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Using Student-Generated Problems (SGP) As An Instructional Strategy To Enhance Undergraduate Engineering Students' Knowledge Application Ability And Problem-Solving Skills

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USING STUDENT-GENERATED PROBLEMS (SGP) AS AN INSTRUCTIONAL STRATEGY TO ENHANCE UNDERGRADUATE ENGINEERING STUDENTS' KNOWLEDGE APPLICATION ABILITY AND PROBLEM-SOLVING SKILLS

by

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Department	Teaching and Learning
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Sameera Algarni
August 2021

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ABSTRACT

The Student-Generated Problems (SGP) instructional strategy represents an exclusive area of real-world practice used by some educators to give powerful support and responsibility to college students for their learning experience (Mestre, 2002; Zurcher, Coppola, & McNeil, 2016). Undergraduate Engineering students often have difficulty applying gained knowledge in real-world settings and are reportedly underprepared for workplace challenges (Luo et al., 2015; Negro et al. 2019). This study examined the effects of the SGP instructional strategy used in an undergraduate Electrical Engineering course to determine students' abilities to apply conceptual knowledge and problem-solving skills in real problem lab activities. The need for this study was to prepare students to be able to function well in the workplace environment in the future. The study also investigated whether there were relationships between students' skills in SGP and their problem-solving skills, conceptual, and application knowledge of Electrical Engineering concepts under study.

This investigation employed a quantitative approach, using a within-subject design with pre-post testing. A single group of participants experienced both the regular and SGP instructional strategy. This study's independent variables were the type of instructional strategy– traditional class instruction and the SGP approach. The dependent variables are the students' learning outcomes. This quantitative study used knowledge test (pre and post) to test the students' conceptual knowledge, a Problem-Solving Inventory (PSI) survey to assess the students' self-perception of problem-solving skills, and a problem identification rubric to assess students' knowledge application in the SGP activity.

Limited differences were revealed in the control and experimental group participants' responses of their conceptual knowledge, knowledge application abilities, and self- perception of problem-solving skills. Test scores in the knowledge areas did not have a statistically significant overall relationship with the most of study variables. However, for all three constructs of Students' self-perception of problem-solving, the test revealed that the difference in the test scores for the approach avoidance style construct was statistically significant. But the test scores for problem-solving confidence and Personal Control constructs were not statistically significant between the control and the experimental groups. Further investigation on the connections between these study variables and the SGP instructional strategy is needed to provide a more insightful depiction of the effects of the Student-Generated Problems approach on students' development of conceptual knowledge, knowledge application, and problem-solving skills in electrical engineering concepts.

Although this study did not report a significant difference between the SGP and the traditional group, there appears to be a difference between the mean scores among the two groups. Hence, it can be implied that SGP has the potential to promote knowledge utilization and problem-solving skills among engineering students. This is because SGP enables students to connect and relate classroom concepts to real-world problems, and as a result contextualizing their learning. The findings of this study are significant for engineering instructors who intend to promote knowledge application and problem-solving skills in their teaching. Also, SGP is a constructivist learning approach and the results from this study suggest that it may offer alternative instructions to the traditional teacher-centered approach, thereby helping instructors better prepare their students for their future workplace challenges.

This study was intended to better understand the potential benefits of implementing the SGP instructional approach within the Electrical Engineering curriculum among undergraduate students. Specifically, this study provided insight and understanding about SGP instructional strategy effectiveness in enhancing student learning outcomes. Determining the effect of SGP on student learning experiences is important not only because it could provide alternative instruction to the traditional methods, but also to inform instructors of the potential benefit of undergraduate education instruction. Furthermore, the study served as a guide for instructors on how to implement the SGP instructional strategy in an Electrical engineering course.

CHAPTER I

INTRODUCTION

The following chapter provides an introduction of study describing the Student-Generated Problem (SGP) instructional method, including its theoretical basis, characteristics as a collaborative, active-learning approach. This introduction includes, among other things, the need for practical skills in college engineering courses, discussions about problems and problem solving, and the roles, effects and means of improving students' problem-solving skills. In addition, this chapter focuses on the undergraduate students' conceptual and application knowledge in a real setting. An outline of why SGP is well suited for these professional disciplines and the results of existing research on learning outcomes for undergraduate educational practice follows, including outcomes from the field of engineering where SGP gained momentum.

Research reveals that problem-solving expertise is one of the highly valued and considered skills every student should possess upon graduation (Apostol, 2017; Frensch & Funke, 2002; Mayer, 2011; Niss, 2012; Wu, 2019). However, some students face difficulties in utilizing the knowledge gained in class to solve real-life problems that are multifaceted, complex, and ill- structured (Maker & Zimmerman, 2008; Reinoso, 2011). According to Atkinson and Pennington (2012), the main area that college graduates are deficient in is practical experience. It appears that the reason some students do not apply knowledge gained in the classroom to solving real-life problems is that they exhibited a high reliance on the cues they received from instructors, textbooks and other instructional materials. From that point of view, the instructors are the ones who should teach students how to apply the received knowledge in real life settings by adopting active learning methods that can supplement their traditional lectures (Darmofal, Soderholm & Brodeur, 2002; Faust & Paulson, 1998). Society needs to produce educated college graduates who are capable of utilizing their knowledge to solve real-world problems and thus able to meet the critical needs of the future-world workplace, according to Hains & Smith (2012).

One area in the labor market where there is an increased demand for college graduates who are adept at problem-solving is engineering (El-Zein & Hedemann, 2016; Saputri & Wilujeng, 2017; Stiwne & Jungert, 2010). However, employers have expressed concerns regarding graduates' abilities to apply their class-gained knowledge to solve real industrial problems (Atkinson & Pennington, 2012). Atkinson and Pennington (2012) further state that although organizations have reported the number of technical and engineering recruits who do not meet the required expectations has been reduced from 39% to 32.7% between 2008 and 2010, such cases are still being reported. Specifically, employers conveyed concerns about graduates' ability to utilize their knowledge to solve real industrial problems.

Cazares (2014) conveyed that more than just technical skills are demanded by employers from the newly graduated professionals. Graduates lack employability skills, i.e. the application of subject matter for the world of work (Hossain et al., 2018). According to Boakye and Ampiah (2017), this can be attributed to the lack of classroom instructional practices needed for the delivery of concepts. Because students have not gained enough practical skills in the classroom, i.e. how to apply the theoretical aspects of engineering to the practical concepts of the subject matter, it has impacted their performance in the workplace (Şahin, 2009). To be ready for the workplace, "students must develop adequate conceptual framework (make meaning) and apply those frameworks in solving complex ill-structured problems" (Jonassen, Strobel, & Lee, 2006, p. 139).

Given that a number of students are not able to bridge the connection between theory and practice, there is an increased need to gain a deeper understanding of how students can utilize their knowledge and apply it to a real-world practice (Bao & Koenig, 2019; Zulnaidi & Zamri, 2017; Coppola & Pontrello, 2019; Gobert & Clement, 1999; Yeong, Chin, & Tan, 2019). To address this need, the Student-Generated Problems (SGP) instructional strategy may be utilized to tie theory to practice.

The SGP instructional strategy represents an exclusive area of real-world practice used by some educators to give powerful support and responsibility to college students for their learning experience (Mestre, 2002; Zurcher, Coppola, & McNeil, 2016). As examples, Coppola and Pontrello stated that the Student-Generated Problems instructional materials approach, also referred to as the SGP instructional strategy, "reveal students building directly upon prior knowledge and developing independence, self-reliance, expertise, ownership, empowerment, inclusivity, metacognition, and transferring their understanding to new and potentially unfamiliar content" (2019, p.1).

In this study, the researcher explores the SGP instructional strategy and how it could enhance undergraduate students' conceptual knowledge, application ability, and problem-solving skills. It is critical to gain a deeper understanding of the SGP instructional strategy.

The Gap between Theory and Real-Life Applications

In traditional classrooms, students solve problems after they have been presented with basic knowledge. The students often do not know the rationale for the concepts they are learning. Often, the problems that students face come from utilizing concepts that are limited in focus and abstract in context. Çakir and Tekkaya stated that "... the problems are presented to students after all information is taught, sending the implicit, though false, impression that professional problems only arise in venues where all the information needed for building is already at hand" (1999, p. 137). Therefore, some students appear unprepared to apply classroom-gained knowledge to solve real-life problems. This lack of formulation can be attributed to traditional teaching and passive learning methods. To begin with, traditional teaching, which is adopted by educators in most college subjects, is mechanistic. De Leon (2018) conveyed that mechanistic teaching approaches entail the use of abstract concepts that are not in a position to be demonstrated in experiments but are necessary for interpreting observations from experiments. Educators who have adopted traditional mechanistic instructional strategies typically do not provide for students to experiment on how they would use the knowledge gained in class to solve real-life problems (Kearney & Schuck, 2005; Wubbels, Korthagen, & Broekman, 1997). Often, the traditional teaching focus is on providing intensive theoretical concepts and less on developing students' skills to apply theory to practice such as problem solving and critical thinking (Aljaraideh, 2019).

Teaching and learning experts urge that to fulfill the current educational needs, strong modifications need to be made in the traditional teaching strategies and roles of educational agents (Philip, Unruh, Lachman, & Pawlina, 2008). The adoption of traditional teaching may have lessened undergraduate students' ability to apply knowledge in solving real-life problems. The traditional college lecture is characteristically passive learning, where students adopt the passive role of an information receiver while the instructor acts as an information dispenser. These teacher-centered practices limit students from engaging their thought processes to mitigate meaningful learning and knowledge application (Spier-Dance, Mayer-Smith, Dance, & Khan, 2005). Active learning, on the other hand, assists in achieving the desired learning outcome (De Witte & Rogge, 2016; Gehringer & Miller, 2009). According to Mascolo (2009), students construct understanding through their experiences and actions. Additionally, Ahn and Class (2011) assert that student-centered learning can be promoted by avoiding traditional lecture styles.

Several studies have indicated that college students have learned to rely on cues from the teachers, instruction, textbooks, and other materials instead of training themselves to identify the appropriate technique (Karpicke, Butler & Roediger III, 2009; Houser & Frymier, 2009). When students become accustomed to being directed, either implicitly or explicitly, to the appropriate approach, procedure, and perspective to use, it may lead teachers to falsely assume that the students have acquired metacognitive skills of identifying appropriate approaches, procedures, and perspectives on their own (Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013). As such, when these students are faced with real-life problems that require them to make decisions on their own (i.e., bridge the gap between theory and practice, they are not in a position to identify the appropriate approach and procedures to follow to solve problems). Generally, because of various factors that contribute to students' unpreparedness to apply conceptual knowledge in solving real-life problems, there is a need to bridge the gap between theory and real-life application. It is critical to teach students how to think, instead of teaching them what to think (Baran, Maskan, & Yasar, 2018; Coppola & Pontrello, 2019).

Bridging the Gap with Student-Generated Problems Instructional Strategy

An effective strategy for teaching students how to think, thus, bridging the gap in the teaching and learning process to facilitate the connection between theory and practice, is the SGP instructional approach. By definition, the SGP is an extensive strategy that includes reading a given material, generating problems by students, gathering and distributing the instructor questions to students, solving the questions by students, and finally reviewing the questions and answers by the instructor and students (Coppola & Pontrello, 2019). The theoretical foundation of the SGP strategy adopts the language of cognitive process instruction, which involves the learning process via modeling and thinking aloud the cognitive processes that underlie the gain of knowledge, or implementation of a task, or solving of a problem in a particular academic domain (Wong, 1992). In relation to the SGP approach, students recall knowledge, apply that knowledge to a task, and solve a real-life problem. This approach is valuable to students aiding them in how to align their prior knowledge and transfer conceptual understanding to new and hypothetically unfamiliar knowledge (Pontrello, 2019). Therefore, this approach assists students in applying knowledge and problem-solving skills to increase students' ability to apply knowledge gained in class to solve real-life problems.

The SGP approach is closely related to the generative learning theory. Notably, the generative learning theory utilizes active integration of new ideas with the existing schemata of learners (Grabowski, 1996). The generative learning theory aims to motivate students to actively understand the information they learn by choosing the most pertinent information, consolidating it into a coherent mental representation, and incorporating it with their existing knowledge (Grabowski, 1996; Ritchie & Volkl, 2000). Educators are encouraged by the compelling power of the generative learning theory that shifts students from objective and routine learning of facts to generative learning that involves personal reflection and ingenuity (Ashamalla & Crocitto, 2001).

The SGP instructional strategy can benefit students by them knowing how to apply conceptual knowledge to solving real-life problems. To maximize this benefit, the SGP approach could be applied uniformly throughout the organization and utilization of the subject content learned. One of the benefits of SGP entails the development of more profound comprehension of the subject content learned, with a shift from knowledge acquisition, to use of knowledge and development of a sense of ownership of the subject content (Devon, Paterson, Moffat, & McCrae, 2012). Furthermore, the SGP approach can promote the increase of students' motivation and desire for self-actualization.

The benefits of the SGP approach extend quite well to large educational institutions. It can facilitate the application of theoretical knowledge in practical situations by enabling college students to visualize the relationships between concepts and the entire system (Schwenk & Whitman, 1984). SGP also allows instructors to determine the levels of student understanding. Consequently, the role of SGP can facilitate the improvement of students' conceptual knowledge, application ability, and problem-solving skills.

Conceptual Knowledge

Conceptual knowledge is defined as the "implicit or explicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain" (Rittle-Johnson & Alibali, 1999, p. 175). According to Parinduri, Sirait & Sani (2017), conceptual knowledge is the knowledge of interrelationships among the basic elements. They explain that it relates to classification, category, principles, generalizations, theory, model, and fundamental conceptual knowledge that is acquired through listening, reading, and viewing materials. It is also generated through reflective mental activities and previous experiences. Conceptual knowledge entails the ability to know more than isolated facts and methods.

The importance of conceptual knowledge is that it facilitates the process of knowledge development. Students can learn new theories and concepts better by relating them to unique experiences with previously acquired knowledge (Rittle-Johnson & Alibali, 1999). Following the ability to master basic concepts and methods, students can further build on and develop that existing knowledge by enhancing their practical knowledge. In particular, the emphasis on conceptual knowledge as an understanding of the values underlying procedures connects well with the learning tasks used to measure the basic principle of understanding in real-world activities (Crooks & Alibali, 2014). Research reveals that allowing students to improve their conceptual knowledge through activities is a vital factor in facilitating their practical knowledge ownership (Brown, Iyobe, & Riley, 2013).

As an example, in learning physics and engineering, the idea of concepts refers to the assertion that conceptual knowledge forms the correlations existing between basic introductory physics with some engineering applied subjects (Perdigones, Gallego, Garcia, Rez-Martín & Del Cerro, 2014). It consequently suggests that students studying physics have to acquire and develop a conceptual knowledge to increase their mastery of physics and engineering subjects. The idea of apparent concepts indicates that there is the existence of an apparent relationship between physics and theoretical knowledge. Nonetheless, the idea discloses that conceptual understanding is not mandatory in the mastery of physics. Research by Liu & Fang (2016) explains that a student's perception of a concept reflects his or her level of course materials understanding. In physics and engineering education, some misconceptions, including "friction always hinders the motion," are not hard to correct. The instructor can demonstrate to learners in a case where a frictionless occasion exists. Liu & Fang (2016) further communicate the importance of conceptual knowledge in physics through the illustration that in comparison to physics, engineering focuses more on increased concept analysis in either linear or curvilinear motion. As engineering is more detailed, undergraduate students are compelled to complete physics before taking an engineering course. The assertion suggests that students use physics knowledge as a baseline for the development of the more complex engineering knowledge.

Despite the importance of conceptual knowledge in promoting learning, some students have difficulty applying theoretical knowledge in real life problems (Hofer, Schumacher, Rubin, & Stern, 2018). Conceptual knowledge is usually introduced in course textbooks in a comparatively obvious and orderly limited practice (Weaver, 2020). However, the typical textbooks of procedural knowledge are almost totally unsatisfactory, involving little about the power of knowledge application technique and real problem solving (Brewe, 2018; Hestenes, 1987). Students are left to learn critical procedural knowledge on their own with practice problems. This process is as difficult for college students as it has been for the educators who have failed to provide a scaffolded approach.

According to Kola (2017), researchers attributed students' failure in engineering to a lack of proper the application of concepts to real world problems. The study suggests that students should be provided with an efficient foundation of real-world practices to help them increase their understanding of sustainability problems (knowledge) and complement their practical competence in applying problem-solving approaches. The research further indicates that in most cases, students exhibit an intimate understanding of science, an aspect that is not scientifically correct and is also not easy to change (Kola, 2017). The failure to correct the mistake results in the difficulty of students to learn (or practice) following the fact that they are likely to create connections for learned facts efficiently.

Knowledge Application Ability

In order to be well prepared for a successful future in an engineering career, transforming abstract theory into concrete application is an ability that is undoubtedly the most crucial skill for college students (Zhu, Zhang, Hu, & Ge, 2008). The knowledge application is an important means of training students' practical ability and professionalism. Knowledge application "is the process of applying the knowledge received by a potential user toward the solution of a problem or the attainment of a goal" (Love, 1985, p. 349). Undergraduate students should not only have a solid theoretical knowledge base, but also have strong practical skills in order to develop problem-solving skills in a real-life setting (Kozminsky & Kozminsky, 2001).

Bogdanović (2017) suggests that students apply knowledge gained in science to solve problems through the use of metacognition. Students' knowledge application in science is the ability of students to convert the learned concepts and theories to effective skills for solving both academic problems and real-life situations (Hong & Lin-Siegler, 2012). The aspect of knowledge application entails the integration of knowledge into a well-organized product or service. The use of knowledge by the students also determines their learning capacity and the ability to apply the abstract theory concepts to real-life situations (Cheng & Wang, 2011). Students' knowledge application ability plays a vital role in facilitating knowledge transfer across settings to promote the application of the learned concepts and theories to solving real-life problems.

