current and resistance sensors) to analogue modules. In order to write a PLC program with analogue values course participants need to know how to use real numbers. In order to work with these and other kinds of numbers the participants also need to get to know additional STEP 7 functions like comparison memory arithmetic conversion and jump functions.

Later in the course participants will learn the basics of MPI-Bus and PROFIBUS systems. PLCs will be connected to each other with a bus cable in order to create an MPI network with the corresponding data configuration in STEP 7. PROFIBUS modules are going to be wired with bus cables to a PLC. Additionally maintenance and troubleshooting of these bus systems are essential components of the course.

Level 2 Course 3 - Automation Systems

Course Description

The Automation Systems course in the Level 2 certification program is divided into two main branches; Manufacturing Technologies including CNC CAD and CAM; and Microcontrollers and Programming which constitute essential tools in modern manufacturing particularly in mechatronic systems. When breaking down a system into its constituent modules it is likely to find a microcontroller as the intelligent core of the entire structure. The
microcontroller section begins to explain the theory behind microcontroller and microprocessor architecture and focuses later on its features and ways of interaction with other electronic elements understanding its particular function and its role as part of a whole. This theory is complemented with practical exercises that reflect the importance of microcontrollers in a mechatronic system. The use of component data sheets for reference calculations and design is also explained. The course culminates with the instruction of Assembly Language programming which is applied when operating microcontrollers and designing and constructing devices that include this type of element. Basic programming skills can be taught parallel to the instruction of the Assembly syntax at the earlier stages as needed. This section makes up for approximately 60% of the total material for Manufacturing Automation.

For the remainder of the class the emphasis turns to manufacturing automation. In this section the main concepts to be covered include Metal Cutting Modal Analysis CNC CAM and CAD. These tools provide students with part of the skill set necessary to maintain and improve mechatronic systems. The class can concentrate on one or more of these topics as needed in each particular case and depending the students’ background. The metal cutting section includes references on material properties tool geometry and mechanics for manufacturing processes. The section on CNC is one of the main focuses of this part of the course and it includes different types of commands an introduction to CNC design and general algorithms. The CAM section explains the use of NC APT parametric definitions as well as tool geometry. The course ends with a general CAD instruction that can be extended as needed.
Level 2 Course 4 - Motor Control

Course Description

This course covers principles of motor control in part as a continuation of the SMSCP Level 1 course on Mechanical Components and Electric Drives. Even though this course builds on the concepts of the related Level 1 course the Level 1 course is not a prerequisite; equivalent knowledge gained elsewhere will also suffice.

In the first part of the course General Machine Operation different types of braking and loads on a motor are addressed as well as questions of improving motor efficiency and power. Different control techniques are then discussed including different methods of starting a motor controlling voltage and frequency and the role of different sensors in relation to motor operation.

Troubleshooting techniques and an examination of the various causes of motor failure are discussed; preventive measures that can be taken in order to protect motors are also taught.

Level 2 Course 5 - Mechanics and Machine Elements

Course Description

This course focuses on the study of the mechanical components that are included in a complex mechatronic system. It begins with an overview of Statics and Kinetics which includes force system analysis study of equilibrium frames and machines friction and effects of forces on the motion of objects among other basic topics.

The second part of the course focuses on Machine Elements fundamentals and classification of a variety of components expanding the material into calculations involving force
stress and wear analysis as well as calculations to determine the different features from a particular component required in given a system. The course focuses on the employment of these techniques for supporting mechatronic systems and to ensure its proper function correct possible defects that may interrupt the process and to plan preventive maintenance operations on them observing and incorporating locally enforced and general safety standards. Course 5 of Level 2 provides a deeper insight into the principles behind the different components of the system. The course aims to form both high and low level mechatronic experts at production and development facilities.

**Level 2 Course 6 - Manufacturing Processes**

**Course Description**

This course is divided into two major parts: a section on process management and a section on the function and importance of a hands-on design project. In each case a blueprint is presented to instructors that they can use when implementing the course at their school.

For the process management component, a factory simulation is conducted. Each participant is assigned a role and the rules of the simulation are discussed. After a series of runs of the simulation a discussion and presentation is made where participants not only present their performance and progress data but also track what they learned.

For the hands-on design project component instructors are encouraged and supported in creating a useful design project for students. Students are divided into teams informed of the rules of the project given a timeline budget and a “customer” as well as other parameters. After completing the project students present their results and learning outcomes.
Thinking smarter, not harder.

Siemens Mechatronic Systems Certification Program

Information for Students

Siemens, one of the world’s largest high-tech manufacturing corporations, is a leader in complex technologies, particularly in complex systems integrating electrical, mechanical and computer engineering. The marriage of these three engineering fields, better known as mechatronic systems, plays an ever-increasing role in modern technology. As a result, there is a high demand for qualified and motivated personnel. For this reason, the Siemens Technik Akademie Berlin has developed a comprehensive industry skill certification, the Siemens Mechatronic Systems Certification Program, offered together with partner schools worldwide for interested students.

Interested?
www.siemens-certifications.com
APPENDIX H

LOW-COST TRAINERS
I was the Principle Investigator of the NSF CollaborATE grant #1601172. One of the outcomes of this grant was to design and build low-cost equipment trainers that can be used in high schools and colleges to introduce students to mechatronics. Low Cost Trainer #1 (top photo) can be used alone or can be integrated into Low Cost Trainer #2 at the bottom of the page. Both trainers are open source and include lab manuals.