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Leadership Development through Sequential Progressive Mentoring in a Project-Based Learning Environment*

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Data from a survey instrument was used to determine the impact that sequential progressive mentoring in an integrated sequence of design courses had on leadership development. The scope of the research study included all undergraduate freshmen through senior students in a mechanical engineering program for five consecutive years (sample size equals 539). Several key findings were obtained from the survey instrument data. The integrated sequence of design courses had a significant impact on the development of professional skills that increased as students progressed through the sequence indicating that the mastering of these skills required multiple experiences. Leadership development through sequential progressive mentoring benefited both the mentor and the protégé and the benefits increased with time spent on the relationship. The survey instrument items also became self-reported manifest variables that were indexed to the latent variables for leadership experience, past mentored experience, past integrated design experience, skill development, and program culture. Structural equation modeling was performed to delineate relationships between leadership experience and the other latent variables. The modeling showed that the senior leadership experience correlated with the students' skill development and past mentored experiences and not with past integrated design experience in the absence of a mentor. These results were invariant to any particular class or project type.

Keywords: leadership; mentoring; experiential learning; structural equation modeling; project based learning

1. Introduction

The need for professional skills (sometimes termed soft skills, behavioral skills, or non-technical skills) consistently appears on attributes sought by organizations for graduates they hire [1, 2] although research has shown that there are shortfalls in graduates' competencies in these skills [3]. Surveys of organizations in science, engineering, and technology sectors show that leadership is one of the professional skills sought by these employers [1, 2].

Leadership is an essential skill for organizations to sustain high performance in our current competitive, global, and rapidly changing environment. Effective leadership can be the difference between organizations that meet performance expectations or not [4]. There is an understanding that effective leadership can provide organizations with a competitive advantage [4–7]. Amagoh [6] states that "organizations with effective leaders tend to innovate, respond to changes in markets and environments, creatively address challenges, and sustain high performance."

The concept of leadership is expanding from the traditional concept of leader development to the complementary concept of leadership development [7–9]. Leader development focuses on improving an individual's skills and capabilities (human capital) while leadership development focuses on the development of networked relationships among individuals (social capital) for a collaborative organizational approach to leadership. Leadership is moving towards everyone, regardless of title, in an organization moving collectively to define direction and gain buy-in and commitment.

There are many methods used for leader and leadership development [6–13]. Day [8] reviewed the relevant literature and summarized the most popular methods: (1) 360-degree feedback, (2) coaching, (3) mentoring, (4) networking, (5) job assignments, and (6) action learning. In 360-degree feedback, individuals receive feedback for development from the full circle of relevant raters. Coaching is goal-focused development and learning while mentoring is more focused on guidance with career facilitation and psychosocial (e.g., acceptance and encouragement) development. Networking expands a person's understanding of problem-solving resources across different functional areas. Job assignments usually involve stretching a person's leadership abilities through new roles and responsibilities. Action learning is experiential project-based learning supported by colleagues through important work-related problems. After an extensive review of the literature, Bush and Glover [11] concluded that process-rich approaches, such as mentoring, coaching, and action learning, are particularly effective in leadership development. The importance of mentoring in leadership development is frequently cited [5–9, 11–14].

Although the traditional model of mentoring is thought of as a more experienced mentor guiding a less experienced protégé with career facilitation, psychosocial support, and role modeling in a one-

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to-one relationship, that view is expanding to encompass other models. Multiple mentors, either established by the protégée or the organization (i.e., collective mentoring) form a mentoring community that allows the protégée to draw on different areas of expertise as needed [15, 16]. Peer mentoring de-emphasizes the hierarchical structure typically found with the traditional and multiple mentoring models [15]. Another model, termed progressive mentoring [17], have all within a community view themselves as both a mentor and protégé. Information and knowledge is shared up and down through a community that has individuals with multiple levels of experience and expertise. In this model, protégés often found that mentors who were closer to their experience and skill level were more beneficial for specific information and cultural knowledge than a senior member who was much more skilled [17].

Many companies have instituted formal mentoring programs to develop employees and increase retention, although some studies show that it is not as effective as informal mentoring [5, 18]. Protégés with informal mentors receive more career development support and earn more than protégés with formal mentors [19, 20]. These differences have been attributed to formal mentors possibly having less commitment, less similarity in the goals and interests of the protégé, shorter mentoring terms, and personality conflicts [5, 19, 20] in spite of the fact that most formal mentoring programs are voluntary with uncompensated mentors to promote intrinsic motivation in the program [5, 13, 18]. However, in spite of these differences, people with mentors, regardless whether the relationship is formal or informal, generally have better outcomes than those without mentors [19, 20].

Project-based learning can facilitate the development of professional skills, such as leadership, through team work, communications, and mentoring, among other things [21]. It has been suggested to integrate project-based learning with more traditional instruction to address the gap between students' levels of professional skills and those desired by employers [3]. Studies have shown that students exposed to project-based learning have better development of professional skills, such as project and time management, formal and interpersonal communications and teaming, than those without these experiences [22–24]. More specifically, Walters and Sirotiak [25] showed statistically significant improvement in leadership and mentoring through project-based learning in the senior capstone courses.