A study by Khalil & Elkhider (2016) conveyed the importance of students' knowledge application ability to the elaboration theory, where students apply gained knowledge in solving problems. Elaboration theory is a model that is crucial for making sequential decisions by students to help in simplifying the assigned tasks. This theory has a great impact on the study of engineering since it increases the effectiveness of instructions given to students by organizing content. This connection shows the ability of students to apply knowledge through cognitive and psychomotor domains.

Also related to knowledge application ability is the concept of student problems, which refers to the case scenarios that are generated by students to determine the efficiency of the knowledge that they acquire in the problem-solving exercises (Coppola & Pontrello, 2019; Ahn & Class, 2011). According to Krawec & Huang (2016), a problem is defined as an unfamiliar situation or challenge. These types of issues are essential, as they facilitate increased class participation and knowledge generation. By encouraging students to use higher order thinking and problem-solving skills, students are able to experience the complexity of generating real problems that require the synthesis of knowledge gained during the learning process (Ahn & Class, 2011). Students would next practice drafting problems in their groups, drawing from real life situations that require answers that include analyzed and synthesized knowledge. These problems are critical in enabling students to gain practice and master the concepts generated in the classroom exercises.

Problem Solving Skills

Many students face immense challenges in solving problems, since they either have not been introduced to the problem-solving process or they do not understand the problem-solving process. Crogman & Trebeau (2016) stated that the SGP instructional strategy can help students to identify and solve problems that arise, hence promoting their problem-solving skills. Yurco (2014) revealed that allowing learners to own the learning process improves their confidence, which, in turn, improves their academic performance. The ability to engage efficiently in solving problems results from the acquisition of problem-solving skills, which occur because of the newly gained knowledge by students. The ability to apply knowledge efficiently for problem-solving purposes depends on the strength that students have for the application of the knowledge generated from both simple and complex learning. The knowledge application ability of students with high thinking order facilitates students with simple to complex education to engage in situations that increase the ability to engage in problem-solving exercises efficiently, according to Zion et al. (2004).

Problem-solving refers to a high-level ability that facilitates the generation of a solution to a problem. Siringo Ringo, Kusairi, Latifah and Tumanggor (2019) suggested that problem-solving skills include the ability of students to solve problems by using steps consisting of understanding the problem, making plans, implementing the idea, and rechecking the problem-solving process. In the problem-solving process, students must efficiently identify and understand the problems at hand. Consequently, students engage in the process that involves planning the solution to the challenge and utilizing the generated plans to review the solution process for the problem (Siringo Ringo, Kusairi, Latifah, & Tumanggor, 2019). The utility of the process is essential in enabling students to use the acquired knowledge in solving problems. A practical understanding of engineering concepts could provide a source of reference for undergraduate students in solving various engineering-related problems.

Solving problems among students requires cognitive interventions that enable students to internalize problems through cognitive domains. Internalizing a question allows for students to have an efficient ability to solve the issues. A study by Krawec & Huang (2016) suggested that internalizing the SGP instructional strategy helps students to acquire cognitive skills which present an automatic solution to problems. Practicing the learned abilities and utilizing a fundamental approach is useful to improve the ability of students to solve real problems. Students need to exercise regularly for them to acquire effective problem-solving techniques, which are essential in the development of the skills learned in engineering and applied in a real setting.

The problem-solving concept and importance of undergraduate college students' problem-solving skills in engineering learning practice is significant. Problem-solving is defined as "a process of understanding the discrepancy between current and goal states of a problem…" (Hung, Jonassen & Liu, 2008, p. 486). This discrepancy, also known as the gap, is the solution deep space that is investigated during the process of problem solving. Students' comprehensive understanding of engineering concepts provides a source of reference for them in solving a number of problems. One of the main challenges experienced by students studying physics is the task of generating an efficient interpretation of concrete and abstract physics concepts. As such, the SGP approach may assist students in connecting their conceptual knowledge with real problems.

Purpose of the Study

Since engineering problems are more practical than theoretical subjects, students need to be able to determine effective ways of interpreting the gained knowledge and problem-solving skills that will fit various scenarios in the course. Specifically, this study examines the effects of the SGP instructional strategy used in an undergraduate Electrical Engineering course, to determine students' abilities to apply conceptual knowledge and problem-solving skills in real problem lab activities.

Problem solving skills are essential in students' future workplace to help them deal with challenges and innovation. These challenges require them to become professional content masters and skillful problem solvers (Fitriani, Zubaidah, Susilo & Al Muhdhar, 2020). Efficient responses to engineering problems depends on the ability to interpret the questions efficiently so as to understand the critical requirements of the problem and root of the questions. Thus, the SGP approach may be a feasible instructional strategy that can be used to address the problems associated with traditional instructions in engineering. It may enable students to activate their pre-existing knowledge and apply conceptual understanding to promote their ability to identify and generate real-world problems. Furthermore, the SGP approach could help foster students' problem-solving skills in order to ensure that they master the concepts and interpret them to facilitate the efficient ability to handle subsequent problems. In engineering subjects, students need the ability to interpret the learned and generated knowledge and concepts to facilitate more effective, efficient problem-solving skills.

Need for Study

The need for this study is to prepare students to be able to function well in the workplace environment in the future. More specifically, the students can practice and bridge the theoretical knowledge of the course of introductory engineering content. They address problems that have workplace context and solve them as peers link to achievement and individuals on real objects. In the design of this study, students have to identify and plan methods to investigate real problems and learning as students became actively engaged in developing their problem-solving skills as well as improve their knowledge to bridge that knowledge to their future workplace. As a result, the SGP instructional strategy supports students in challenging the individual cognitive understanding of solving problems in real-life situations.

Research Questions and Hypotheses

The research was guided by the following questions and hypotheses:

1. **Does the SGP instructional strategy enhance students' learning outcomes of engineering concepts?**

- Research Hypothesis 1-1: The engineering students who engage in SGP lab activity will obtain significantly higher test score on their conceptual knowledge of Root Locus than do the engineering students who engage in traditional lab activity as measured by the means score on solving the conceptual questions.

- Research Hypothesis 1-2: The engineering students who engage in SGP lab activity will obtain significantly higher test score on their application knowledge of Root Locus than do the engineering students who engage in traditional lab activity as measured by the means score on solving the application problem questions.

2. **Does the SGP instructional strategy promote students' self-perception of problem-solving skills?**

- Research Hypothesis 2-1: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving confidence than do the engineering students who engage in traditional lab activity as measured by the PSI questionnaire.
- Research Hypothesis 2-2: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving approach-avoidance style than do the engineering students who engage in traditional lab activity as measured by the PSI questionnaire.
- Research Hypothesis 2-3: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving personal control than do the engineering students who engage in traditional lab activity as measured by the PSI questionnaire.

3. **Does a correlation exist between students' self-perception of problem-solving skills, conceptual knowledge, application knowledge, and their final score on the Root Locus concept?**

- Research Hypothesis 3-1: There will be a significant correlation between students' self-perception of problem-solving skills and their final score on the Root Locus concept.
- Research Hypothesis 3-2: There will be a significant correlation between students' conceptual knowledge and their final score on the Root Locus concept.
- Research Hypothesis 3-3: There will be a significant correlation between students' application knowledge and their final score on the Root Locus concept.

4. **Which of the predictor variables (final test score, self-perception score, and conceptual knowledge score) are most influential in predicting students' performance during a SPG activity? Are there any predictor variables that do not contribute significantly to the prediction model?**

Benefits of Study

The benefit of this study is a contribution to the literature related to SGP instructional strategy design, specifically exploring the impact of SGP when applying theory to real-life problems. It provides instructors with an example of how students identifying real-life problems may contribute to students' knowledge application ability connection to an authentic problem scenario and, therefore, the effects of problem-solving skills during SGP. It is important to determine whether there is a benefit in using the SGP instructional strategy with an expanded level of knowledge application connection to the student or with conceptual knowledge. The process of incorporating real students as problem subjects and identifying ways to increase problem-solving authenticity during the SGP design is potentially effective; thus, its value to the learning process should be demonstrated. Additional examples of successful implementations of SGP at the undergraduate level are needed to provide instructors with instructional strategies that enhance problem-solving skills and prepare students for the future workplace.

Definitions

Conceptual Knowledge: Conceptual knowledge referred to "implicit or explicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain" (Rittle-Johnson & Alibali, 1999, p. 175).

Knowledge Application: it "is the process of applying the knowledge received by a potential user toward the solution of a problem or the attainment of a goal" (Love, 1985, p. 349).

Problem Solving: "Problem-solving is a cognitive process through which knowledge, skills, and personal experiences are mobilized to identify problems, find solutions, and resolve conflicts effectively" (Fitriani, Zubaidah, Susilo & Al Muhdhar, 2020, p. 46).

Student-Generated Problems (SGP): Student-Generated Problems refers also as Student-Generated Instructional Materials, "as the term implies, asks learners to provide objects that other students can use in their own learning" (Coppola & Pontrello , 2019, p. 1).

Organization of the Dissertation

Chapter I includes an overview of undergraduate students' challenges and needs to make a practical connection of their theoretical knowledge to real-life problems. This background information was provided to contextualize the research topic, identify a gap in the literature, and justify the importance of the current study. This chapter also includes the purpose of the study, the research questions and hypotheses, definitions, as well as organization of the study.

Chapter II includes a review of the literature related to the topic of college students' need for conceptual knowledge, knowledge application, and problem-solving skills. The specific focus of the literature review is on the SGP instructional strategy for undergraduate students who have taken science courses.

Chapter III includes the quantitative methodology and why it is appropriate for answering the research questions in this study. Details are included regarding methods and procedures, participant selection, and data collection and analysis.

Chapter IV includes a presentation of the data with respect to the literature. Findings from the quantitative data analysis are discussed in relation to the relevant research in order to ensure the data reliability and validity.

Chapter V includes the researcher's interpretation and discussion of the quantitative data analysis. In addition, this chapter concludes with a summary of the study, conclusions and implications for practice, as well as recommendations for future research.

CHAPTER II

REVIEW OF LITERATURE

The following chapter provides an overview of literature describing the Student-Generated Problem (SGP) instructional method, including its theoretical basis, characteristics as a collaborative, active-learning approach. This review includes the need for practical skills in college engineering courses, discussions about problems and problem solving, and the roles, effects and means of improving students' problem-solving skills. Because the setting for this study is undergraduate sciences educational practice, most of the focus is placed on engineering. An outline of why SGP is well suited for these professional disciplines and the results of existing research on learning outcomes for undergraduate educational practice follows, including outcomes from the field of sciences since this is where SGP gained momentum.

College Science Challenge: The Need for Practical Skills

College students face many challenges in applying gained knowledge to solve problems in their academics as well as real-life situations. A study by Dunlosky et al., (2013) implied that students face challenges in knowledge application because they do not gain a deep understanding of the taught concepts in class. This lack of practical learning poses a threat of misunderstanding or forgetting the theoretical concepts. According to Paris & Paris (2001), the learning and knowledge application capacity of students relies on their thoughts and actions, which influence their level of understanding. Negative perceptions by some students and instructors may cause a failure in knowledge application because they ignore the concepts, which are necessary to solve the problems they face (Khoshaim & Aiadi, 2018).

Khoshaim and Aiadi (2018) argued that real-life examples help students to gain knowledge and concepts about the practical application of knowledge. Biggs (1999) suggested that the greatest problem in students' ability to apply knowledge lies in the typical manner in which the subjects are delivered and received: note-taking, lecturing, memorization, and practical laboratory sessions that contain specific instructions with predetermined results (Jafari et al., 2017). However, learning engineering concepts is essential for the application in real-life problems. According to Bao and Koenig (2019), students lack the ability and skills to solve problems because they do not get chances to engage in inquiry-based learning where they learn practical concepts.

Thus, the use of real-life problems enables learners to visualize the problem at hand and develop the urge to engage more in real-life situations. Without using real-life situations, students will not be able to gain the skills and concepts necessary for them to solve problems that they face in their careers and normal life. High dropout rates, negative perceptions, and massive failure are significant hindrances to the achievement of educational goals and the ability to solve real-life problems by students since they do not gain fundamental science concepts (Khoshaim & Aiadi, 2018). Thus, there is a need to change the mode of teaching and implement new techniques that engage students comprehensively in their learning to ensure they understand concepts and are familiar with the application strategies.

Students should develop their knowledge application ability and problem-solving skills in real problem situations. The development of these skills is effective through the implementation of methods such as knowledge-based guidance, which aims at learning flexible problem-solving skills. These skills could be improved by explicitly instructing students in generalized forms of schematic knowledge constructions that are applicable to a greater variety of real problems

(Kalyuga & Hanham, 2011). Real problem situations require students' intervention where they are expected to apply their acquired knowledge. A study by Fadeeva, Mochizuki, Brundiers, Wiek and Redman (2010) suggested there is a need to apply real world problems to prepare undergraduate students for future work experience, which is a graduation requirement. The real-world learning opportunities aims at ensuring that the gained conceptual knowledge is useful in real life to promote cohesive existence of students in society. Conceptual knowledge also equips students with critical literacy, which is a key aspect of problem-solving (Boakye & Ampiah, 2017). The implementation of various real-world learning opportunities has the likelihood of enabling undergraduate students to reach optimal levels of learning and gain both conceptual and practical domain knowledge.

Knowledge application in everyday life of science presents students with a platform to engage and extend their conceptual knowledge in solving real problems. According to Coştu (2008), the knowledge application to everyday life problems has a positive learning effect, since it is critical in equipping students with skills to make the connection between their knowledge of science and related everyday situations. An effective approach that assists students to acquire more in-depth, as well as meaningful science education through increased interaction between the learner and the concepts being examined, is the daily life problems. For example, daily life problems targeted in sciences education is expressed as problems that are encountered at the everyday level and is related to life (Tasdemir & Demirbas, 2010; Gulen, 2018). Students who learn problem solving skills through knowledge application in everyday life problems strategies tend to gain knowledge and confidence necessary in solving real-life problems as well as creating ideas to improve situations that require their interventions.

According to Yu, Fan & Lin, (2015), problem solving is often challenging for students because they do not understand the problem-solving process. The authors note that within the use of real-life application examples, it helps to stimulate interest among the students who then feel motivated and confident to apply the problem-solving process in real-problem situations. The use of real-life examples trains learners to develop their ideas based on real-life scenarios or experience. Students need instruction on how to address the issues related to their daily lives to gain better problem-solving skills. More critical, knowledge application assists in building broad concepts allowing new procedures or problems to be well understood. Prahani et al., (2016) argue that students tend to develop interest and eagerness in getting actively engaged in conceptual understanding of abstract details that precisely exist in real problems solving.

Problems and Problem Solving

A number of definitions and theoretical frameworks of problem solving have been published in the literature (e.g., Sugrue, 1995; Hsu, Brewe, Foster & Harper, 2004; Kim & Hannafin, 2011; Nurita, Hastuti & Sari, 2017). Investigators have proposed several definitions related to the major terms, for both problems and problem solving.

Defining Problems

There is no perfect definition of what represents a "problem." It is important, however, for this study, to provide an explanation of a "problem" by gathering some of the common aspects of various definitions. Some of the definitions concentrated on the process of an observable learning task. Leak, et al., (2017) explored the meaning of problems as a "problem set" that commonly delivers as assignments in higher education. These problems, though, "fit consensus about the abstract definition of a problem—the difference between the current state (e.g., knowledge and resources) and a goal state (e.g., a desired outcome), actual concrete problems come in an enormous variety of forms" (Leak et al., 2017, p. 2).

Another physics educational study defined the problem as “a task which requires one to devise a sequence of actions leading from some initial situation to some specified goal” (Reif, 1995, p. 52). However, within the results evaluating shifts, “problems from the bare, abstract questions posed in textbooks to more open-ended questions based on real-world situations”, in educators’ views about problems are introduced (Garrett et al., 1990, p. 4; Hsu, Brewe, Foster & Harper, 2004). An example of real world-problems, *Physics on the Move* units, covers Newton’s laws in differing situations. *Physics on a Plate and Physics for Sport* both reflect the *kinetic theory of gases*. This has the possibility to support students in transferring their understanding among situations and also emphasize their learning by facilitating students to rethink the same physics concepts in a range of real-life situations (Whitelegg & Parry,1999).

Some other definitions emphasize the behaviorist point of view. For example, in 1973 Davis pointed out that a problem is “a stimulus situation for which an organism does not have a ready response” (Davis, 1973, p. 12). Likewise, Woods, Crow, Hoffman, and Wright (1985) considered that a problem is a “stimulus situation for which an organism does not have a response,” while a problem arises “when the individual cannot immediately and effectively respond to the situation” (p. 1).

At the same time, some definitions emphasize the cognitive perspective. For example, Hayes (1980) explained that “whenever there is a gap between where you are now and where you want to be, and you do not know how to find a way to cross that gap, you have a problem.” (p. i). Newell and Simon (1972) indicated that “a person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it”, (p. 72).

Based upon the above definitions, a “problem” is described by researchers providing different perspectives. However, what is common among these definitions are the focus on the task, the problem solver, and the learning goal. Unfortunately, there is no clear definition that describes the connection between the task, solver, and learning goal. After analyzing the “problem” meaning, Wu (2019) conveyed that “a problem arises if there is a gap between task and problem solver, or a barrier between the given state and the problem solver’s goal state” (p. 19). As a result, “problem” should be described based on the learning tasks, inputs, success, principles, framework, structure, and abstractness; this framework enables investigators to research about “problem,” including real-world problems with open-ended, several, and unknown solution directions (Leak et al., 2017).

Problem Solving

The definition and instructional framework of problem solving was developed in past research studies. Newell and Simon (1972) established the framework for understanding problem solving, which provides the essential needed link between learning and performance. Their evaluation of means-ends problem solving can be viewed as a common characterization of the structure of human cognition (Anderson, 1993). Anderson also illustrated that problem-solving needs to be explained with a strength conceptual knowledge to account for variability in behavior and enhancement in problem-solving skill with real practice. From behaviorist viewpoints, Wu (2019) stated that problem solving was commonly labeled as “a passive, reproductive and domain-general stepwise process, which is based on trial and error” (p. 19). Conversely, problem solving was considered by Gestalt psychologists to be an effective and dynamic process, where understanding, reorganization and practical fixedness perform an important role (Fiore, & Schooler, 1998; Wu, 2019).

According to Çalışkan, Selçuk and Erol (2010), problem solving is to know what to do when you do not know what to do. Defined as a procedure, Çalışkan et al., (2010) explained that problem solving is a cognitive method that involves the memory to select the applicable activities, utilize them, and perform systematically. From a cognitive standpoint, the role of problem solving is the most obvious way to explain the learning process. For example, Jonassen (2000) illustrated that problem solving is generally considered as the most valuable cognitive activity in everyday and professional contexts, and most students are needed to and rewarded for solving problems. Similarity, problem solving was described as "cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious." (OECD, 2013, p. 122). Fischer, Greiff and Funke (2012) defined problem solving as "knowledge acquisition and knowledge application concerning the goal-oriented control of systems that contain many highly interrelated elements" (p. 19).

In the knowledge acquisition stage of problem solving Carbonell (1983) noted that "the problem solver is required to focus on the means for problems, knowledge which transfers from previous experience to the current situation, how the knowledge transfer process occurs, and how related experiences are selected from a possibly vast long-term memory of previous problem-solving experiences" (p. 13). While in the knowledge application stage the problem solver employed the learned knowledge to understand the move from given state to goal state (Novick, & Bassok, 2005; Wu, 2019).

A study by Glaser (1984) confirmed that the knowledge application stage led problem solvers through a problem-solving development, and that appropriate ideas are required to state the problem in their own thinking, frame questions, analyze information, generate new thoughts, test hypotheses, and evaluate possible concepts of action. Glaser formulated knowledge application as thinking guides that are presented throughout the various problem sets. Frensch and Funke (1995) indicated that problem solving is a goal-directed "thinking that occurs to overcome barriers between a given state and a desired goal state by means of behavioral and/or cognitive, multistep activities" (p. 18). The problem solvers have to organize their information and deal with ill-defined or more or less well-defined goals (Wu, 2019). The problem solvers do not directly realize how to solve the problem or how to reach the goal (Frensch, & Funke, 1995).

The early research studies on problem solving were typically conducted with relatively simple laboratory tasks that were novel to research participants (Frensch & Funke. 2002; Wu, 2019). For example, Frensch and Funke (2002) noted that these simple novel tasks were utilized for a variety of purposes: (1) they had obviously defined best possible solutions, they were solvable in a relatively brief time, research participants' problem-solving stages could be traced, and so on. Frensch and Funke (2002) then verified that

> the underlying assumption was, of course, that simple tasks, such as the Tower of Hanoi, capture the main properties of "real" problems, and that the cognitive processes underlying participants' solution attempts on simple problems were representative of the processes engaged in when solving real problems (p. 3).

Consequently, a simple problem could be used for reasons of accessibility; the broad view to more complex problems was thought possible. For example, Ewert and Lambert (1932) utilized the disk problem (common name is Tower of Hanoi) in their problem-solving research study. These types of simple novel tasks typically had clearly well-defined optimal solutions, and problem solvers were to be expected to solve the problem within a relatively short period. Ewert and Lambert (1932) expected that the simple tasks could bring together the most important assumptions of real problems, therefore they could utilize such experiments to investigate the problem solvers' cognitive processes while solving real world problems (Wu, 2019).

Another example of the research work on simple laboratory tasks was conducted by Newell and Simon (1972). Their research concentrated on the information processing system theory that mainly focused on three main issues. First, the characteristics of the information processing system are sufficient to define that a task situation is represented as a problem space, and that problem solving requires place as a problem space. In this scenario, the problem solver is efficient in decision problem space to be required to have sufficient knowledge about the task environment. Second, the structure of the task environment defines the potential structures of the problem space for each task a different type of problem space is generated, which means that the task environment can control the problem space. The third issue is the structures of problem space that defines the potential programs that can be utilized for problem-solving. From Anderson's analysis (1993), Newell and Simon did not maintain that there is an internal interpretation of problem space as a whole unit. The generation process is not only supported by problem solvers to dynamically generate paths in the problem space by applying their operators, but also directs their actions to take, in which situation the problem solver thinks about some sequence of actions to evaluate them as well (Anderson, 1993). In this regard, based on the clarity of the problem, which is an essential critical distinction, there are two types of problems—well-defined problems and ill-defined problems.

Problem Solving Types

Research by Jonassen (1997, p. 65) explains the two types of problems—well-defined problems and ill-defined problems—as follows:

> Well-structured problems are constrained problems with convergent solutions that engage the application of a limited number of rules and principles within well-defined parameters. Ill-structured problems possess multiple solutions, solution paths, fewer parameters which are less manipulable, and contain uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized and which solution is best.

Jonassen (1997) stated that the types of problems that students solve vary dramatically, as do the kind of problem situations, solutions, and procedures. The domain, objective, and procedures entailed by a problem might be well-structured such as solving a quadratic equation and identifying molar equivalents or it might be ill-structured such as designing an addition at home, "well-defined or ill-defined, simple or complex, long-term or short term, and familiar or unfamiliar" (p. 67).

An example of a well-defined problem is a predictable mathematical problem such as 2 + 2 = 4. This problem has a definitive and correct answer. On the other hand, "an ill-defined problem has a poorly specified given state, goal state, and/or operators" (Mayer, 2011. p. 112). For example, if a problem does not give specific numbers for all of the needed variables, the algebraic method cannot be utilized, and the problem is referred then to as "ill-defined" according to Ringenberg & VanLehn (2008). In this case, choosing an applicable practice for real life problems is an ill-defined problem since the target and allowable operators are not obviously specified (Mayer, 2011). Most problems encountered in college science courses are well-defined problems, yet most critical problems in everyday life are ill-defined problem (Sensibaugh, Madrid, Choi, Anderson & Osgood, 2017).

Simon (1973) considered the difference between well-defined problems and ill-defined problems as the depth of the problem-solving procedure, which is described as an experimental procedure. To succeed as a well-defined problem Le, Loll, and Pinkwart (2013) convey that the solution procedure for the problem should have: "1) uniquely specified start and end points, 2) a formal procedure that describes the transition between the start and the end points, and 3) an evaluation function which verifies the correctness of the state transitions" (p. 260). Le, Loll, and Pinkwart (2013) concluded that the solution of the well-defined problems, which consist of one solution, were smaller and simpler than that of the ill-defined problems, which include an open-ended solution space.

In this regard, Ringenberg & VanLehn (2008) illustrated that one of the biggest failures in physics learning practice is that physics teaching methods lead to shallow learning. In particular, physics students, regardless of their course scores, have a poor conceptual understanding of the course content being taught. One potential source of this discrepancy between conceptual understanding and knowledge application is that teaching methods depend heavily on the utilization of well-defined problems as both the main practice and evaluation activities (Ringenberg & VanLehn, 2008; Leonard, Dufresne & Mestre, 1996). Although it is critical for students in physics courses to be able to solve the well-defined problems, it is definitely not enough to be successful in the work force.

Mayer (2011) noted that the major challenge to effective problem solving is students' understanding of concepts. For example, in most problem-solving settings, students should use an object in a real situation, such as utilizing a brick as a doorstop or using a pencil as a bookmark. When students can only conceive of applying an object in its most common function, a brick for building and a pencil for writing, the problem cannot be solved. Ringenberg and

VanLehn (2008) argued that effective strategy for attempting to enhance physics students' conceptual understanding in the classroom practice setting is the use of ill-defined problems. The authors observed that ill-defined problems cannot easily be solved using algebraic shortcuts; they need first to be qualitatively approached to verify what conceptual knowledge is required to solve the problem. To achieve conceptual understanding of an ill-defined problem, students are required to have confidence in solving ill-defined problems which is helpful for conceptual understanding (Ringenberg & VanLehn; 2008: Lund, 2019; Sensibaugh et.al, 2017). Students should be required to evaluate the problems in a conceptual way to determine which theories and equations to use to decide what numbers need to be specified to make the problem well-defined. This way of learning could encourage students to evaluate the principles on a deeper level as they understand the weaknesses of any problem.

Problem Solving in Real Situations

Cognitive science research, which concentrated primarily on problem-solving and reasoning, has been shifting to real situations involving everyday problem-solving in the subject matter (Dörner & Funke, 2017; Mayer, 2011; Holyoak & Morrison, 2005). Research on real situations problem solving has shown that students not often utilize concepts taught in the classroom to solve problems real-life sitting (Slavin, 2019; Khoshaim & Aiadi, 2018). For example, Pavkov-Hrvojević & Bogdanović (2019) examined physics students' real problem practice to understand the level of these problems linked between physics and other subjects that were represented in the classroom. The researchers' results showed that students often do not make real-life connections or connections between physics and other subjects. The lack of these connections has impacts students' conceptual understanding of physics. The National Research Council (2003) found that undergraduate students were not able to use the course content taught.

Instead, they developed practical skills suited to real situations. For example, “the ratio strategy in which the problem solver notes that the larger one is a better buy because it costs twice as much and gives you more than twice as many ounces” (Mayer, 2011, p.116).

Another example of problem solving in real situations involves psychologies of subject matter, which is an examination of problem solving in subjects such as mathematics, science, and history (Mayer, 2008). In its place of enquiry, they ask how students think about concepts learned, instructors enquired, how do students think about challenging a scientific theory, solving a mathematics problem, or how do students think as they create an essay or make sense out of a printed passage (Mayer, 2011). This method suggests that teaching content should concentrate on facilitating students to learn the cognitive processes and schemes needed for successful problem solving.

According to Walsh, Howard and Bowe (2007), the goal of educational research in physics is to improve students’ ability to solve problems “as one of the principal goals of a physics course is to produce adept problem solvers who can transfer their knowledge and understanding to real world situations”, (p. 020108-1). Niss (2012) developed conceptual framework for identifying the challenges college students face when solving real-world problems involving physics. Niss used three standards that were formulated in everyday language: 1) the situations described were appropriate to the real world instead of the artificial physics world, 2) the problem solver questions capacity actually posed in the real-world situation, and, 3) their solutions involved the application of physics content.

Conceptual Knowledge during Problem Solving

Problem solving has been shown to increase conceptual knowledge as well as transfer to real life situations (Weaver, 2020). Conceptual knowledge has been specified as the way of understanding the principles and relationships that underlie a specific domain or knowing why (Gilmore & Cragg, 2018). De Jong & Ferguson-Hessler (1996) defined conceptual knowledge as "static knowledge of facts, concepts, principles that can be applied in a certain domain" (p. 107) and it operates as an improvement of knowledge to help students solve problems (Sangguroa & Surifa, 2019). Jonassen (2009) also explained that conceptual knowledge is a way understanding the structure concept in knowledge and its integration with other concepts. Therefore, to solve any engineering problem, students need to have conceptual knowledge.

Surif, Ibrahim and Mokhtar (2012) indicated that students need conceptual knowledge support to solve chemical problems. For example, the content or concepts that students have learned in order to link chemicals and chemical materials to real world experiences can be enhanced through classroom experiments. Surif, et al., (2012) confirmed that in learning chemistry the understanding of chemical concepts (conceptual knowledge). Based on that assumption, students require both real applications of conceptual knowledge (Zulnaidi & Zamri, 2017). Likewise, Zulnaidi & Zamri (2017) stated that students who have developed conceptual knowledge could have the ability and skills to efficiently apply specific procedures to solve problems by using a precise symbolic system effectively. Regardless of this evidence, several experiments have been performed in relation to this dilemma and the findings showed that while many students were able to solve problems, they did not understand the concepts tested.

Weaver, Chastain, DeCaro and DeCaro (2018) conducted a study on undergraduate students studying introductory physics. The students were randomly assigned to practice the electric potential in different instructional structures named *explore-first* and *instruct-first* groups. In the first experiment called "*explore-first*", students in small groups were given an unknown problem to solve. They were not expected to come up with the correct solution but were to utilize prior knowledge to understand the problem. After that, the instructor gave a lecture on the electric potential concept and described the correct solution to the activity. In the "*instruct-first*" experiment, the students learned first from the teacher's lecture, which is a traditional teaching method, and then tried to solve the same problems as the first group. After students examined the activity with the instructor, they took an instructor-created test that involved conceptual knowledge. Weaver et al., (2018) found that the students who studied the problem before receiving instruction on how to solve it were not able to solve it correctly, although in the end outperformed the direct-instruction evaluation group on methods of conceptual knowledge on the test. The *explore-first* group performed a higher score on conceptual understanding, while the *instruct-first* group's test scores were lower. Students in the *explore-first* experiment had the same problem-solving accuracy on the test as the *instruct-first* students. Weaver et al., (2018) interpreted their results to mean that the conceptual knowledge averages were higher in the *explore-first* group.

Another recent study by Serbin, Robayo, Truman, Watson and Wawro (2020) was about students' understanding of algebra. The researchers explored physics students' conceptual knowledge of developing and utilizing the characteristic Equation. Serbin et al., (2020) used the conceptual knowledge framework for assessing the quality of students' conceptual knowledge of both acquiring and utilizing the *Characteristic Equation*—the mathematical equation which is solved to find a matrix's eigenvalues—along a range. Most of the students demonstrated deeper conceptual knowledge of utilizing the *Characteristic Equation* than of acquiring the *Characteristic Equation*. Likewise, most students exhibited deeper conceptual knowledge of acquiring the *Characteristic Equation*. To apply the conceptual knowledge methods in practice, educators should allow students to struggle with a new problem and its material. It is the students' journey through the struggle in order to solve the problem that significant learning occurs.

Application of Knowledge and Problem-Solving Skills Instruction

Recent literature reviews (Siswanto, Susantini, & Jatmiko, 2018; Sumirattana, Makanong, & Thipkong, 2017) concluded that one of the ways that works best during science learning practice is to allow students to develop their application of knowledge ability and problem-solving skills using real life problems. Comparison approaches have also been found to aid in real life problems (Hassinger-Das, Toub, Hirsh-Pasek, & Golinkoff, 2017). Experiments that require science students in applying knowledge in real problem solutions benefits learning outcomes and students' future in the workplace (Forinash, & Wisman, 2005). For example, one of the goals of the introductory physics laboratory is to understand the basis of knowledge in physics, according to the American Association of Physics Teachers (1998). Etkina, Murthy & Zou (2006) stated that the goal of knowledge application in physics lab experiments is to solve real problems. Therefore, students utilized and performed these experiments after they became familiar with a specific concept, or they merged several concepts to solve the real problem. Etkina et al., (2006) then recommended that it is important to encourage students to utilize several concepts and then choose the applicable ones they can practice using the available equipment to solve real life problems. Students can also solve these real problems using different methods and then evaluate the results. Thus, the understanding of the way of applying knowledge becomes especially important in problem solving process.

According to Antonietti, Ignazi, and Perego (2000) students are mostly encouraged to find relationships between the existing problem and other problems or domains; this should prompt the knowledge application ability that students have of previous solutions to the new situation.

The ability to apply previous knowledge to an existing problem involves specific sets of problem-solving skills transfer (Mayer & Wittrock, 1996). Furthermore, if students are aware of the roles of conceptual and procedural knowledge involved in each problem-solving process, they can utilize the concepts that are more in tune with their skills (Antonietti et al., 2000). After all, the effort and degree of problem difficulty in learning and in applying problem solving in real life situations varies according to students' knowledge application ability at hand. Students' knowledge application ability appears to be required to use real problem-solving techniques successfully.

A study by Wahyuni, Indrawati, Sudarti, Suana (2017) developed science process skills and problem-solving skills based on outdoor learning that focused on real life application. Wahyuni et al., (2017) applied the outdoor application learning principles in six major stages: "identify the problem, examine the question (to formulate the problem), create a hypothesis, collect data, analyze the data and make conclusions, as well as build and communicate the report" (p. 167). These six stages required a variety of processes to practice and improve the science process skills and problem-solving ability of students. Wahyuni et al., (2017) found that using the outdoor application learning approach for solving real world problems is a framework that helps students to learn and understand the concept of knowledge, thus enhancing their critical thinking skills and problem-solving skills. The application of knowledge can be used as an instructional strategy in real practice because it demonstrates for students how to learn competently and enhance their problem-solving abilities.

Overall, the best way to address the problem of students' impoverished conceptual understanding is through real life application. The abilities of knowledge application, and skill in solving real life problems is defined as transfer and has long been considered the primary objective of 21st century education (Pugh & Bergin, 2005; Wagner, 2006). Sciences education, in particular, should capitalize on and extend students' conceptual and procedural knowledge by applying instructional methods that train their students to have skills like experts in the subject matter.

Student-Generated Problems

Teaching in ways that facilitate and enhance the application of knowledge taught to situations other than those in which the knowledge was primarily learned is an essential target in science education. It has been recognized that students' abilities to solve problems often results in limited transfer to other problems in which the situation is different (Bao & Koenig, 2019; Zulnaidi & Zamri, 2017; Coppola & Pontrello, 2019; Gobert & Clement, 1999; Yeong, Chin & Tan, 2019). What does effective transfer depend on and how can it be adopted by instructional approach? Student-Generated Problems (SGP) is an instructional strategy related to problem solving (Mestre, 2002). SGP is a potentially effective instructional strategy for students within which to transfer and utilize knowledge to explore their conceptual understanding in real life situations (Coppola & Pontrello, 2019).