There appears to be an imperative for leadership development using project-based learning throughout the entire engineering curriculum. Cain and Cocco [21] argue that the senior capstone course alone does not allow students enough opportunities to practice their skills nor faculty to evaluate them and then go on to discuss a continuum of incorporating project-based learning throughout the curriculum. Likewise, Savage, Chen, and Vanasupa [26] similarly argue that project-based learning must be integrated throughout the entire undergraduate curriculum to give students multiple opportunities to master professional skills. Knight and Novoselich [27] used hierarchical linear modeling to analyze a large dataset (i.e., over 5000 undergraduate engineers from 150 undergraduate engineering programs) to show the relevance of independent variables on leadership skills outcomes. Leadership development increased throughout the students' undergraduate experiences and correlated with their experiential learning. Interestingly, pre-college characteristics had little impact on the development of the engineering students' leadership skills. These results are in contrast to the findings of another large study [28] (i.e., over 50,000 students of all majors from 55 campuses) that showed pre-college experiences explained most of the variations in college leadership outcomes for the general undergraduate student population. This is a significant difference and indicates that the deliberate integration of professional skills in an engineering curriculum appears to be an effective method for leadership development among undergraduate engineering students.

There are few programs that integrate project-based learning throughout the entire engineering curriculum. For example, some programs provide separate experiential learning experiences at each grade level in the curriculum [26, 29]. An even richer opportunity for leadership development is through the vertical integration of project-based learning through common projects shared by all of the various grade levels. Examples of this type of project-based learning include the Engineering Projects in Community Service (EPICS) Program, which has large, vertically integrated teams of freshmen through seniors working on service-learning projects [30]. There is also a Vertically-Integrated Projects (VIP) Program that integrates sophomores through PhD students to work on research and development projects [31]. However, in these two examples, students volunteer for these programs and the experience is not shared by all students in the engineering program. Warnick, Schmidt, and Bowden [29] discuss that implementing experiential learning into required engineering courses is a desirable but more difficult approach.

The following points can summarize what has been learned through research into leadership development in engineering education. Leadership is an essential skill for the success of organizations although there is a gap between engineers' skill levels and those desired by employers. Process-rich methods, such as mentoring and experiential learning, are most effective in the development of leadership skills. While project-based learning in the capstone course provides one form of experiential learning, research has shown that students need multiple opportunities to master professional skills. There appears to be an imperative to incorporate project-based learning throughout the entire engineering curriculum although it has been acknowledged that there are problems implementing this approach. Kumar and Hsiao [32] recognize the constraints of adding new courses to a full engineering curriculum or even to a single capstone course. They recommend modifying existing courses to teach professional skills throughout the students' engineering education. However, a review of the literature indicates that there has been limited success implementing this approach, especially for required courses throughout the four-year curriculum. A model is needed to provide sequential project-based learning experiences throughout the entire curriculum to provide the multiple opportunities needed to master engineering students' leadership skills.

A model proposed for this approach is the Integrated Design Sequence, which modifies existing required engineering courses at every grade level to teach design topics through traditional lectures and project-based learning and also vertically integrates the courses through teams of freshmen through seniors working on common design projects. Not only does the Integrated Design Sequence provide students with multiple design, build, and test experiences but students also learn a host of professional skills through managing projects and working on vertically integrated teams. The fact that every engineering student in the program goes through a project-based learning experience at every grade level offers the opportunity for leadership development through sequential progressive mentoring. This study will quantify the impact that multiple opportunities with experiential learning and progressive mentoring have on a student's ability to develop leadership and other professional skills. The model is scalable and transferrable to other engineering programs.

One purpose of this study was to evaluate the impact of sequential progressive mentoring in an integrated project-based learning environment on leadership development. A second purpose was to delineate the relationship between skill development from the design sequence, program culture, previous integrated design experiences, and progressive mentoring on leadership development.

2. Integrated design sequence

The Integrated Design Sequence consists of five mechanical engineering courses, one each spring semester for freshmen through juniors and the two-semester professional practice courses during the fall and spring semesters for seniors. An introductory engineering course for freshmen in the fall semester is a microcosm of the Integrated Design Sequence and has evolved into an informal sixth course of the sequence. The courses use a mixture of traditional lectures to teach engineering design and professional skills, lab periods to allow students to learn practical skills associated with lecture material, and teams to work on design, build, and test projects. An overview of the Integrated Design Sequence is given in this section and a detailed description is given by Stamps [33].

The freshmen course, Integrated Design I, uses traditional lectures to teach the engineering design process and solid modeling software to create three-dimensional and isometric drawings for graphical communications. The students also learn practical fabrication skills in lab workshops that provide skills for senior-led projects. The sophomore course, Integrated Design II, uses traditional lectures to introduce students to the principles of computer-aided manufacturing. Students also expand their capabilities in solid modeling and learn CNC control programming to develop G-code programs for rapid prototyping and numerically controlled milling and lathing through a series of assignments. The junior course, Integrated Design III, uses traditional lectures to teach students experimental methods and the design of experiments. Lab assignments are used to allow the students to acquire practical skills in the use of various instruments and automated data acquisition. The senior fall course, Professional Practice I, uses traditional lectures and workshops to teach professional skills, such as project management, teaming, time management, leadership, professional ethics, and many others. Seniors must also write a proposal and give a formal oral presentation for a two-semester engineering project, perform engineering design calculations, write a design report, and give a formal oral design review. In the senior spring course, Professional Practice II, students complete any remaining engineering design calculations and complete fabrication and testing. Students write a final project report and defend their work before faculty, project sponsors, a program advisory council, and other student integrated design teams. All courses meet at a common time in the spring semester for possible team project work and team presentations.