In 1995, van den Heuvel-Panhuizen, Middleton, and Streefland defined SGP as "problems generated by the students themselves may reflect in an informal manner, some sort of anticipation of their future learning so serving as a guiding principle for future teaching" (p. 21). SGP is also considered a developmental instructional strategy for critical thinking since it can support students' development of what they know in order to build on subject matter and involve them in higher-order thinking (Rosli, Capraro, & Capraro, 2014). For example, in math practice Lavy and Bershadsky (2003) indicated students not only required to think mathematically but also think critically how to reformulate situations and generate new mathematical problems. Using SGP allows educators to bring their students’ experiences and voices into the real life of practice and recognizes the value of their prior experiences in knowledge construction (Coppola & Pontrello, 2019; Rosli, Capraro, & Capraro, 2014).

Theoretical Foundations

Various cues have the likelihood to trigger cognitive process instruction necessary for the student-generated instructional strategy (Coppola & Pontrello, 2019; Mintzes, 2019). To be more specific, Mintzes (2019) summarized six principles that can guide knowledge practice, provided from research on the cognitive process instruction learning:

> “1) Prior Knowledge Shapes Learning; 2) Learning is a Process of Actively Constructing Knowledge; 3) Experts Organize Knowledge and Approach Problems Differently than Students; 4) Metacognition can Help Students Learn; 5) Students Who can Transfer their Knowledge to New Situations Learn More Readily; and 6) Interactions with Others can Promote Learning” (p. 201)

These principles are essential to build a deep understanding of students’ cognitive instruction process. The Student-Generated Problems instructional strategy can meet the criteria as an example of cognitive process instruction (Coppola & Pontrello, 2019). The authors concluded that it raises the level of students in a class to be co-instructors, inviting them to learn, expecting them to teach others, and to shape and evaluate real practical work. Critically, students then follow through by utilizing the student-generated problems as part of the canonical instructional materials connected with the course of action.

Student-Generated Problems as an instructional strategy can be perceived as a paradigm shift from cognitive theory to constructivism. Students use their ideas and understanding to solve real-world problems, which brings about their cognitive development. Constructivist perspectives have specified instructors' new understandings on how students acquire, process information, and construct knowledge. Considering the Constructivist viewpoint, a number of instructional strategies have been conceived, tested, and now have become common instructional methods in higher education (Jardine, Levin & Cooke, 2020; Jonassen, Mayes & McAleese, 1993; Hung & Amida, 2020; Ulutak & Ataizi, 2005). The Student-Generated Problems instructional method developed as a part of the instructional strategies that reflects active learning and Constructivist philosophy. According to Hung and Amida (2020), "these instructional strategies include problem-initiated instruction, real-life complex ill-structured problems, self-directed learning, and collaborative small group learning" (p. 326). From that point of view, the Student-Generated Problems approach is an instructional strategy for helping students obtain and utilize content knowledge and develop higher-order thinking and problem-solving skills. Examples show students developing directly from prior knowledge and acquiring independence, self-reliance, expertise, metacognition, and transferring their understanding to new and potentially unfamiliar content knowledge (Hsu & Wang, 2018; Coppola & Pontrello, 2019).

The available literature on knowledge gain function and learning emphasizes a constructivist perspective, whereby existing knowledge provides a foundation that can get leveraged when incorporating new information into more complex or sophisticated schemas (Aflalo, 2018). The Student-Generated Problems approach, which is in line with suggestions of constructivism, allows learners to explore specific concepts of learning interest. For example, Hsu & Wang (2018) provided a functional model for learning, focusing on students' cognitive processes that they use to generate meaning as well as understanding from the SGP strategy to encourage algorithmic thinking skills in an online puzzle-based game learning structure. Constructivism philosophy contends that students construct their understanding and knowledge about the real world through experience and reflecting on the same. To generalize, Student-Generated Problems instructional approach claims the significance of belief and knowledge, as well as problem solving skills that learners bring to the learning experience from varying interests and building upon their prior knowledge (Hruby & Roegiers, 2012; Hyslop-Margison and Strobel, 2007).

The Student-Generated Problems approach could be also defined under the umbrella of Elaboration Theory. According to Hamilton (1989), the Elaboration Theory has two types of approaches—student-generated and author-generated. The student-generated elaborations consistently have been found to facilitate and encourage students to search for relevant past experiences and to relate this knowledge and experience to conceptual knowledge. The students are expected to generate personal examples of the specific concepts. This approach induces students to access knowledge derived from experiences accrued prior to the experimental situation. Hamilton noted that this results in a stronger cognitive structure, which should assist transfer of knowledge to real problem-solving situations. Elaboration, then, would enhance the accessibility of related conceptual knowledge through the use of the SGP instructional method. Hamilton (1989), revealed that student-generated elaborations may supply better problem-solving performances because of the nature of the generative activities and their relationship to problem-solving activities. Students are, therefore, exposed to real-life contexts that help them cope effectively by becoming creative and innovative.

Student and Faculty Roles in SGP

One of the biggest challenges of teaching any science course is to get students to see the relevance, the connections, and the applications of course contents utilizing their prior knowledge from other disciplines and from everyday learning experiences (Kearney & Schuck, 2005). Employing the SGP teaching method lends itself to better connect college students to the content of many of courses and meet some of those challenges. The learning practice generated by students, resulting from divergent tasks, can be returned to the class as student-generated instructional materials, such as, problems. Consequent assignments and/or testing based on student-generated materials explicitly allocates the role of "instructor" in the instructional setting (Coppola, 2015).

Searches of contemporary research literature revealed that not many studies have been conducted that focus on the learning that has occurred in college classrooms through the use and generation of real problems by students. However, this is increasingly becoming an area of interest to researchers in science education. The power of this approach is that it is more learner-centered instruction and less teacher-centered instruction, which increases student learning and motivation to learn in many classrooms (Davis, 2013). Students are invited to have more involvement in formulating the direction and content learned in class. The more connections and application they have, the better they will learn new knowledge. A number of studies have indicated that students' ownership of the course results in better retention and better application of knowledge after the course (e.g., McLean, 2020; McCollum, 2020; Weimer, 2002; Blumberg, 2009).

Chin and Chia (2004) noted that there are five stages to implement the using students' questions or problems to drive knowledge building into learning tasks: "(1) identifying the problem to be investigated, (2) exploring the problem space, (3) carrying out scientific inquiry, (4) putting the information together, and (5) presenting the findings, teacher evaluation and self-reflection" (p. 712).

In stage one, in groups, the students discuss their views and share them with the rest of the class. The groups, then, share their individual problems and decide on a topic. Next, they put together their problems in the form of a report. In generating their problems, the students are encouraged to engage in real-life problem-solving roles.

In stage two to explore the problem space, the students are required to answer: (a) What do they know? (b) What do they need to know? (c) How can they find out what they need to know? In the meantime, students write down their ideas and questions on to a Need-to-Know group worksheet. The students also identify the resources that they had to use and the type of tasks they had to engage in to solve their problems. In stage three the students gather information from what they have learned in lecture to solve their own problems. In stage four, the students then provide the written reports as to what they had completed on their Need-to-Know worksheets and what they planned for additional learning tasks. In the last stage, each group gives a short presentation on what they learned about their target topic. Chin & Chia (2004) concluded from their research that the students also had the ability to respond to feedback regarding what they reported about their sources of inspiration for the problems and questions.

A recent study by Davis (2013) described a teaching technique where students generate their own questions in a biology course. Davis asked students to generate their own questions about the topic and worked with the class to answer their questions throughout a particular section of the course. Through discussion and research students became better connected and more motivated to learn the content as the course continued. Davis noted that this method was successful in a number of Biology courses “including anatomy, physiology, environmental biology and introductory biology” (p. 32).

Another example of a study by Yu (2009) using student-generated instructional materials is seen in a recent online learning environment. Yu’s study concentrated on the shift to give some of this responsibility to students, and to expand the sources of course questions that students responded to by allowing them to generate questions. This method in the teaching and learning process enhanced students’ knowledge understanding, question-generation abilities, problem-solving abilities, and cognitive strategy development toward the course materials learned. Yu (2009) concluded the study by recommending instructors adopt student-generated questions to make them accessible at pedagogically applicable points to support students intellectually in online learning environments.

According to Coppola (2015), educators must “rely on the willingness of an instructor to relinquish direct control over every learning resource in favor of directing and supervising the construction of materials that might not be as polished as those of an experienced instructor, but for which the construction might provide students with a uniquely valuable learning situation” (p. 246). Taken together, the role of SGP in teaching and learning is to create a learner-centered classroom environment, which is essential for helping students develop a foundation for critical inquiry and improve their skills in problem-solving (Davis 2013; Nardone & Lee, 2010; Yu, 2009). Implementing the Student-Generated Problems approach as an active learning method is a fundamental change for teachers. Their role shifts from what they tell students about target concepts to what they do to help students learn better, to intellectually engage and practice with the ideas of target concepts (Cook, 2006; Coppola & Pontrello, 2019; Slater, 2020).

Effects of SGP on Learning Outcomes

After discussing the theoretical basis and the role of teaching using the SGP instructional strategy, most scholars turned their attention to several perspectives from which to view the importance and role of Student-Generated Problems as an object of pedagogical and educational research. The research features inquiry-oriented instruction and real-world activity, improvement of conceptual understanding, knowledge application ability, and problem-solving skills perspectives as lenses through which to understand the various research studies and instructional interventions that have been undertaken.

SGP as a Feature of Inquiry-Oriented Instruction

In classrooms where undergraduates are encouraged to be autonomous students, the Student-Generated Problems approach would be a natural and frequent occurrence (Chin & Chia, 2004; Silver, 1994). Inquiry-oriented instruction refers to real learning experiences that involve students in several combinations of generating questions, gathering and interpreting evidence, formulating explanations, and communicating their findings that are reliable with science standards and recent reports (Lee, Linn, Varma & Liu, 2010, p. 71; National Research Council, 1996). Inquiry-oriented instruction extends to the making of student-generated problems that demonstrate and/or incorporate real-life practice. It is one approach of providing students' opportunities to engage in learning and to equip graduates with skills to participate in professional practice in a changing world in a manner that stops them from being passive learners in their learning process (Riley, 2015; Yuliati, Riantoni & Mufti, 2018).

Rasmussen & Kwon (2007) investigated the real learning experiences in student-generated approaches, they developed three aims for inquiry-oriented instruction that extend contemporary dynamical systems approaches. The first goal to engage students in challenging problems that provide an opportunity for them to create their own analytical, graphical, and numerical approaches. Instructors, for their part, facilitate and assist students' self-generated mathematical ideas and inscriptions, often on the way to more typical ones. The second goal is to provide experientially real-life situations that should drive the need for the key mathematical ideas that lead to various techniques of solving differential problems. Instructors' thoughtful guidance with students' thinking has helped students identify such experientially real-life situations. The last goal is for instructors to take responsibility to support students in identifying the relevant concepts they have learned. For example, the analytical, numerical, and graphical methods are three different methods that come only after students have made significant improvement in their participation in the SGP approach.

According to Kuster, Johnson, Keene and Andrews-Larson (2018), students in an inquiry-oriented learning environment engage in activities that promote the emergence of important SGP and solution approaches, such as the mathematical "fodder" accessible to instructors for the progression of the mathematical agenda. Kuster et al., (2018) demonstrated that this fodder was generated by the students as they participated with the mathematical activities that consisted of the instructional sequence, and by sharing in argumentation and justification as students explained their ways of thinking to make sense of the conceptual understanding of others. Along these lines, student inquiry and being thoroughly involved in the learning task sequences provided instructional opportunities, yet it was with the support of the instructor that these opportunities were promoted, developed, and leveraged. Taken together, with inquiry-oriented instruction, one of the key instructional tenets is that students' Informal mathematical thinking is suggested and then leveraged to build up to the more formal mathematics. Kuster et al., (2018) concluded that this tenet gives rise to generating students' ways of thinking and building on student contributions in the learning process.

SGP as a Prominent Feature of Real Work

Real work experiences are the main source of inspiration for many academics who have contributed in an attempt to understand learning (Hero & Lindfors, 2019). The value of real work as practical, real-life activities has been emphasized to enable college students to act as valued, equal and responsible members of their learning process. College science students, in practice, are expected to solve problems (Jonassen, Strobel, & Lee, 2006; Trevelyan, 2007). However, the well-structured, constrained problems that college science, physics and engineering students need to solve in practice fail to prepare them for the complexity of ill-structured workplace problems (Henry, Jonassen, Winholtz, & Khanna, 2010). The Student-Generated Problems instructional strategy that focuses on authentic physics and engineering problems may enhance students' readiness to meet the demands of their future real work (Coppola, 2015). According to Coppola (2015), the attributes of real work include utilizing real sources (problems), using the knowledge that professionals use, collaboration, and peer review to bring intentional reflection into the generation and the enhancement of encouraging creativity through real tasks.

A range of advantages from SGP instructional materials can be attributed to observations of school children all the way through college students, including exam scores, knowledge application, and conceptual understanding (Coppola & Pontrello, 2019; Gobert & Clement, 1999; Yeong, Chin & Tan, 2019). These advantages expand to creating and utilizing prompts for students to explaining concepts learned to themselves (Kramarski & Kohen, 2017). A study by Yu and Wu (2020) recently evaluated student feedback corresponding to possible answers to the student-generated questions, and the learning effects on four classes of seventh graders. Yu and

Wu (2020) concluded that considerably more advantages were obtained from students engaging in feedback-generation for student-generated questions. These advantages were noted in terms of increases in the usefulness of cognitive strategies, the support of better question-generation value, the encouraging of knowledge application abilities, and problem-solving skills.

Zurcher, Coppola and McNeil (2016) also applied the SGP instructional materials approach in an e-Homework Platform, which provided undergraduate science students with a wide-ranging set of practice generating questions that can accompany and improve other instructional resources. According to Zurcher et al., (2016), students were motivated to create their own questions. In addition, educators used this gap as an opportunity to engage their students in building and reviewing course-aligned subject matter within a commercial e-Homework Platform. The students successfully generated about 1,000 open-ended chemistry questions, bridging a variety of cognitive levels that skewed, as expected, on the way to skill-building. The questions generated by students are being utilized by their instructors' currently enrolled students. Consequently, Zurcher et al., (2016) strongly advocated that collaborating with undergraduate students in a "teaching team" can be a broadly effective method for instructors to generate high-quality instructional materials associated with their course subject matter.

SGP as a Means of Improving Problem Solving Skills

From the early stages of the Student-Generated Problems approach, perhaps the most frequently cited motivation for instructional interest is its perceived potential importance in assisting students to become better problem solvers (e.g., Silverman, Winograd & Strohauer, 1992; Silver, 1994; Moses, Bjork & Goldenberg, 1993). In turn, student-generated instructional materials approaches are considered a major driver of the 21st century economy and a required skill for college sciences practice to facilitate and improve students' problem-solving skills (e.g., Coppola & Pontrello, 2019; McLean, 2020; McCollum, 2020; Nordin & Osman, 2018; Yu & Wu, 2020). These cited researchers advocate the use of the SGP approach and student-generated instructional materials for promoting students' problem-solving skills in real life application. However, further knowledge is needed to better understand how problem-solving skills takes shape and how to evaluate it. There is a need to address this gap by examining science students' real-life application through the use of the Student-Generated Problems instructional strategy and characterizing their quality and level of problem-solving skills, particularly in the subjects of physics and engineering, which is of utmost importance in the 21st century (Valentine, Belski, & Hamilton, 2017; Nordin & Osman, 2018).

SGP has been incorporated as a feature of several experimental teaching methods as a means of supporting students to explore problems more completely, thus enhancing students' problem-solving skills. Several researchers (Dolmans, Schmidt & Gijselaers, 1994; Gok, 2010; Leak, et.al, 2017) have described different styles of teaching known as the "open-ended problems" approach. Their descriptions, and those of others, suggest various ways that SGP is embedded in the instructional method. For example, Nardone and Lee (2010) adopted Student-Generated Problem Posing in developing students' learning experiences where teachers are "identifying a focused context to frame the course content and give students a context for developing their problem-posing skills and investing students with responsibility for their learning process and developing their own questions" (p. 15).

Another interesting examination of the Student-Generated Problems strategy has been conducted by Kolarkar and Callender (2016). They involved ill-structured physics problems from algebra-based introductory physics courses for life science students. In general, this study demonstrated that students selected a few problems from their regular homework and made slight modifications to those problems. For example, “some simply replaced surface features, for example, a “bike” from the homework problem to “car” but this was nevertheless deemed significant given the students’ prior perceptions about “never-before-seen” exam problems” (p. 2). Put another way, this method would be effective to give students hands-on experience in selecting and using their conceptual knowledge; to develop problem solving skills in using real materials around them; to enable students to see science, engineering concepts ‘in action’; to enable students to generate and create problems in different learning environment. Moreover, Kolarkar and Callender (2016) results showed that SGP implementation was successful in that the students were able to use their conceptual understanding to come up with modifications to existing problems. They were able to solve their own problems as well as the ones by other groups, and they were able to identify when information was missing from some problems. Kolarkar and Callender (2016) concluded that this was a dramatic improvement in the students’ skills with regard to physics as a whole, and the entire dynamics of the recitation sessions gained a positive effect on their subsequent knowledge and problem solving.

Although there is interest in the Student-Generated Problems approach because of its potential to improve problem-solving, additional interest has been expressed in the simple link established between competence in generating and solving problems. By using student questions, Wagner (2017) described the core principles of knowledge building to improve problem-solving skills in physics education. This study applied five stages of knowledge-building principles to the classroom in the topic of modern physics. The first stage required students to select a knowledge building topic that they would use to generate questions. Stage two, then, focused on fostering the development of questions and ideas, including providing a hook to gain students’ attention and promote the interest of the topic selected. For example, Wagner (2017) noted that “the hook may consist of a news story, a thought-provoking question, guest speaker, field trip or high-quality video" (p. 3). Once students' questions were developed, stage three took place to form Knowledge Building Communities. In this stage, the students' questions were considered afterward in the knowledge building activity as students' opening knowledge grew to develop their problem-solving skills. Stage four referenced the work of the students in the group to highlight the collaborative nature of generated questions improvement in their effort. In the last stage, assessing a knowledge building environment was the focus to engage students with authentic, real-world problems in physics. Wagner (2017) concluded that students became familiar with identifying important questions based on what they needed to know to facilitate understanding the scope of their problem-solving skills.

SGP as a Means to Promote Conceptual Understanding

Interest in the Student-Generated Problems method as a means of supporting students essential knowledge about facts and relations embedded in situations has been obvious for a long time. For example, Spier-Dance, Mayer-Smith, Dance and Khan (2005) advocated the value of using student-generated analogies with undergraduate science students as an approach for promoting conceptual understanding. To be more specific, the Spier-Dance et al., (2005) study involved students in the course developed, completed, and discussed analogies demonstrating a conceptually difficult chemistry subject matter. To evaluate the effect of student-generated analogies, students' performances on a final exam question were analyzed for evidence of depth of conceptual understanding. Spier-Dance et al., (2005) concluded that the students who generated their own analogies performed much better on the exam and showed a high level of conceptual understanding compared to the traditional instruction method.

Mestre (2002) used the SGP strategy as one instructional method to examine students' conceptual understanding and transfer of learning in an introductory physics course. The students were asked to generate mechanics problems. They "were given concept scenarios (i.e., a description of the principles and concepts that apply to a problem and the order in which they apply) and asked to generate problems that matched the scenarios" (p. 11). The result of this study indicated that using the SGP approach is a powerful measurement tool for students' understanding of physics concepts, as well as their capacity to transfer knowledge to real life contexts. In many examples, however, students generated appropriate, solvable problems, and still presented main flaws in conceptual understanding. Mestre (2002) suggested that even good students are lacking in the sense that their conceptual knowledge is structured in memory and linked to real life problem contexts and processes.

More recently, a study by Alibali, Stephens, Brown, Kao and Nathan (2014) examined middle school students' conceptual understanding of algebraic equations by generating story problems to correspond with given equations. The focus of this study was on how structural qualities of the equations—position of unknown, number of operations, and operation type—influenced students' performance on the learning tasks. Alibali et al., (2014) then analyzed the most common types of students' errors on the problem story through writing tasks, with concentration towards examining the types of errors involved in students' conceptual understanding of algebraic equations. As the brief research reports suggested, some scholars found the SGP instructional strategy to have potential as a means of exploring the nature of students' understanding of subject matter.

Researchers have commonly found that there is a critical need to make connection between real life problems and theoretical contents. For example, Alibali et al., (2014) found two main gaps in students' conceptual understanding. The first gap was that students needed a robust understanding of the link between the operation of multiplication and its symbolic representation. The other gap was about the difficulty of students' demonstration and combination of multiple mathematical operations into consistent student-generated problem stories. Therefore, it appears that the SGP method provides not only a window through which to view students' conceptual understandings of subject matter but also a mirror that reflects the nature of their learning experiences. Opening the SGP approach window also offers an opportunity to view aspects of students' knowledge application abilities toward the science field.

SGP as a Window into Knowledge Application Ability

There are several different aspects of SGP that are thought to have important relationships to student application abilities toward conceptual understanding. For example, identifying or generating problems offers a means of connecting conceptual understanding to students' real-life application. Other examples include that the benefits of SGP are many, such as students' ability to strengthen understanding of subject matter, to move from acquiring knowledge to applying it, to reach deeper stages of critical thinking and reflection, and to more readily identify the connections between subject matter, their own learning, and real life setting (Nardone & Lee, 2010; Yu & Liu 2009; Yu & Wu, 2020). Increasing students' real-life application and problem-solving skills are required to investigate a practical skill and its process to ensure that they are fitting within the needs and prior knowledge of the students for whom they are intended (Singh & Haileselassie, 2010). In this study the researcher examines one instructional strategy that exploits SGP and holds the potential for helping students with a wide range of knowledge utilization and skills. The focus of the study is on helping students in introductory physics courses to develop a functional understanding of how to utilize the content knowledge of physics while learning practical problem-solving skills through the implantation of SGP (Singh & Haileselassie, 2010).

Within a classroom activity, possessing effective SGP skills is important as students enter the workplace, where experts' ability to ask effective questions is essential to knowledge application assessment. In a study of one instructional experiment—a mathematics course in junior high school—Lee, Capraro, and Capraro (2018) reported the application of SGP allowed students to connect their knowledge with their experiences or real-life concepts so that it created a better conceptual understanding and ultimately increased confidence. Lee et al., (2018) conclude that the application of the SGP learning was effective in improving students' mathematical knowledge application in problem-solving ability.

Summary

This literature review has described studies pertaining to the structure of SGP as an instructional method, its characteristics, and effects on learning. An overview of the basis for using SGP in undergraduate science education and related studies on outcomes when using SGP was also described, followed by potential effects of SGP on students' knowledge application and problem-solving skills on the learning outcomes, specifically related to real-life problems with student need in a challenging, active learning environment. A discussion of the potential features of SGP as inquiry-oriented instruction and real-world activity, improvement of conceptual understanding, knowledge application ability, and problem-solving skills perspectives as lenses through which to understand the various research studies and instructional interventions that have been undertaken.

Within the literature connect to the structure and landscape of SGP in general, there was a general consensus that SGP provides an active learning approach, more effective students outcomes, and a positive student learning experience (Bao & Koenig, 2019; Coppola & Pontrello, 2019; Gobert & Clement, 1999; Yeong, Chin & Tan, 2019; Rosli, Capraro & Capraro, 2014; Zulnaidi & Zamri, 2017). The biggest challenge of teaching any science course is to get students to see the relevance, the connections, and the applications of course contents utilizing their prior knowledge from other disciplines and from everyday learning experiences (Kearney & Schuck, 2005). By employing the SGP in the teaching method, it lends itself to better connect college students to the content of many of courses and meet some of those challenges. The SGP literature represented examples of a variety of problem presentation formats, including some perceived benefits of using real life problems to provide a context for applying knowledge (e.g. McLean, 2020; McCollum, 2020; Weimer, 2002; Blumberg, 2009).

The specific SGP problem design process real -life problems was vaguely described in the literature refer to science education curriculum (Jonassen, Strobel, & Lee, 2006; Rasmussen & Kwon, 2007; Trevelyan, 2007). A range of benefit from SGP instructional materials can be attributed to observations of college students, including exam scores, knowledge application, and conceptual understanding (Coppola & Pontrello, 2019; Gobert & Clement, 1999; Yeong, Chin & Tan, 2019). Applying SGP approach may allow researchers to systematically compare the SGP in knowledge application and understand the possible benefits of using real problems with more validity than has been described in the existing literature review. To sum up, the literature explained in this review apprised the foundation for the purpose of the current study, the study design, and the development of effective descriptions for the variables of subject demonstration. In the next chapter, the research methodology for this study is provided in detail.

CHAPTER III

METHODS

This study was aimed at examining the effects of the Student-Generated Problems (SGP) instructional strategy on students' ability to apply engineering concepts in real life situations in an undergraduate electrical engineering course. This research study used a quantitative method to investigate SGP's effects and assess the instructional strategy's potential to enhance: (1) students' conceptual knowledge of the topic studied during SGP activity, (2) students' knowledge application abilities to assess knowledge application understanding, and (3) students' perception of problem-solving skills. The relationships between the SGP method and students' conceptual knowledge, knowledge application abilities, and problem-solving skills, and demographic variables were also explored.

The nature of the research questions was well-aligned with using the quantitative method. An experimental research design with a pretest and a posttest quantitative method design is a type of methods research design that collects and analyzes quantitative data to compare the two student groups—experimental group and control group—for understanding a research question and hypotheses. This method also addressed whatever the hypotheses or questions support or whatever they refute within the research design (Creswell & Creswell, 2018). Science educational researchers used quantitative methodologies to address research questions about connection, generalizability, or magnitude of effects (Creswell & Clark, 2011). It is especially useful when variables to be used and/or examined are clearly defined and statistical data is present. Appropriate reasoning for using a quantitative methods approach is when the research design is structured, and the experiment takes place in a controlled environment. In addition, the researcher in a quantitative study remained objective and unbiased (Chen, 2011).

The study's independent variable for this research was the type of instructional strategy used (i.e., traditional instructor-led lab activities versus the SGP approach). The dependent variable included: (1) conceptual knowledge (measured by knowledge tests), (2) knowledge application abilities (measured by lab report activities scores), and (3) problem-solving skills (measured by problem-solving inventory survey (PSI)).

Research Questions and Hypotheses

The research was guided by the following questions and hypotheses:

1. **Does the SGP instructional strategy enhance students' learning outcomes of engineering concepts?**
   - Research Hypothesis 1-1: The engineering students who engage in SGP lab activity will obtain significantly higher test score on their conceptual knowledge of Root Locus than do the engineering students who engage in traditional lab activity as measured by the means score on solving the conceptual questions.
   - Research Hypothesis 1-2: The engineering students who engage in SGP lab activity will obtain significantly higher test score on their application knowledge of Root Locus than do the engineering students who engage in traditional lab activity as measured by the means score on solving the application problem questions.
2. **Does the SGP instructional strategy promote students' self-perception of problem-solving skills?**
   - Research Hypothesis 2-1: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving confidence than do the

engineering students who engage in traditional lab activity as measured by the PSI questionnaire.

- Research Hypothesis 2-2: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving approach-avoidance style than do the engineering students who engage in traditional lab activity as measured by the PSI questionnaire.
- Research Hypothesis 2-3: The engineering students who engage in SGP lab activity will report a significantly higher self-reported problem-solving personal control than do the engineering students who engage in traditional lab activity as measured by the PSI questionnaire.

3. **Does a correlation exist between students' self-perception of problem-solving skills, conceptual knowledge, application knowledge, and their final score on the Root Locus concept?**

- Research Hypothesis 3-1: There will be a significant correlation between students' self-perception of problem-solving skills and their final score on the Root Locus concept.
- Research Hypothesis 3-2: There will be a significant correlation between students' conceptual knowledge and their final score on the Root Locus concept.
- Research Hypothesis 3-3: There will be a significant correlation between students' application knowledge and their final score on the Root Locus concept.

4. **Which of the predictor variables (final test score, self-perception score, and conceptual knowledge score) are most influential in predicting students' performance during a SPG activity? Are there any predictor variables that do not contribute significantly to the prediction model?**

Participants

The participants for this study were 32 undergraduate electrical engineering students enrolled in EE 405: Control Systems I course at a Midwestern university during the 2021 spring semester. Most of the participants were in their last semester of their programs as this was typically a senior level course for students completing their undergraduate major in electrical engineering at the university of North Dakota. Topics normally covered in this Control Systems I are mathematical modeling and dynamic response of linear control systems; stability analysis; design of linear controllers using the root locus and frequency response techniques. This course developed for the students to be able to:

- Identify the methodologies of solving engineering problems, collecting data and interpreting this data.
- Identify the appropriate analytical and computational methods used in electrical power and machines engineering.
- Identify the principles of operation and the performance specifications of electrical and electromechanical engineering systems.
- Analyze, design and implement various methods of control techniques using analogue and digital control systems.
- Formulate the problem through realizing the requirements and identifying the constraints.

All in all, students were able to differentiate between different types of control systems along with systems' properties. Furthermore, students were able to graphically represent different types of control systems and analyze systems' stabilities. All students in the course were seeking an undergraduate degree in engineering. Students were provided with a written informed consent statement per the university's approved Institutional Review Board (IRB) protocol at the start of the course as an addendum to their syllabus. The consent form describes the purpose of the study studying methods of instruction in one of their course lab activities.

Undergraduate electrical engineering students' data were collected between March 21, 2021, and May 13, 2021. The survey link through the Qualtrics software was kept opened throughout this period. The Qualtrics software allowed the researcher to download the entire document through the SPSS. The researcher downloaded all the data and securely saved them on her laptop with a password in order to protect the files from the contact of the public. The total participants number was 39. Of this number, seven participants did not complete all the survey questions or as the study activity. For this reason, their data were deleted from the research. This brought the total number of electrical engineering students, who participated in this study, to thirty-two participants (32). The electrical engineering students survey, on the other hand, was administered in an online section during one of the seminar classes on Zoom. In all, a total of 32 completed the survey and returned the responses to the researcher.

Table 1 below displays the demographic characteristics of the participants in both control and experimental groups. The total number of participants in the control group was 16, with 12 males (75% of the total) and 4 females (25% of the total). Of the 16 control group participants, 12.5% were Sophomores, 81.3% were Juniors, and 6.3% were Seniors. All of the participants were of White ethnicity. Their ages ranged from 20 to 30+ years old with the largest representation of participants between the ages of 20-25 years old, which was 9 or 56.3% of the total participants. All participants in the control group were electrical engineer majors with the exception of one. Fourteen of the participants did not have any engineering internship experience.

In addition, Table 1 also reports the demographic characteristics of the participants in the experimental group. The total number of participants in this group was 16 with 11 Males (68.8% of the total) and 1 Female (26.3% of the total). Four of the participants did not specify their gender. The experimental group included 31.3% freshmen and 68.8% sophomores. Eleven of the participants specified that they were not Hispanic or Latino or Spanish Origin. The participants' ages ranged from 20-25 years old with the exception of one, which was below 20 years old. More than two-thirds (68.8%) of the experimental group were electrical engineer majors. Eleven of the participants did not have any engineering internship experience.

Table 1.

Demographic Characteristics of Respondents in the Study Groups

	Control Group		Experimental Group	
Variable	N	%	N	%
Gender				
Male	12	75	11	68.8
Female	4	25	1	26.3
Not to specify	0	0	4	25
Current Status				
Freshman year	0	0	5	31.3
Sophomore	2	12.5	11	68.8
junior	13	81.3	0	0
Senior	1	6.3	0	0
Age				
Below 20 years	0	0	1	6.3
Between 20-25 years	9	56.3	15	93.8
Between 26-30 years	4	25	0	0
31 years and above	3	18.8	0	0
Major				
No	1	6.3	5	31.3
Yes	15	93.8	11	68.8
Internship Experience				
No	14	87.5	11	68.8
Yes	2	12.5	5	31.3

Instruments

In this study, the instruments that used to collect data were three sets of data: conceptual knowledge test, Problem-Solving Inventory Survey (PSI), and SGP rubric to assess knowledge application ability. Participants final exam scores, demographics regarding gender, academic program, undergraduate student class standing, and age were also be collected within the survey.

Knowledge Tests

There were knowledge tests administered to the students at the beginning of the experiment and at the end, pre- and post-tests. The course professor developed the knowledge test to include conceptual, and application knowledge questions. These questions assessed the students' knowledge before and after both instructional methods (regular and SGP). The knowledge tests were enabled the researcher to determine whether the SGP activity influenced students' conceptual, and application knowledge.

Student-Generated Problems (SGP) Rubric

An SGP activities rubric (Hung & Algarni, 2019) used in this study as a scoring guide to evaluate students' written reports after they complete the SGP activities. The rubric assessed six areas of conceptual knowledge application: (1) description of the target concepts; (2) description of the problem (issue, symptoms, etc.); (3) analysis of the cause of the problem; (4) explanation of why the target concepts are needed to solve the problem; (5) authenticity of the problem; and (6) possible problem solutions (see Appendix A). The rubric's rating scale for problem identification included the following three levels: (a) exceeds expectations (five points); (b) meets expectations (three points), and (c) needs improvement (one point).

The rubric's content validity and reliability were focused on six criteria. In Criterion 1, the description of the target concepts entails two problem identification phases: (a) the concept is clearly described, explained, and well-defined, and (b) the explanation of the concept is accurate, complete, and concise. In Criterion 2, the description of the problem (issue, symptoms, etc.) indicates the extent to which the description of the problem's context and the main problem are clear and complete, and the problem-solving goal is clearly defined.

Criterion 3, which was the analysis of the problem's cause, was the key to describing the extent to which students present their logical analysis of the problem's root cause clearly and with no errors (Chi & VanLehn, 1991). One aim of this criterion was to determine whether students make an accurate conceptual connection between the target concepts and the problem. Based on that hypothesis, the rationale behind the problem identification should be logical, contain no gaps in reasoning, and include an explanation that is accurate, clear, and concise.

The rationale behind the use of the target concept to solve the problem was Criterion 4. Its purpose was to evaluate whether the student's rationale of the problem identification was logical, contains no gaps in the reasoning, and includes an explanation that is accurate, clear, and concise.

In criterion 5, the authenticity of the students' problem identification evaluates whether the problems identified were real-world, daily, or professional problems. Thus, evaluating the authenticity of the problem identified was to assess the students' ability in applying the target concept(s) in an ill-structured, complex context.

In criterion 6, the students also might be able to provide possible solutions that demonstrate the following: (a) multiple competing solutions; (b) solutions that are clearly explained in terms of how the target concepts are applied; and (c) evaluations of the competing solutions. Because students generate problems or solve problems generated by others, they must identify key points in a given problem, control the solution, solve the problem, and reflect upon their problem-solving process (Chang, et al., 2012).

Problem Solving Inventory

The Problem-Solving Inventory Survey (PSI) was used to assess the student participants' perception of their own problem-solving skills. Heppner and Petersen (1982) originally developed the PSI to assess problem-solving skills and since then researchers have used this instrument in more than 120 empirical studies. It is one of the most widely used self-reporting, problem-solving instruments.

The constructs include: (1) problem-solving confidence (PSC), (2) approach-avoidance style (AAS), and (3) personal control (PC) (see Appendix B). The PSC section of the PSI includes 11 items and is classified as self-assurance while engaging in a wide range of problem-solving skills. A sample item that assesses this factor is "When I make plans to solve a problem, I am almost certain that I can make them work."