The Integrated Design Sequence features project-based learning through either senior-led projects or course-specified projects. Rising seniors typically select their engineering projects by the end of their junior year. The projects may be competition-type projects, such as the Society of Automotive Engineers (SAE) Formula Car or the human-powered NASA Rover project, service-learning projects, industrially-sponsored projects, and undergraduate research projects typically for students interested in attending graduate school. An early attempt to require all students in the Integrated Design Sequence to work on senior-led projects resulted in problems. Because of attrition, there were typically more freshmen and sophomores than seniors could effectively manage. To manage this issue, course-specified design, build, and test engineering projects are provided for any freshmen through juniors not selected for senior-led teams. For the course-specific projects, students have also worked on non-senior integrated teams, such as freshmen-sophomore teams, depending on the course instructors.

Senior-led projects are required to have vertically integrated teams. However, team composition and size is determined by project requirements and is not dictated by a rigid formula for each grade level. Team size depends on project complexity and projects may not have a proportionate number of freshmen through juniors due to project requirements. For example, a project may require a large number of juniors for extensive testing requirements.

Typically, senior-led Integrated Design teams will select a project leader and a number of technical area leaders. Teams then determine if they will adopt a mentoring program, which may involve a formal or informal pairing of a mentor and protégée. In a formal mentoring program, non-seniors will typically be assigned to a senior but may also be assigned to a non-senior. It is typical that the mentor will meet with their protégée on a regular basis to answer questions and help the protégé develop project skills. If the mentor-protégé relationship is informal, protégés have a contact person to answer questions when help is needed. Often teams that work on legacy projects, that is, projects that continue year after year, have the technical area leaders help train lower level students to take over their technical areas the following year. For all teams, students are free to seek help from any team member at any grade level as needed. Students are also free to seek help from any faculty member and not just the faculty project adviser.

A freshmen cornerstone course, Introduction to Engineering, has evolved into an informal ancillary sixth course of the Integrated Design Sequence. Taken in the fall semester of their freshmen year, students are introduced to engineering design through project-based learning. Students learn about engineering design through traditional lectures, labs, and a design, build, and test project. Students are taught sufficient introductory physical principles to produce an engineering design, Students are introduced to solid modeling software that can be used to graphically communicate their design. Traditional lectures are used to teach professional skills, such as teaming, project management, time management, and professional ethics. Students form teams to design, build, and test their project. The students document their work in a proposal, design report, and final report. They also defend their work to their peers and course faculty in a formal oral presentation at the end of the semester. Because it contains elements of all of the courses in the Integrated Design Sequence, the Introduction to Engineering course is a microcosm of the Integrated Design Sequence.

3. Method

3.1 Survey instrument

Students in the Integrated Design Sequence complete a survey instrument annually that contain questions pertaining to skill development, program culture, past integrated design experience, past mentored experience, and current leadership experience. Most questions require a self-reported response based on a 5-point Likert scale. For questions on skill development and program culture, the 5-point Likert scale corresponded to 1-No apparent impact, 2-Slight impact, 3-Moderate impact, 4-Substantial impact, 5-Exceptional impact. Questions are identified with an "S" prefix for skill development questions and "P" prefix for program culture questions.

Students answered the following questions in the area of skill development.

S1. *Evaluate the impact that your integrated design course(s) had on your ability to understand the design process.*
S2. *Evaluate the impact that your integrated design course(s) had on your ability to work on a team.*
S3. *Evaluate the impact that your integrated design course(s) had on your ability to develop mentoring skills.*
S4. *Evaluate the impact that your integrated design course(s) had on your ability to develop leadership skills.*

Students answered the following two questions in the area of program culture.

P1. *My integrated design course(s) promoted further interest in my discipline.*

P2. *My integrated design course(s) had a positive impact on my resolve to continue in engineering.*

For questions on past integrated design experience, past mentored experience, and current leadership experience, the 5-point Likert scale corresponded to 1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree. Questions are identified with the prefix "D" for past integrated design experience, "M" for past mentored experience, and "L" for current leadership experience.

Those students who had worked on a senior-led integrated design project answered the following two questions.

D1. *I had a rewarding teaming experience on my senior-led project.*
D2. *I made meaningful contributions to my senior-led project.*

Those students who had worked on a senior-led project and also had a senior who they considered to be a mentor answered the following questions.

M1. *The mentor was able to provide technical advice within his/her area of technical expertise when I asked for it.*
M2. *The mentor provided useful feedback on various aspects of the project (e.g., report writing, presentations, design plans, prototype fabrication, etc.).*
M3. *The mentor was willing to meet with me to discuss problems within a reasonable time frame.*
M4. *The mentor helped me be a more productive team member than if I had done the work without this relationship.*
M5. *My team experience was more rewarding based on the involvement with my mentor.*
M6. *I developed more positive feelings about engineering as my major as a result of the relationship with my mentor.*
M7. *Overall, I had an excellent mentor.*

For the purpose of the survey, a protégé was considered to be a person on the project with whom a senior had regular contact, either informally or by formal assignment, with the purpose of helping them by the use of their technical knowledge, professional skills, or experience. Seniors who had a protégé were asked to categorize the relationship as formal or informal and how much time they spent with the protégé each week, on average. The seniors then answered the following questions.

L1. *I developed leadership skills as a result of working with my protégé.*
L2. *I developed professionally through my relationship with my protégé.*
L3. *The protégé was a more productive team member as a result of our relationship.*
L4. *My teaming experience was more rewarding based on the involvement with my protégé.*

3.2 Structural model study design

The research study design consisted of a five-year pseudo-panel study of student leadership development through sequential progressive mentoring in an undergraduate mechanical engineering program. The design is considered a pseudo-panel design in that each student did not necessarily participate in each subsequent year of the study due to attrition and transfer circumstances. Research has indicated that student self-reported leadership skill obtainment can be enhanced through a myriad of team-led, project-based, co-curricular activities that enable mentorship [27]. The leadership development structural model (Fig. 1) hypothesizes the relationships between the latent variables of senior class Current Leadership Experience, Past Progressive Mentored Experience, Past Integrated Design Experience, Skill Development, and the existing Program Culture.