The AAS section of the PSI includes 16 items and is defined as a general tendency to engage in various problem-solving activities. Low scores associated with this factor are correlated with the tendency to avoid problems, whereas higher scores are correlated with the tendency to approach problems. An example item for this construct is "When I have a problem, I think of as many possible ways to handle it as I can until I cannot come up with any problems more ideas." In this item, whether a student tends to avoid or address problems is essential to the problem-solving process because of this tendency's effects on consequent problem-solving behaviors, decision-making styles, and coping focused on solving problems.

The PC section of the PSI includes 5 items and is described as believing one is in control of one's emotions and behaviors during problem-solving. This construct appears to reflect emotional reactivity and behavioral control. An example item for this construct is "Even though I work on a problem, sometimes I feel like I’m groping or wandering and not getting down to the real issue.”

The original PSI’s validity and reliability are widely studied and well established. A wide range of researchers have produced data that support the PSI’s validity (Heppner, 1988; Heppner & Lee, 2002; Heppner & Petersen 1982). Heppner and Petersen (1982) determined the PSIs test–retest reliability by obtaining average alpha coefficients in the high .80s, whereas two constructs (PSC and AAS) had average alpha coefficients in the low to mid .80s, and the third construct (PC) had average alpha coefficients in the low .70s. Overall, these results indicated that the PSI could be utilized among different research culture groups. For example, Heppner and Petersen noted that five studies provided estimations of the PSIs stability across various time periods ranging from two weeks to two years and among various samples. In addition, the total PSI scores are associated with average alpha coefficients in the high .80s. Overall, the results indicate that PSI scores are stable among various culture and population groups.

In this study, the pretest survey assessed more of students’ general perceptions on problem-solving skills. These included items like “when I make plans to solve a problem, I am almost certain that I can make them work” and “when given a problem, I use a systematic method to solve the problem”. The posttest survey, on the other hand, assessed the students’ perception of problem-solving skills with reference to the completed activities. These included items such as “the SGP task helped me to thinking about the multiple ways of solving a problem” and “the SGP task enable me to make a problem-solving plan that will almost certainly work”.

On the PSI scale, students will indicate their perceptions of PSS on a 6-point Likert scale (1 = Strongly Agree to 6 = Strongly Disagree). Students' self-reported PSI scores for the traditional and SM instructional sessions will be compared.

Procedures

The study used an experimental research design with a pretest and a posttest. In addition, the control and experimental groups were compared using Root Locus concept to minimize learning effect transfer. The students in one lab sections were randomly assigned to either the control or experimental group. The students were instructed by a single instructor. The participants signed the consent form one week before the experiment. In addition, the study's participants were provided a link to complete online the pretest Problem-Solving Inventory Survey (PSI), which was used to assess their perception of their problem-solving skills, before the day of the experiment.

A video conference was held to explain the natural of the study to the participants. Before conducting the study, the participants received an electronic copy of the consent form to sign. The study activity was explained to the participants by the class professor and took place during one of the lab sessions via Zoom, which was a web-based video conferencing tool.

The participants in the experimental group (SGP) were divided into groups of 2 students to discuss online via Zoom and identify an appropriate real-life problem that can be explained or solved using the concept of Root Locus. The students did take pretest and posttest on the topic of Control System: (1) conceptual knowledge (pretest and posttest) (both control and experimental groups); (2) PSI (pre and posttest, both control and experimental groups); and (3) lab activity score scores (both control and experimental groups). Participants were given a pre-test (PSI scale) to assess their level of problem-solving skills test before and after the SGP activity.

In addition, the survey included questions that assessed participant demographics regarding gender, academic program or field of study, age, and undergraduate student class standing. Gender was operationalized by asking students to choose from the independent variables' male and female. Academic field of study was operationalized by asking students to choose from the independent variables on the academic program list. Age was operationalized by asking students to choose the independent variable of their age at the time of survey completion. Undergraduate student class standing was operationalized by asking students to choose one of the four following independent variables: freshman, sophomore, junior, or senior.

The lab section was randomly assigned into experimental and control groups. The SGP activity did take place during the lab session where the experimental group students were required to identify a real-life problem that can be explained or solved with the Engineering concept under study, while the control group students were did the regular lab activity (step-by-step Engineering experiment). After the lab activity, the experimental group students submitted a problem identification report, and the control group students submitted their experiment report. A PSI posttest and a portion of participants' final exam scores pertaining to the topic studied during the SGP activity was extracted as part of the data set for analysis. (See Figure 1).

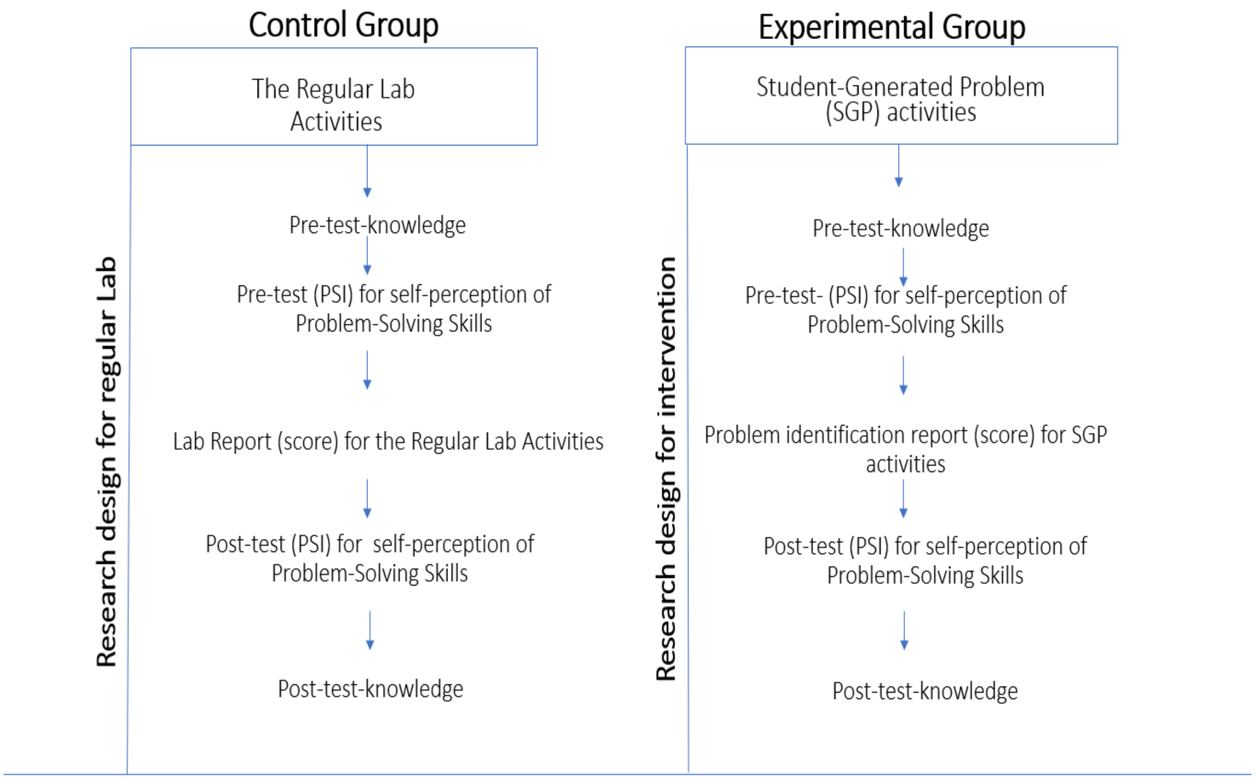


Figure 1. Graphic Depicts the Quantitative Method Study Design Overview.

Data Analysis

Descriptive statistics were obtained, and quantitative data analysis was performed using SPSS statistical software. To answer the research questions, the researcher used a number of statistical procedures for the study. For the first and the second research questions, the need was to test the group differences in their conceptual and application knowledge as well as self-prescription of problem-solving skills. A Mann-Whitney U test was run to determine if there were differences between the pre- and post-test of these knowledge students' conceptual knowledge, application knowledge, and self-reported problem-solving skills. A Mann-Whitney U test was used because the distributions showed non-normal distribution characteristics. Also, a two-way mixed ANOVA was run to determine whether there is a two-way interaction between the between-subjects and within-subjects factors (time and group) of students' self-perception of problem-solving skills test scores and conceptual knowledge test scores.

For the third research question, the relationships between students' self-perception of problem-solving skills test scores, conceptual knowledge test scores, knowledge application abilities test scores and their final scores (a portion the final score of the students' exam that related to the Root Locus concept) were examined using the Pearson's Correlation Coefficient test. For the fourth question, a regression analysis was used to test how the study dimensions studied students' conceptual knowledge and self-perception of problem-solving skills affected by their performance during the SGP activity.

Summary

As described, the research approach used in the current study is an experimental quantitative method. The purpose of this experimental study was to describe and better understand the effects of SGP instructional strategy on undergraduate students' conceptual knowledge, knowledge application ability, and problem-solving skills. The study's philosophical underpinnings shaped the research approach with the use of purposeful sampling of participants. A process of quantitative analysis, moving between the whole, to the parts, and back to the whole, led to the identification and explanation of the real meaning of the SGP instructional strategy. The next chapter is the presentation and the interpretation of the results obtained from the study. The first part is the presentation of the descriptive statistics. The rest of the data are organized and based on the order of the research questions. Each research question is followed by the statement of the hypothesis. Thus, Research Question 1 is followed by Hypothesis 1.

CHAPTER IV

RESULTS AND ANALYSIS

This quantitative study sought to investigate the Student-Generated Problems (SGP) instructional strategy's potential to enhance students': (1) conceptual knowledge of the topic studied during an SGP activity, (2) knowledge application abilities to assess knowledge application understanding, and (3) perception of problem-solving skills. The relationships between the SGP method and students' conceptual knowledge, knowledge application abilities, and problem-solving skills, as well as demographic variables were explored.

This study addresses three major research questions that were broken down into hypothetical statements. For the purpose of clarity, every research question is followed by the relative hypothesis as well as the results that emerged from this study.

Statistical Analysis

Descriptive statistics were obtained, and quantitative data analysis was performed using SPSS statistical software. The researcher used two main statistical procedures for the study, which were a test of group differences. A Mann-Whitney U test was run to determine if there were differences between the pre and posttest of the students' conceptual knowledge, application knowledge, and self-reported problem-solving skills. The Root Locus represents the control and the experimental group scores. A Mann-Whitney U test was used because the distributions showed non-normal distribution characteristics. Also, a two-way mixed ANOVA was run to determine whether there is a two-way interaction between the between-subjects and within-subjects factors (time and group) of students' self-perception of problem-solving skills test scores and conceptual knowledge test scores. The relationships between students' self-perception of problem-solving skills test scores, conceptual knowledge test scores, knowledge application abilities test scores and their final scores (a portion of the final score of the students' exam that related to the Root Locus concept) were examined using the Pearson's Correlation Coefficient test. A regression analysis was used to test how the study dimensions studied students' conceptual knowledge and self-perception of problem-solving skills affected by their performance during the SGP activity.

Students' Learning Outcomes

The outcome of the test scores in the knowledge areas, conceptual knowledge and knowledge application, did not have a statistically significant overall relationship between group differences. The analysis of students' learning outcomes was focused on conceptual knowledge and knowledge application. The conceptual knowledge test score was conducted to assess the group differences (control vs experimental) using the grade point test score (5= Excellent, 4= Good, 3= Fair, 2= Poor, 1= Failing). The test was to assess their conceptual knowledge about the expectation of the graphical representation of the system's Root Locus concept in real life situations (see Appendix C). The knowledge application ability test was conducted to assess the group differences (control vs experimental) using the grade point test score (10= Outstanding, 9= Excellent, 8= Very good, 7= Good, 6= Above Average, 5= Average, 4= Below Average, 3= Weak, 2= Very Weak, 1= Poor). The test was used to assess students' knowledge application abilities during both a traditional lab activity and an SGP activity in the system's Root Locus concept (see Appendix D).

Research Question 1: *Does the SGP instructional strategy enhance students' learning outcomes of engineering concepts?*

Conceptual Knowledge

Hypothesis 1-1. The engineering students who engage in an SGP lab activity will obtain significantly higher test scores on their conceptual knowledge of Root Locus than do the engineering students who engage in a traditional lab activity as measured by the means score on solving the conceptual questions.

Table 2.
Descriptive Statistic of Conceptual Knowledge

	Group	N	Mean	SD	Median
Conceptual Knowledge	Control	16	4.75	.447	4.75
	Experimental	16	4.81	.403	4.81

The mean score shows that the experimental group has a score *M*=4.81 than the control group *M*= 4.75. A Mann-Whitney U test was run to determine if there were differences in conceptual knowledge of Root Locus score between the control and the experimental groups (see Table 3). The results show that there was no statistically significant difference between the control *Mdn* = 4.75 and the experimental groups *Mdn* = 4.81 in conceptual knowledge of Root Locus score, *U* = 136, *z* = .421, *p* = .780 (see Tables 3 and 4).

Table 3.
Independent-Samples Mann-Whitney U Test for Conceptual Knowledge

	Mann-Whitney U Test			
Variable	N	U	z	P
Conceptual Knowledge	32	136	.421	.780

*The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

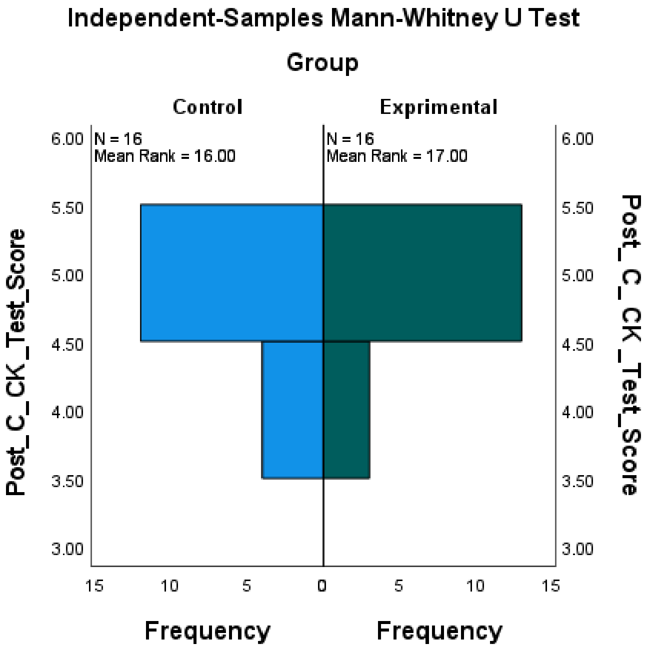


Figure 2. Histogram Shows Students' Conceptual Knowledge Group Differences.

In addition, Conceptual knowledge was analyzed with separate 2*2 pre–post Mixed Factorial analyses of variance (Campbell & Stanley, 1963) with SGP lab activity as the between-subjects factor (Experimental vs Control) and Time as the repeated within-subjects factor (Time 1 pre-test vs Time 2 post-test). Baseline t-tests confirmed that there were no pre-existing differences between groups in terms of conceptual knowledge, *t* =.237, ns, or post-existing differences, *t* =-.415, ns. Comparison I examined the change in conceptual knowledge among the experimental group from pre-test to post-test, whereas Comparison II tested the same difference among the control group. Finally, Comparison III assessed differences between the experimental and control groups by comparing the post test of the experimental group to the control group (See Tables 4 and 5).

Table 4.

Descriptive Statistics Between Groups and on Students' Conceptual Knowledge

	Group	Mean	SD	N
Pre conceptual knowledge	control	1.94	.680	16
	Experimental	1.88	.806	16
	Total	1.91	.734	32
Post conceptual knowledge	control	4.75	.447	16
	Experimental	4.81	.403	16
	Total	4.78	.420	32

Table 5.

2 × 2 Mixed ANOVA Analysis (pre-post) and Group (control vs experimental) Interaction Between Groups and Time on Students' Conceptual Knowledge

	df	*Ms*	*F*	*Partial Eta Squared*
Conceptual Knowledge				
Between-subjects				
Experimental group	1	.031	.172	.006
Error	32	.202	-------	------
Within-subjects				
Time	32	.912	2.34	.912
Time* Experimental	32	.005	1.94	.005
Group	32	-------	3.393	-----
Error			----------	

*p < .05, **p < .01

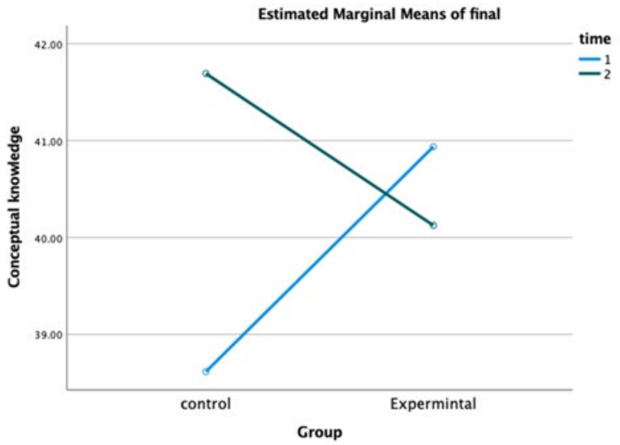


Figure 3. The Interaction between Groups and Time on Students' Conceptual Knowledge.

Knowledge Application Abilities

Hypothesis 1-2. The engineering students who engage in an SGP lab activity will obtain significantly higher test scores on their application knowledge of Root Locus than do the engineering students who engage in a traditional lab activity as measured by the means score on solving the application problem questions.

Table 6.
Descriptive Statistic of Knowledge Application

	Group	N	Mean	SD	Median
Knowledge Application	Control	16	8.87	1.59	10
	Experimental	16	9.37	1.20	10

Table 7.
Independent-Samples Mann-Whitney U Test for Knowledge Application Abilities

	Mann-Whitney U Test			
Variable	N	U	z	P
Knowledge Application Abilities	32	148	.920	.468

*The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

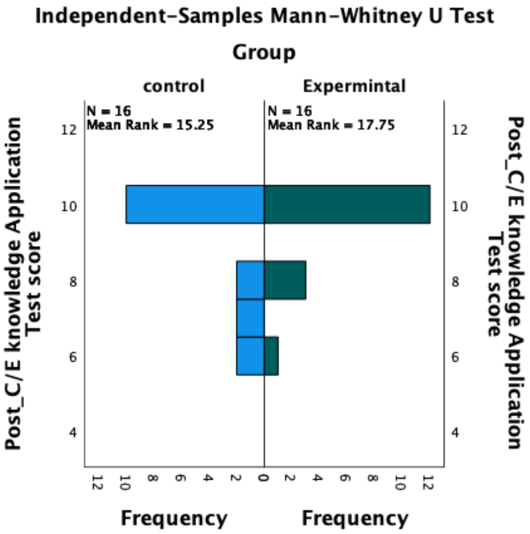


Figure 4. Histogram Shows Group Differences of Knowledge Application Abilities.

The mean score shows that the experimental group has a higher score *M*=9.37 than the control group *M*= 8.87. A Mann-Whitney U test was run to determine if there were differences in application knowledge of Root Locus score between the control and the experimental groups (see Table 5). There was no statistically significant difference between the control *Mdn* = 10 and the experimental groups *Mdn* = 10 in application knowledge of Root Locus score, $U = 148$, $z = .920$, $p = .47$ (see Table 7).

Students' Self-Perception of Problem-Solving Skills

The outcome of the test scores in the students' self-perception of problem-solving skills, did not have a statistically significant overall relationship between group differences. The students' perception of problem-solving test was conducted to assess the group differences (control vs experimental) using Problem Solving Inventory (PSI) questionnaires and used a Likert scale from 1-6 (1= Strongly disagree, 6 =Strongly agree) to describe students' thinking during the problem-solving task (control vs experimental) in three main constructs: (1) Problem Solving Confidence (three items); (2) Approach-Avoidance Style (three items); and (3) Personal Control (three items) (see Appendix E).

Research Question 2: *Does the SGP instructional strategy promote students' self-perception of problem-solving skills?*

The descriptive statistics of individual problem-solving skills items in each group reports in Table 8. For problem-solving confidence (PSC) construct, the mean response for the control Group students who agreed that their problem-solving confidence could meet their learning needs was arranged $M = 4.69$ to 5.19, and for the experimental group students who agreed that a problem-solving confidence could meet their learning needs, it was arranged $M = 4.69$ to 4.81. For approach-avoidance style (AAS) construct, the mean for the control group students who agreed that the different ways of solving were allotted well was arranged *M* = 5 to 5.38, and for the experimental group students who agreed that different ways of solving was allotted well, the mean was arranged *M* = 4.44 to 4.84. For the personal control (PC) construct, the mean response for the experimental group was higher than the control group response.

Table 8.

Descriptive Statistics of Individual Problem-Solving Skills Items

	Individual Items in Each Group				
Variable	Group	N	Mean	SD	Median
Problem-Solving Confidence (PSC)					
(PSC_ Item 1)					
	Control	16	4.69	.704	5
	Experimental	16	4.81	.911	5
(PSC_ Item 2)					
	Control	16	4.81	.544	5
	Experimental	16	4.69	.946	5
(PSC_ Item 3)					
	Control	16	5.19	.750	5
	Experimental	16	4.81	.911	5
Approach-Avoidance Style (AAS)					
(AAS _ Item 1)					
	Control	16	5	.632	5
	Experimental	16	4.87	.806	5
(AAS _ Item 2)					
	Control	16	5.06	.854	5
	Experimental	16	4.88	.619	5
(AAS_ Item 3)					
	Control	16	5.38	.806	6
	Experimental	16	4.44	1.32	4.5
Personal Control (PC)					
(PC _ Item 1)					
	Control	16	4.63	.957	4
	Experimental	16	4	1.18	3.5
(PC _ Item 2)					
	Control	16	3.63	1.025	3.5
	Experimental	16	4.19	.981	4
(PCI_ Item 3)					
	Control	16	3.88	1.025	4
	Experimental	16	4.19	.981	4

A Mann-Whitney U test was run to determine if there were differences in students' self-perception of individual problem-solving skills items (see Table 9 below). Problem-solving confidence (Item 1) of Root Locus score "*When I make plans to solve a problem, I am almost certain that I can make them work*" between the control and the experimental groups. There was no statistically significant difference between the control *Mdn* =5 and the experimental groups *Mdn* = 5 in problem-solving confidence (Item 1) of Root Locus score, $U = 143.5$, z = .66, $p =$ .51. For problem-solving confidence (Item 2) "*When given a new problem, I have confidence that I can solve it.*", there was no statistically significant difference between the control (Mdn =5) and the experimental groups *Mdn* =5, $U = 121$, z = -.294, and $p = .81$. In addition, the result of (Item 3) "*When given a new problem, I have confidence that I can solve it.*" shows that there was no statistically significant difference between the control (Mdn =5) and the experimental groups *Mdn* = 5 in students' self-perception of problem-solving confidence score of Root Locus score, $U = 98.5$, $z = -1.18$, $p = .27$.

The students' self-perception of problem-solving approach-avoidance scores (Item1) *"When given a problem, I think about different ways of solving it"* showed there was no statistically significant difference between the control *Mdn* = 5 and the experimental *Mdn* = 5 groups, $U = 115$, $z = -.53$, $p = .64$. For (Item 2) *"When given a problem, I use a systematic method to solve the problem"*, the problem-solving approach-avoidance scores indicated that there was no statistically significant difference between the control *Mdn* = 5 and the experimental *Mdn* = 5 groups, $U = 105$, $z = -.966$, $p = .402$. However, the students' self-perception of problem-solving approach-avoidance scores for (Item 3) *"When given a problem, I usually first evaluate the problem to identify the important information"* were statistically significantly higher in the control *Mdn* = 4.50 than the experimental *Mdn* = 6 groups, *U* = 73.5, *z* = -2.16, *p* = .04.

For the personal control (Item 1), "*When presented with a problem, I avoid jumping directly into the solution"*, the results indicated that test scores were statistically significantly higher in the control group *Mdn* = 4 than the experimental *Mdn* = 3.5 group, *U* = 52.5, *z* = -2.99, *p* = .003. Nevertheless, the students' self-perception of problem-solving personal control scores for (Item 2), *"When my first efforts to solve a problem fail, I become uneasy about my ability to solve the problem"*, were not statistically significantly different between the control (Mdn = 3.5) and the experimental *Mdn* = 4 groups, *U* = 165, *z* = 1.46, *p* = .17. In addition, the students' self-perception of problem-solving personal control scores for (Item 3), "*When I work on a problem, I feel that I am not getting to the real solution"*, were not statistically significantly different between the control group *Mdn* = 4 and the experimental *Mdn* = 4 group, *U* = 148, *z* =.79, *p* = .47.

Table 9.
Independent-Samples Mann-Whitney U Test for Individual Problem-Solving Skills Items

	Mann-Whitney U Test			
Variable	N	U	z	P
Problem-Solving Confidence (PSC)				
(PSC_ Item 1)	32	143.5	.66	.51
(PSC_ Item 2)	32	121	-.29	.81
(PSC_ Item 3)	32	98.5	-1.18	.27
Approach-Avoidance Style (AAS)				
(AAS _ Item 1)	32	115	-.53	.64
(AAS _ Item 2)	32	105	-.97	.40
(AAS_ Item 3)	32	73.5	-2.16	.04
Personal Control (PC)				
(PC _ Item 1)	32	52.5	-2.99	.003
(PC _ Item 2)	32	165	1.46	.17
(PC _ Item 3)	32	148	.79	.47

*The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

Problem-Solving Confidence (PSC)

Hypothesis 2-1. The engineering students who engage in an SGP lab activity will report significantly higher self-reported problem-solving confidence than the engineering students who engaged in a traditional lab activity as measured by the PSI questionnaire.

Table 10.
Descriptive Statistic of the Average of Students' Self-Perception of Problem-Solving Confidence

	Group	N	Mean	SD	Median
Problem-Solving	Control	16	14.69	1.49	15
Confidence (PSC)	Experimental	16	14.31	2.30	14.5

Table 11.
Independent-Samples Mann-Whitney U Test for the Average of Students' Self-Perception of Problem-Solving Confidence

	Mann-Whitney U Test			
Variable	N	U	z	P
Average of Problem-Solving Confidence (PSC)	32	112	-.619	.564

The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

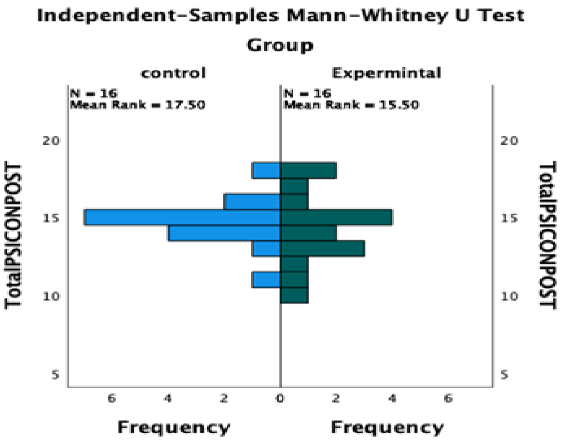


Figure 5. Histogram Shows the Students' Self-Perception of Problem-Solving Confidence Group Differences.

The mean score shows that the experimental group has a lower score *M*=14.31 than the control group *M*= 14.69. A Mann-Whitney U test was run to determine if there were differences in the average scores of the students' self-perception of problem-solving confidence between the control and the experimental groups (see Table 13). Students' self-perception of problem-solving confidence scores showed there was no statistically significant difference between the control *Mdn* =15 and the experimental *Mdn* = 14.50 groups, $U = 112$, $z = -.619$, $p = .564$ (see Tables 10 and 11).

Approach-Avoidance Style (AAS)

Hypothesis 2-2. The engineering students who engage in an SGP lab activity will report a significantly higher self-reported problem-solving approach-avoidance style than do the engineering students who engage in a traditional lab activity as measured by the PSI questionnaire.

Table 12.
Descriptive Statistic for the Average of Students' Self-Perception of Problem-Solving Approach-Avoidance

	Group	N	Mean	SD	Median
Problem-Solving	Control	16	15.44	1.83	16
Approach-Avoidance	Experimental	16	14.19	1.68	14

Table 13.
Independent-Samples Mann-Whitney U Test for the Average of Students' Self-Perception of Problem-Solving Approach-Avoidance

	Mann-Whitney U Test			
Variable	N	U	z	P
Average of Approach-Avoidance Style (AAS)	32	69.5	-2.24	.026

The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

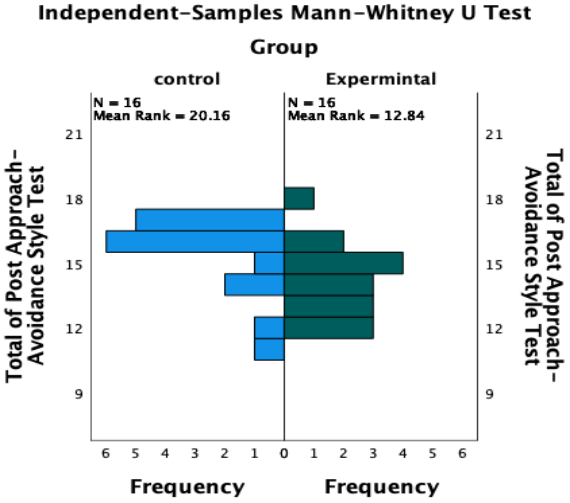


Figure 6. Histogram Shows Students' Self-Perception of Problem-Solving Approach-Avoidance Style.

The mean score shows that the experimental group has a lower score *M*=14.19 than the control group *M*= 15.44. A Mann-Whitney U test was run to determine if there were differences in students' self-perception of problem-solving approach-avoidance style average scores between the control and experimental groups (see Tables 12 and 13). Students' self-perception of problem-solving approach-avoidance score was statistically significantly higher in the control *Mdn* =16 than the experimental *Mdn* = 14 groups, *U* = 69.5, *z* = -2.24, *p* = .026 (see Tables 12 and13).

Personal Control (PC)

Hypothesis 2-3. The engineering students who engage in an SGP lab activity will report a significantly higher self-reported problem-solving personal control than do the engineering students who engage in a traditional lab activity as measured by the PSI questionnaire.

Table 14.
Descriptive Statistic for the Average of Students' Self-Perception of Problem-Solving Personal Control

	Group	N	Mean	SD	Median
Problem-Solving	Control	16	5.38	.806	6
Personal Control	Experimental	16	4.44	1.32	4.5

Table 15.
Independent-Samples Mann-Whitney U Test Summary for the Average of Students' Self-Perception of Problem-Solving Personal Control

	Mann-Whitney U Test			
Variable	N	U	z	P
Average of Personal Control (PC)	32	115.5	-.49	.64

The significance level is 0.05. z=Standardized Test Statistic. U=Mann-Whitney U.

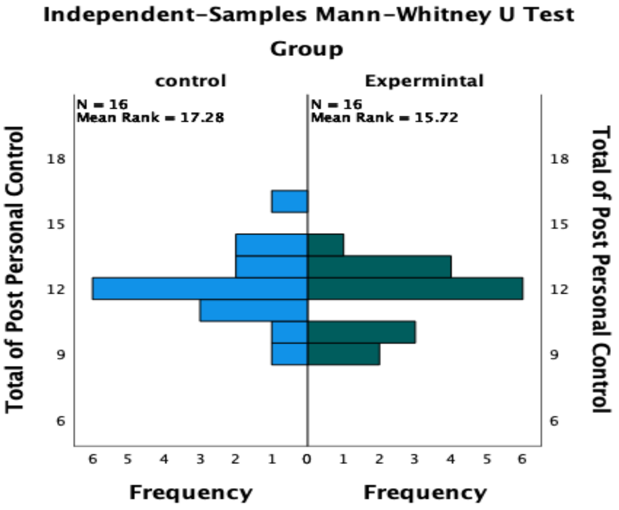


Figure 7: Histogram Shows Students' Self-Perception of Problem-Solving Personal Control.

The mean score shows that the experimental group has a lower score *M*=5.38 than the control group *M*= 4.44. A Mann-Whitney U test was run to determine if there were differences in the average of students' self-perception of problem-solving personal control scores between the control and the experimental groups (See Table 15). The students' self-perception of problem-solving personal control scores were not statistically significantly different between the control *Mdn* = 6 and the experimental *Mdn* = 4.5 groups, $U = 115.5$, $z = -.49$, $p = .64$ (see Tables 14 and 15).

Overall Results of Students' Self-Perception of Problem-Solving Skills

The mean differences (pre-post score) shows that the experimental group has a lower score *M*=39.90 than the control group *M*= 40.83. Self-perception was analyzed with separate 2*2 pre–post Mixed Factorial analyses of variance (Campbell & Stanley, 1963) with SGP lab activity as the between-subjects factor (Experimental vs Control) and Time as the repeated within-subjects factor (Time 1 pre-test vs Time 2 post-test). Baseline t tests confirmed that there were no pre-existing differences between groups in terms of self-perception, t =-2.26, ns, or post-existing differences, t =1.72, ns. Comparison I examined the change in self-perception among the experimental group from pre-test to post-test, whereas Comparison II tested the same difference among the control group. Finally, Comparison III assessed differences between the experimental and control groups by comparing the post test of the experimental group to the control group (See Tables 16 and 17).

Table 16.

Descriptive Statistics (pre-post) of Students' Self-Perception of Problem-Solving Skills

	Group	Mean	Std. Deviation	N
Pre-self-perception of PSS	control	38.62	3.84	16
	Experimental	40.94	3.68	16
	Total	39.90	3.87	32
Post self-perception of PSS	control	41.69	3.40	16
	Experimental	40.13	3.36	16
	Total	40.83	3.41	32

Table 17.

2 × 2 Mixed ANOVA Analysis (pre-post) and Group (control vs experimental) Interaction Between Groups and Time on Students' Self-Perception of Problem-Solving Skills

	df	*Ms*	*F*	*Partial Eta Squared*
Students' self-perception of PSS				
Between-subjects				
Experimental group	1	1.88	1.15	.864
Error	32	.202	------	------
Within-subjects				
Time	32	18.39	1.15	0.41
Time* Experimental Group	32	54.25	3.39	0.112
Error	32	-------	---------	------

*a Numerator df ¼ 1 for all F tests.
*p < .05, **p < .01

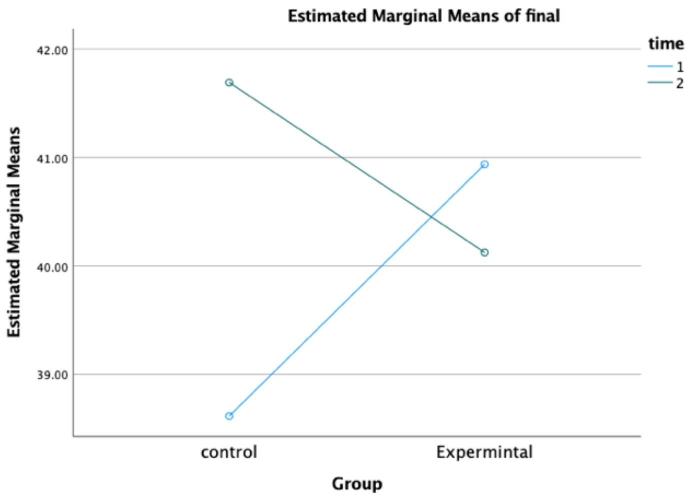


Figure 8: The Interaction between Groups and Time on Students' Self-Perception of PSS.