The dependent latent variable of Current Leadership Experience (of senior mechanical engineering students) was modeled as a causal result of the Past Integrated Design Experience and Past Progressive Mentored Experience, as well as the causal effect of the four-year independent latent variables of Skill Development and Program Culture immersion. Each latent variable was described by observed manifest variables developed from the survey questions.

Structural equation modeling (SEM) techniques have been used in various organizational domains [34] to evaluate leadership development as a causal result of identified independent variables. The SEM technique was utilized in this study to statistically conduct a factor analysis of the model path coefficients and evaluate the model variance and variable correlations. Descriptive statistics were also employed to evaluate specific manifest variable behavior.

3.3 Study procedures and sampling frame

Data used in this study was a survey instrument

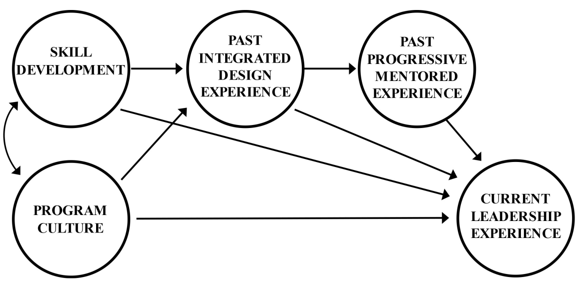

Fig. 1. Hypothesized Leadership Development Structural Model.

Table 1. Latent measurement model constructs with manifest variable descriptors

Skill Development Latent Variable (4)	Past Integrated Design Experience Latent Variable (3)	Past Progressive Mentored Experience Latent Variable (3)
S1. Design Process	IDS Experience (Y/N)	Had Mentor (Y/N)
S2. Team Work	D1. Team Experience	M4. Improved Production
S3. Mentor Skills	D2. Contribution Experience	M5. Improved Team Experience
S4. Leadership Skills		
Program Culture Latent Variable (2)		**Current Leadership Experience Latent Variable (4)**
P1. Promote Interest		Have Protégé (Y/N)
P2. Impacts Resolve		L1. Improved Leadership
		L3. Improved Protégé Production
		L4. Rewarding Team Experience thru Protégé

developed by a program faculty member. This instrument was administered to the entire vertically integrated design sequence; freshmen through senior mechanical engineering students responded to questionnaire items using a 5-point Likert scale at the end of a calendar year, for five consecutive years. The instrument items became self-reported manifest variables that were indexed to the structural model latent variables (Table 1).

A total of 539 questionnaire-based responses (non-probability sample size = 539) from an undergraduate mechanical engineering program (freshmen through senior status students) were collected over a span of five consecutive academic years (Table 2).

The represented students were involved in a vertically integrated, project-based learning environment. Each of the different engineering projects involved freshmen, sophomore, junior, and senior students working on the same project team. This co-curricular learning environment included curriculum-based skill development in the areas of team work, mentoring, leadership, as well as the engineering design process. The project teams were student-led where progressive mentoring was modeled and encouraged; throughout a four-year program of study the mechanical engineering students operated as both mentors and protégés within various project teams.

3.4 *Structural equation modeling (SEM) analysis*

SEM provides a multivariate analysis and aids the conceptualization of complex relationships within both manifest and latent variables. SEM techniques have been utilized in student learning, [35], entrepreneurship [36], psychology [37] and business [38] research. SEM maximum-likelihood estimates were utilized by the IBM AMOS© SEM software in developing and evaluating the specific latent variable measurement models (including manifest variables), as well as the structural model hypothesizing that the Current Leadership Experience is the causal dependent latent variable affected by the two independent latent variables of Skill Development and Program Culture, mediated by the Past Integrated Design Experience and Past Progressive Mentored Experience. The latent variable measurement models consisted of the manifest variables indicated on Table 1.

The primary statistical test of the SEM is the evaluation of the statistical significance of rejecting the null hypothesis that the estimated model covariance matrix equals the observed sample covariance matrix by virtue of a multitude of goodness of fit indices [39]. These indices evaluate metrics based on covariance values, a calculated chi-squared statistic, defined model degree of freedom, model complexity, and sample size as a summary listing.

Contextual (across different senior cohorts, different projects) Invariance Analysis

The 539 study sample database includes a total 125 senior sample size across five years. It is hypothesized that while each senior class (cohort) is comprised of different students that are associated with different projects, individual senior cohorts from

Table 2. Student study participants per study year

Class Status	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Freshmen	29	29	35	29	25	**147**
Sophomore	21	28	33	31	26	**139**
Junior	28	19	23	29	29	**128**
Senior	31	32	15	23	24	**125**
Total	**109**	**108**	**106**	**112**	**104**	**539**

different years (and different projects) fit the general SEM model. Specific senior class contextual differences can be statistically differentiated and evaluated in order to evaluate if the leadership development process varies across the five-year study period.

SEM multi-group invariance (equivalence) analysis [40, 41] evaluates the contextual hypothesis and provides a statistical assessment of the senior cohort context as a moderating factor of the SEM model. This study evaluated the invariance of the SEM latent variable structural model by assessing the invariance of the path coefficients: [Past Progressive Mentored Experience → Current Leadership Experience], [Past Integrated Design Experience → Current Leadership Experience], [Skill Development → Current Leadership Experience], and [Program Culture → Current Leadership Experience]. The basis for the multi-group invariance testing centers on the chi-squared statistic assessment for the summative individual senior class evaluations in reference to the single, simultaneous multi-group assessment. In each case, the results follow a chi-squared distribution. Therefore, the overall invariance analysis evaluates the chi-squared statistic difference between the summative individual senior class analysis and the simultaneous, multi-group analysis; the result itself follows a chi-squared distribution [41]. An insignificant chi-squared result would indicate invariance (equivalence) of the identified senior class structural SEM model path coefficients and indicate that there is no statistically significant difference (as measured by the specific path coefficients) between the identified senior cohorts.

Temporal (Freshmen through Senior) Invariance Analysis

SEM temporal invariance analysis is utilized to identify differences between the freshman, sophomore, junior, and senior classes. It is hypothesized that the degree of skill development varies across the four-year undergraduate mechanical engineering student experience. SEM multi-group invariance (equivalence) analysis evaluates the temporal hypothesis and provides a statistical assessment of the class status as a moderating factor of the SEM model. This analysis evaluated the invariance of the SEM latent variable model by assessing the invariance of the measurement model path coefficients associated with the latent independent variable, Skill Development.

4. Results

Table 3 shows the impact that the Integrated Design Sequence had on the development of student's different skills and their feelings towards their major sorted by grade level. The table reports the percentage of students who responded that the Integrated Design Sequence had a substantial or exceptional impact.

Three observations can be made from the data. The first is that the percentage of students who feel that the Integrated Design Sequence had a substantial or exceptional impact on their major or development of their professional skills generally increased with the number of years they were involved with the program. This supports the argument by others that students need multiple opportunities to master professional skills [21, 26]. The second observation is that a large percentage of students (approximately 85–90%), regardless of grade level, felt that the Integrated Design Sequence had a large impact on their interest in mechanical engineering and their resolve to continue with their major. The third observation is that most seniors felt that the Integrated Design Sequence had a substantial or exceptional impact on the development of different professional skills or different aspects of program culture. The main exception is with the development of mentoring skills. However, this is a reasonable outcome since not every senior had a protégé.

Table 4 shows the impact that the Integrated Design Sequence had on students who were part of senior-led teams who either had a mentor or not. Two trends can be observed. One is that students had a more rewarding teaming experience and made more meaningful contributions to the project with a

Table 3. Percentage of the students by grade level that responded that there was a substantial or exceptional impact of the Integrated Design Sequence on the development of different skills and different aspects of program culture

	Freshmen	Sophomore	Junior	Senior
S1. Understand the design process	75.2%	84.5%	82.8%	89.8%
S2. Work on a team	77.8%	79.6%	89.1%	92.1%
S3. Develop mentoring skills	25.5%	34.5%	38.6%	63.0%
S4. Develop leadership skills	62.5%	68.3%	66.4%	83.5%
P1. Promote interest in my discipline	84.7%	86.5%	89.8%	89.0%
P2. Positive impact on my resolve	84.0%	88.7%	87.4%	89.0%

6-Item Cronbach's Alpha = 0.771, n = 539.

Table 4. Percentage of students that participated in a senior-led project and responded that they agreed or strongly agreed that the Integrated Design Sequence made an impact on their design experience (D-series questions) and, for those who had a senior mentor, the impact that the mentor had on their project experience (M-series questions)

	No Mentor	Mentor	Mentor <1 hour/week	Mentor ≥1 hour/week
D1. Rewarding teaming experience	70.1%	88.1%	80.0%	95.6%
D2. Made meaningful contributions	66.4%	74.6%	70.6%	77.8%
M1. Mentor provided technical advice		85.9%	80.0%	91.1%
M2. Mentor provided useful feedback		85.9%	80.0%	92.9%
M3. Mentor discussed problems in a reasonable timeframe		85.9%	80.0%	91.1%
M4. Mentor made me a more productive member		80.7%	76.5%	84.3%
M5. Mentor made teaming experience more rewarding		79.5%	75.3%	83.1%
M6. Mentor helped develop positive feelings with major		73.3%	70.6%	75.3%
M7. Overall, I had an excellent mentor		83.5%	77.6%	88.8%

2-Item Design Experience (D) Cronbach's Alpha = not applicable, n = 289
7-Item Mentor Impact (M) Cronbach's Alpha = 0.932, n = 177.

mentor than those without. The second trend is that time spent with the mentor mattered. Protégés who spent more time with their mentor reported higher results on every metric reported without exception. One observation is that a large number of students felt that the mentor made for a better experience on the project, i.e., made them a more productive team member (80.7%), made the teaming experience more rewarding (79.5%), and helped them develop more positive feelings towards their major (73.3%).

Table 5 shows the impact of the Integrated Design Sequence on the development of senior mentors. One observation is that time spent with the protégé matters. Significantly higher results are reported for mentors that spent more than one hour per week with their protégé than those who didn't. However, it should also be pointed out that, even for those mentors who spent less than one hour per week with their protégé, the majority still reported benefits in the development of their professional skills. This is an important point for programs that might convert over to a sequential progressive mentoring model. At the beginning of the transition, seniors may be reluctant to invest time with protégés feeling that it's a cost to their available time without any benefits. However, not only does it make the protégé more productive, it offers personal benefits to the mentor through professional growth. A second observation is that, if the mentor is spending more than one hour per week with the protégé, the benefits obtained do not appear to increase if the relationship is formally designated. Finally, with regard to the nature of the relationship (formal versus informal), there appears to be no obvious preferred method for assigning a protégé to a mentor as each has benefits over the other depending on the metric.

4.1 Leadership development structural model

The Leadership Development relationship involved the SEM optimization of the five-latent variable relationship comprising of the 16 manifest variables (Cronbach's alpha = 0.853, n = 125 seniors) listed in Table 1. The result of the IBM AMOS© optimization yielded an SEM model (Fig. 2) with structural and measurement model standardized regression path coefficients ($p < 0.005$), with the exception of the noted three not significant (NS*) path coefficients. The standardized path coefficients, or straight arrows of this model, are considered a validity measurement; the larger the value the stronger the association between the associated variables. As an example, the interpretation of the standardized path coefficient for the Mentor Skills variable (0.69, $p < 0.005$) indicates that an increase in the Mentor Skills attribute results in a direct effect (0.69 multiplier) on the improvement in the Skills Development latent variable.

It is noted that there exists a high correlation (ρ = 0.72), indicated by the curved arrow between the latent independent variables of Skill Development

Table 5. Percentage of seniors having protégés that responded that they agreed or strongly agreed how mentoring impacted their personal development and teaming experience

	Formal Protégée	Informal Protégée	Protégée <1 hour/week	Protégée ≥ 1 hour/week	Formal Protégée ≥ 1 hour/week
L1. Developed leadership skills	79.2%	70.4%	64.3%	90.2%	91.7%
L2. Developed professionally	62.3%	85.2%	57.1%	85.4%	79.2%
L3. Protégé was more productive	75.5%	74.1%	64.3%	87.8%	87.5%
L4. More rewarding team experience	64.2%	70.4%	54.8%	80.5%	79.2%

4-Item Cronbach's Alpha = 0.756, n = 83.

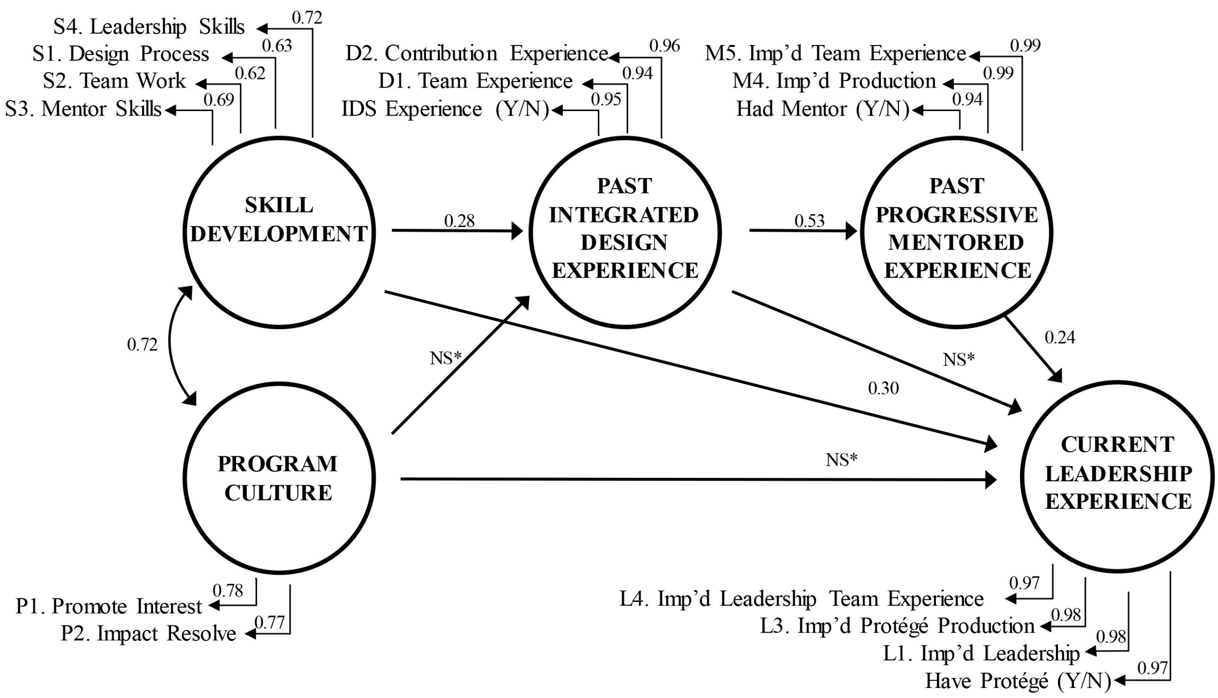

Fig. 2. Leadership development model indicating significant standardized path coefficients n = 125, Group = Total Seniors. ($p < 0.005$) for standardized path coefficient magnitudes illustrated. NS*—path coefficient not significant ($p > 0.2$) for current study; removed from model.

and Program Culture, which indicates that a change in one variable is positively associated with a comparable change in the other variable. This high correlation explains the lack of significance associated with the two hypothesized "not significant" path coefficients associated with the Program Culture latent variable.

The testing of the overall SEM goodness of fit with respect to the null hypothesis that the estimated model covariance matrix equals the observed sample covariance matrix is generally accepted to include the evaluation of several goodness of fit indices with respect to published reasonable fit criteria [42]. The SEM goodness of fit results when compared to the reasonable fit criteria (Table 6), indicate that the SEM model (Fig. 2) is a reasonably good fit with the illustrated standardized path coefficients providing a reasonable representation of the observed data.

An evaluation of the Table 6 indices includes the $\chi 2$/df, GFI, AGFI, PGFI, and RMSEA indices as absolute fit indices reflecting the testing of the SEM null hypothesis of equal model and sample covariance matrices. Only the goodness of fit (GFI) and the adjusted goodness of fit index (AGFI) are slightly outside of the Table 6 reasonable fit criteria. The GFI evaluates the relative amount of the observed variances and covariance accounted for by the model. The AGFI is an adjusted goodness of fit index that makes an adjustment for the degrees of freedom present in the model. Both the GFI and the AGFI tend to decline as the SEM model complexity

Table 6. Leadership Development SEM Goodness of Fit Indices

Goodness of Fit Indices	Reasonable Fit Criteria	Model Results
Degree of Freedom	–	100
Chi-square statistic	–	134.9
Chi-square statistic/df. (χ^2/df)	$\leq$ 2:1 to 5:1	1.35:1
Goodness of Fit Index (GFI)	> 0.90	0.88
Adjusted Goodness of Fit Index (AGFI)	> 0.90	0.84
Parsimony Goodness of Fit Index (PGFI)	> 0.50	0.65
Root Mean Square Error of Approx. (RMSEA)	< 0.08	0.05
Comparative Fit Index (CFI)	> 0.90	0.99
Normed Fit Index (NFI)	> 0.90	0.95
Tucker-Lewis Index (TLI)	> 0.90	0.98
Incremental Fit Index (IFI)	> 0.90	0.99

and model degrees of freedom increase, thereby suggesting that for the given sample size (n = 125) the Fig. 2 model complexity and degree of freedom may be slightly too large.

The comparative fit indices of CFI, NFI, TLI, and IFI compare the fit of the estimated model to a baseline model that has complete variable independence, which is in effect a bad model approximation having no structure [42]. The comparative fit indices all indicate a reasonable fit with regards to the Fig. 2 SEM.

An interpretation of the SEM validity process is illustrated in reviewing the Fig. 2 standardized path coefficient for Skill Development → Past Integrated Design Experience (0.28, $p < 0.001$) which is interpreted such that an increase in the Skills Development attribute of a senior student will result in a direct effect (0.28 multiplier) on the increase of the Past Integrated Design Experience dependent latent variable. The independent latent variable of Skill Development is modeled as being described by the standardized path coefficient (0.63, $p < 0.001$) associated with the Design Process manifest variable, such that an increase in the Design Process attribute will have a direct effect (0.63 multiplier), which effectively increases the Skill Development latent variable. Further interpretation of the SEM validity of the SEM model indicates that the standardized correlation coefficient ($\rho = 0.72$) between the two independent latent variables, Skill Development and Program Culture indicate there exists a correlation between the two variables, implying latent variable dependence.

4.2 Testing for contextual invariance across different senior cohorts, different projects: Cohort and project context as a moderating factor

The evaluation of the SEM where the senior cohort context is suggested to act as a moderating factor evaluated the statistical difference between the five senior cohorts, although the Year 3 Senior Cohort had to be removed from the analysis due to its sample size (n = 15) being too small.

The testing of the structural model invariance (equivalence) between the senior cohorts was chosen to include the significant structural model path coefficients [Past Mentored Experience → Current Leadership Experience] and [Skill Development → Current Leadership Experience]. The process includes the evaluation of the summative chi-squared statistics for each cohort, then comparing the result to the IBM AMOS© SEM simultaneous multi-group statistic for a measure of model factorial significance [40-41]. To evaluate the invariance of the above listed structural path coefficients across the senior cohorts, the summative overall chi-squared value (Table 7) of the four SEMs (χ^2= 655.2, df = 400) was compared with the simultaneous multi-group analysis which yielded χ^2= 659.2, df = 406.

The difference of these two multi-group models yielded $\Delta\chi^2 = 4.0$, $\Delta df = 6$, which was not significant ($p < 0.05$). Therefore, the two structural path coefficients are invariant (equivalent) across the senior cohorts, implying that the two path coefficients chosen to discriminate the structural model do not vary between the senior cohorts, providing support that there is no significant difference between the contextual attributes of the senior cohorts (or the projects they were associated with) in regards to the leadership development experienced.

4.3 Testing for temporal invariance across freshmen through senior students: Class status as a moderating factor

It is hypothesized that the degree of Skill Development (Cronbach's alpha = 0.717, n = 539) varies across the four-year undergraduate mechanical engineering student experience. Therefore, class status is suggested as a moderating factor of the SEM model. The testing of the Skill Development measurement model invariance (equivalence) between the freshmen, sophomore, junior, and senior classes was chosen to include the three measurement model path coefficients [Team Work → Skill Development], [Mentor Skills → Skill Development], [Leadership Skills → Skill Development] associated with the independent Skill Development latent variable. This decision was based on the previous illustrated significance that the Skill Development latent variable had on the Leadership Development SEM (Fig. 2) and the fact that only the senior students provided manifest variable responses to the Current Leadership Experience latent variable. To evaluate the invariance of the above listed manifest path coefficients across the different class years, the summative overall chi-squared value (Table 8) of the four SEMs (χ^2= 26.29, df = 8) was compared with the simulta-

Table 7. Multi-group invariance testing across senior cohorts (and projects)

Model Description	Sample Size	χ^2	*df*
Year 1 Senior Cohort	31	170.3	100
Year 2 Senior Cohort	32	134.4	100
Year 3 Senior Cohort	15*	*	*
Year 4 Senior Cohort	23	166.1	100
Year 5 Senior Cohort	24	184.4	100
Total:	110	655.2	400
Simultaneous Analysis:	110	659.2	406

* Sample size (n = 15) was not sufficient for analysis, this data removed.

Table 8. Multi-group invariance testing across freshmen, sophomore, junior, and senior classes

Model Description	Sample Size	χ^2	*df*
Freshmen	147	3.63	2
Sophomore	139	3.19	2
Junior	128	14.71	2
Senior	125	4.76	2
Total:	539	26.29	8
Simultaneous Analysis:	539	40.24	14

neous multi-group analysis which yielded χ^2 = 40.24, df = 14.

The difference of these two multi-group models yielded $\Delta\chi^2 = 13.95$, Δ df = 6, which was significant ($p < 0.05$). Therefore, the three path coefficients are not invariant (not equivalent) across the class years. This implies that the three path coefficients chosen to discriminate the measurement model do vary between the class years, which provides support that there is significant difference between the temporal attributes of the class years in regards to the skill development experienced. This temporal difference was also observed in the Table 3 assessment of the individual skill development questions. Analysis of the substantive squared multiple correlations associated with the Skill Development latent variable moderated by class status suggests that freshmen students exhibit substantive variance in Team Work, Mentor Skills, and Leadership Skills. In a similar fashion, sophomore students exhibit Team Work as substantive skill, junior students exhibit substantive skills of Mentor Skills and Leadership Skills. Senior students exhibit all four manifest variables (Team Work, Mentor Skills, Leadership Skills, and Design Process) as substantive.

5. Discussion

The Integrated Design Sequence requires students to take design courses every year throughout the curriculum and the opportunity to work on senior-led, vertically integrated teams in a project-based learning environment. It also provides scaffolding for a sequential progressive mentoring model, which offers sequential opportunities for students in teams to view themselves as both mentors and protégés.

A large portion of the students reported that the sequence had a significant impact on the development of their skills in the design process, teamwork, and leadership. The development of those skills generally improved over the four years, indicating that the mastering of professional skills required multiple experiences. A large portion of students, regardless of grade level, reported that the Integrated Design Sequence had a significant impact on their interest in their major and resolve to continue with it.

Sequential progressive mentoring benefited both the mentor and the protégée. Protégées reported being more productive and having a more rewarding team experience compared to their peers without a mentor. Seniors reported that they developed leadership skills and professional skills, in general, through their mentoring experience. They also felt that the protégés were more productive and that they had a more rewarding team experience as a result of their mentoring experience. For both mentor and protégé, the richer the experience (i.e., the more time spent with each other), the larger the impact the sequential progressive mentoring had on all metrics surveyed. There appears to be no clear-cut benefit to either assigning a formal mentor or allowing an informal mentoring relationship to develop.

Student leadership development has been modeled as a causal result of sequential progressive mentoring through a project-based, vertically integrated design sequence. Students enhance their leadership development by participating in experiential-based team projects where the student has the opportunity to serve as both protégé and mentor potentially all four years of the integrated design experience.

The senior leadership experience was found to be affected by the mentoring experience gained during the junior year and the skill development accumulated over the student's Integrated Design Sequence experience. It is interesting to note that no statistical significance (Fig. 2 "NS" path coefficients) was associated with past integrated design experience that did not include a mentoring experience, implying that the project-based, integrated design exposure is not enough. An opportunity to be immersed in a progressive mentoring relationship is what affords student leadership development.

The leadership experience was found to be invariant across the five senior cohorts implying that the particular cohort or the specific project did not matter. The leadership development process was enhanced if the student exercised their accumulated skill development and took advantage of the progressive mentoring opportunities regardless of any specific project context.

Skill development was seen to take place during all four years of the Integrated Design sequence, and the students learned different attributes during the different years. Therefore, there exists a temporal element of leadership development within the skill development process. It takes time to refine leadership and teaming experiences and learn through the progressive mentoring process.

The high correlation between the Program Culture and the students' Skill Development was an interesting finding. The Program Culture as measured by the manifest variables of "promoting interest in the student's major" and "impacting the student's resolve to complete the program" was originally modeled as an independent variable with path coefficients directly affecting the student's integrated design experience as well as the student's leadership experience. These two path coefficients were found to be statistically insignificant due to the high correlation that existed with the skill development latent variable. Multicollinearity is undesirable in structural equation modeling techniques since path regression coefficients are not just a function of correlations between independent and dependent variables, but independent variable correlations among themselves as well. Causality among the Skill Development and Program Culture latent variables was not implied in this study, but a potential consideration for future study may be the investigation of whether the program culture enables student skill development, or if the program culture is developed from the students' skill development process.

6. Conclusions

Mechanical engineering students self-reported the impact that an integrated sequence of design courses employing vertically-integrated senior-led teams had on their skill development, program culture, past integrated design experience, past mentored experience, and current leadership experience.

Based on the responses of students in the Integrated Design Sequence, the following conclusions were drawn from the results of the survey. An integrated series of project-based learning experiences had significant impact on the development of students' professional skills, such as design skills, teamwork, and leadership skills, that improved with time. Protégés have a more rewarding teaming experience and are more productive with a mentor compared to their peers without a mentor. Not only does mentoring benefit the team collectively but mentors benefit personally through the development of their own professional skills. Time spent developing the mentor-protégé relationship matters. The benefits for both the mentor and protégé improve with time spent on the relationship.

Through the use of structural equation modeling, the student's leadership development was correlated with their skill development and their prior mentoring experience and was not dependent on the contextual nature of the project or senior cohort. Project-based design experiences in the absence of mentoring experiences did not contribute to leadership development. Leadership development occurred over each year of the four years of the Integrated Design Sequence reinforcing the idea that students need multiple opportunities to master leadership skills.

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