Correlations Among Study Variables with Students' Final Learning Outcomes

The outcome of the test scores in the correlation between study variables with students' final learning outcomes showed a week correlation. A portion of the final test that was related to the system's Root Locus concept using the grade for the control vs experimental groups used a Likert score of 1-10 (10= Outstanding, 9= Excellent, 8= Very good, 7= Good, 6= Above Average, 5= Average, 4= Below Average, 3= Weak, 2= Very Weak, 1= Poor) (see Appendix F). Research Question 3: *Does a correlation exist between students' self-perception of problem-solving skills, conceptual knowledge, application knowledge, and their final score on the Root Locus concept?*

Hypothesis 3-1. There will be a significant correlation between students' self-perception of problem-solving skills and their final score on the Root Locus concept.

Table 18.

Correlations Between Students' Self-Perception of Problem-Solving Skills Test Scores and Their Final Scores

		PSS	PSC	AAS	PC	Final Test Score
Self-perception (PSS)	Pearson Correlation	1	.580*	.797**	.446	.163
	Significance. (2-tailed)		.018	.000	.083	.546
	N	16	16	16	16	16
Problem Solving Confidence (PSC)	Pearson Correlation	.580*	1	.122	-.359	-.247
	Significance. (2-tailed)	.018		.654	.172	.356
	N	16	16	16	16	16
Approach-Avoidance Style (AAS)	Pearson Correlation	.797**	.122	1	.465	.282
	Significance. (2-tailed)	.000	.654		.069	.291
	N	16	16	16	16	16
Personal Control (PC)	Pearson Correlation	.446	-.359	.465	1	.418
	Significance. (2-tailed)	.083	.172	.069		.107
	N	16	16	16	16	16
Final Test Score	Pearson Correlation	.163	-.247	.282	.418	1
	Significance. (2-tailed)	.546	.356	.291	.107	
	N	16	16	16	16	16

The relationships between students' self-perception of problem-solving skills (PSS) test scores and their final scores were examined by Pearson's Correlation Coefficients. There was a weak correlation between the final test score and Approach-Avoidance Style (AAS), Personal Control, and Problem-Solving Confidence (PSC). There was no significant correlation between students' self-perception, conceptual knowledge, application knowledge and their final scores on the Root Locus concept, $r = .16$, $p = .55$(See Table 18).

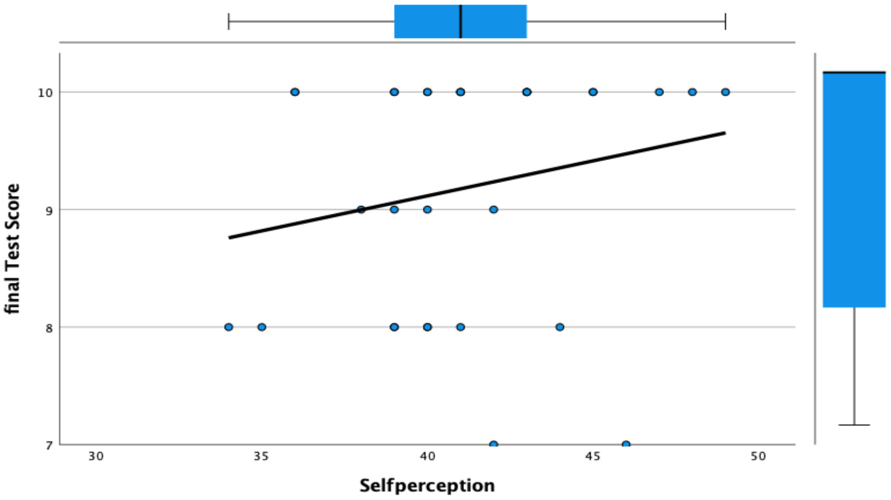


Figure 9: Correlations between Students' Self-Perception of Problem-Solving Skills Test Scores and Final Scores.

Hypothesis 3-2. There will be a significant correlation between students' conceptual knowledge and their final scores on the Root Locus concept.

Table 19.
Correlations Between Conceptual Knowledge and Students' Final Scores

		Final Test Score	Conceptual Knowledge
Final Test Score	Pearson Correlation	1	.023
	Significance. (2-tailed)		.899
	N	32	32

The relationships between students' conceptual knowledge test score and their final scores were examined by Pearson correlation coefficients. There was no significant correlation between students' conceptual knowledge and their final score on the Root Locus concept, $r = .02$, $p = .90$ (See Table 19).

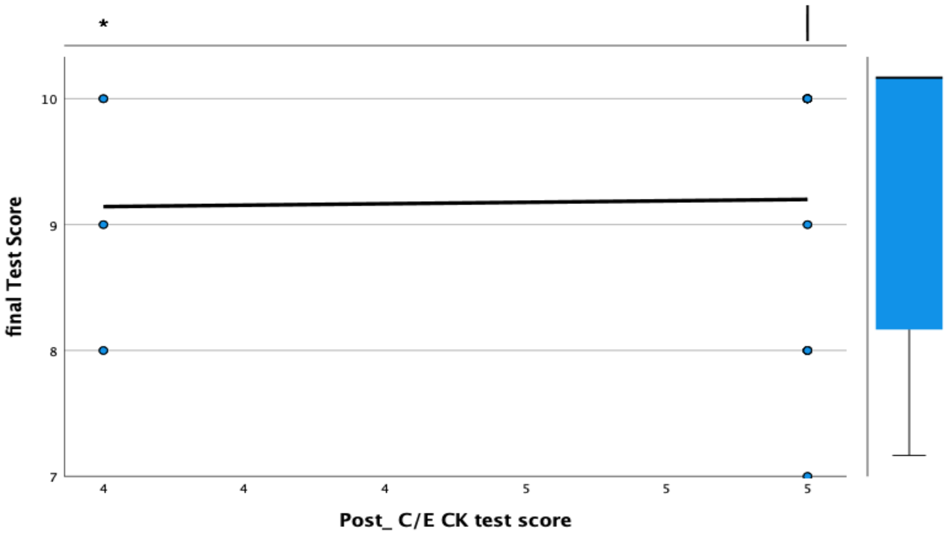


Figure 10: Correlations between Students' Conceptual Knowledge Test scores and Final Scores.

Hypothesis 3-3. There will be a significant correlation between students' application knowledge and their final scores on the Root Locus concept.

Table 20.
Correlations Between Knowledge Application Test Scores and Students' Final Scores.

		Final Test Score	Knowledge Application
Final Test Score	Pearson Correlation	1	.161
	Significance. (2-tailed)		.378
	N	32	32

The relationships between students' application knowledge test score and their final scores were examined by Pearson Correlation coefficients. There was not a significant correlation between students' application knowledge and their final score on the Root Locus concept, $r = .16$, p = .38 (See Table 20).

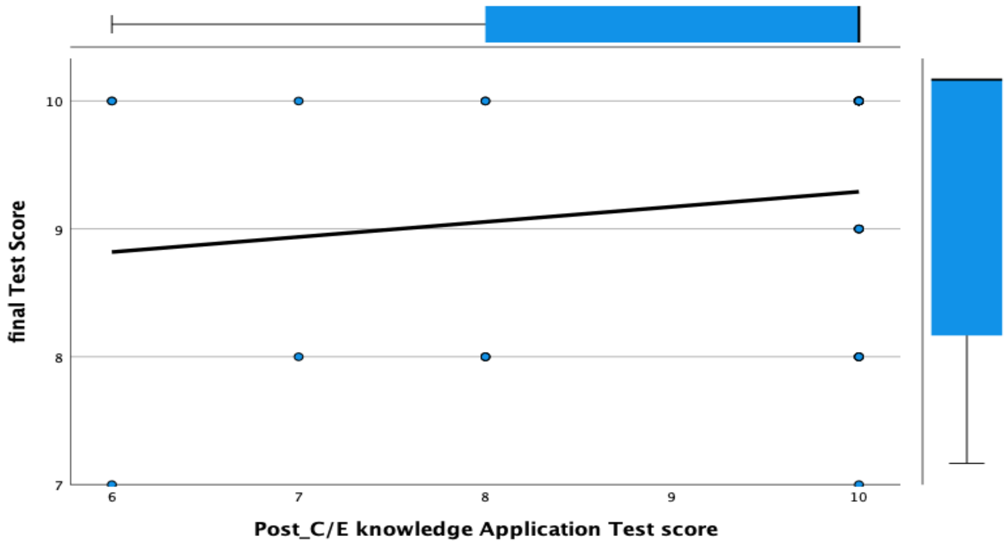


Figure 11: Correlations between Students' Knowledge Application Test Scores and Final Scores.

The Effect of Students' Performance during SGP on Study Variables

The outcome of the multiple regression in the effect of students' performance during SGP on study variables showed that the model statistically did not significantly predict students' performance.

Research Question 4: *Which of the predictor variables (final test score, self- perception score, and conceptual knowledge score) are most influential in predicting students' performance during SPG? Are there any predictor variables that do not contribute significantly to the prediction model?*

Table 21.

Model Summary of Pre-Conceptual Knowledge Test Score and PSS Test Score

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.374[a]	.140	.007	5.372

a. Predictors: (Constant), Pre conceptual knowledge test score and pre-Self-perception of PSS

b. Dependent Variable: Performance

R^2 for the overall model was 14% with an adjusted R^2 of 0.7% with a small size effect.

Table 22.

ANOVA[a] of Pre -Conceptual Knowledge Test Score and PSS Test Score

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	60.850	3	30.425	1.054	.376[b]
	Residual	375.150	12	28.858		
	Total	436.000	15			

A multiple regression was run to predict students' performance from self- perception, and conceptual knowledge test score. The multiple regression model statistically not significantly predicted students' performance, $F(3\ 12) = 1.05$, $p = .376$, adj. $R^2 = .14$. Regression coefficients and standard errors can be found in Table 22 and 23.

Table 23.

Coefficients for Model (Conceptual Knowledge Test Score, and PSS Test Score) Variables

	B	Std. Error	Beta	t	sig
Self- perception of PSS	.240	.360	.175	.667	.516
Conceptual knowledge	-4.420	3.165	.367	-1.397	.186

a. Dependent Variable: Performance

Summary

In this chapter the researcher reviewed the results of the administered PSI survey and knowledge test scores. Limited differences were revealed in the control and experimental group participants' responses of their conceptual knowledge, knowledge application abilities, and self-perception of problem-solving skills. Test scores in the knowledge areas did not have a statistically significant overall relationship with the most of study variables. However, for all three constructs of Students' self-perception of problem-solving, the test revealed that the difference in the test scores for the approach avoidance style construct was statistically significant. But the test scores for problem-solving confidence and Personal Control constructs were not statistically significant between the control and the experimental groups. In the final chapter the researcher discusses the findings of the study. Following the same organization as in Chapter IV, the discussion is based on the order of the research questions as well as the related hypotheses. The discussion is solely based on the data results.

CHAPTER V

DISCUSSION

This quantitative study sought to compare the Student-Generated Problems instructional strategy (SGP) and regular instructional strategy of an electrical engineering concept. In the following section, the researcher discusses the educational implications derived from the interpretations of the study results, the limitations of the study, and the recommendations for future research.

In this study, 32 undergraduate students were purposely sampled to respond to a Problem-Solving Inventory (PSI) survey that measured their self-perception of problem-solving skills. In addition, the test scores of students' conceptual knowledge, knowledge application abilities, and performance during a Student-Generated Problems activity were recruited from a Midwestern University in the United States.

Based on the literature reviewed, related theories and studies support the SGP instructional strategy in college science courses as fundamental practical skills. Therefore, this study was designed to examine the relationship in learning outcomes of undergraduate electrical engineering students in a course lab activity. With the use of the 9-item PSI focused on self-perception of problem-solving skills questionnaire by Heppner and Petersen (1982), 6-items focused on students' performance during SGP activity using Student-Generated Problems (SGP) Rubric by Hung and Algarni (2019), and test score of conceptual knowledge, knowledge application ability, a comparative study was conducted between two instructional strategies—the control group and the experimental group of undergraduate electrical engineering students.

Below is a discussion of the four research questions with related hypotheses. The implications of the study for practice and limitations for future research are discussed.

Research Question 1: Differences between Learning Outcomes

Research Question 1: *Does the SGP instructional strategy enhance students' learning outcomes of engineering concepts?*

As the statistical results indicated in the previous chapter, overall, there was no significant difference between the control and experimental students' learning outcomes of engineering concepts. The results showed that students' learning outcomes of undergraduate electrical engineering were more likely to have similar learning outcomes about the conceptual knowledge and knowledge application abilities of the Root Locus concept. However, there is a consensus among researchers studying learning outcomes that knowledge gain is developmental in the SGP instructional strategy practice (Dunlosky et al., 2013; Khoshaim & Aiadi, 2018).

Conceptual Knowledge. The results show that there was no statistically significant difference between the control group Mdn = 4.75 and the experimental group Mdn = 4.81 in conceptual knowledge of the Root Locus score, $U = 136$, $z = .421$, $p = .780$. This finding suggests there seems to be no improvement on the experimental group regarding their conceptual knowledge after applying the SGP activity. The experimental group was slightly more advanced in their conceptual knowledge than the control group.

The conceptual knowledge is developmental in real instructional strategies practice (Biggs 1999; Dunlosky et al.,2013; Khoshaim & Aiadi, 2018) and as a result, one would expect undergraduate electrical engineering students to have developed in their conceptual knowledge within real application practice. However, the results from this study showed otherwise. Though this finding was not significant between the two groups, students' conceptual knowledge of Root

Locus in the experimental test score was similar to the control group test score. It can be hypothesized that both groups might have variance knowledge about the Root Locus concept.

Again, it is possible that conceptual knowledge of the experimental group students did not develop after they participated in the SGP activity. Surprisingly, there has not been much research on how students' conceptual knowledge develops by applying real life practice in college (Biggs, 1999). Because the researcher could not apply the SGP instructional strategy for more than one concept in the electrical engineering course, there is no basis to make a strong case as to whether the experimental group students developed in their conceptual knowledge over the course period.

In any of these cases, somewhat average learning outcomes implied that students in both the control and experimental group were likely to view their conceptual knowledge as somewhat similar and stable, based on their scores in pre and post conceptual knowledge in Root Locus concept. Because there is limited literature on the development of conceptual knowledge during college, it makes it complicated to assess the conceptual knowledge level of undergraduate electrical engineering students. If such information were available, it would have been easier to compare the conceptual knowledge development level of these electrical engineering students to what researchers have reported. In this specific context, the need exists for further research into the developmental stages of electrical engineering students' conceptual knowledge throughout their professional application of real-life instructional strategies such as the SGP method. To support this argument, Spier-Dance, Mayer-Smith, Dance and Khan (2005) resulted that the value of using student-generated analogies instructional strategy with undergraduate science students as an approach for promoting conceptual knowledge. The finding from Spier-Dance et al., partially explains how long-term application of the SGP made significant differences on students’ conceptual knowledge. However, with only a one-time application of SGP in this study, it was expected that there would be a difference between control and experimental groups students’ conceptual knowledge.

Knowledge Application Ability. Among the study dimensions of learning outcomes, there was no significant difference reported between the control and experimental groups regarding students’ knowledge application abilities. This result indicated that experimental group in their test scores of knowledge application (ages ranging from 20-25 years old with one exception of a student under 20) were more likely to have similar knowledge application abilities about the Root Locus concept. The median difference between the control group *Mdn* = 10 and the experimental group *Mdn* = 10 in application knowledge of Root Locus score was $U = 148$, $z = .920$, $p = .47$.

Recent literature reviews (e.g., Forinash, & Wisman, 2005: Siswanto, Susantini, & Jatmiko, 2018; Sumirattana, Makanong, & Thipkong, 2017) demonstrated that one of the best methods in science and engineering learning practice is to allow students to develop their knowledge application abilities using effective instructional strategies to benefit in learning outcomes. As a result, the SGP instructional strategy that assists students to acquire more in-depth knowledge was useful as well as meaningful science education through increased interaction between the students and the concepts being examined in daily life problems. The focus of this study was on helping engineering students to develop a functional understanding of how to utilize the content knowledge while learning practical problem-solving skills through SGP instructional strategy. This process is supported by the Singh and Haileselassie (2010) study that also examined instructional strategy that exploits SGP and holds the potential for helping undergraduate students with a wide range of real-life knowledge application.

For this reason, the findings in this study should not be surprising, as both control and experimental groups showed that there was no difference in their knowledge application ability. Therefore, it is possible that the experimental group might have been influenced by the SGP adversely in their knowledge application because of the limited utilization of the SGP instructional method in long term practice. Another reason that might possibly explain why there was no significant difference between the two groups is the small sample size, which may have affected the normal distribution.

Research Question 2: Differences between Problem-Solving Skills

Research Question 2: *Does the SGP instructional strategy promote students' self-perception of problem-solving skills?*

Based on the research premise that the use of the SGP approach for promoting students' problem-solving skills in real life application (Coppola & Pontrello, 2019; McLean, 2020), the researcher wanted to discover whether or not there was a significant difference between the control and experimental groups regarding students' self-perception of problem-solving skills in the electrical engineering concept. There was no significant difference between students' self-perception of problem-solving skills in the SGP instructional strategy practice or the regular instructional practice of electrical engineering concept. As can be seen from the results of the data, the students' self-perception about their problem-solving skills was found to be similar in both groups. Students have to be supported with long-term application of the SGP method that requires high order thinking in order to help them develop problem solving skills (Krawec & Huang, 2016).

Conversely, based on the literature and expert opinions, it is obvious that the SGP instructional practice can enhance problem solving capabilities of students, which demands the need for the development of science education, especially for college students (Crogman & Trebeau, 2016). A study by Kolarkar and Callender (2016) showed that SGP implementation was successful in that students were able to solve their own problems as well as the ones of other groups, and they were able to identify when information was missing from some problems. The study concluded that it was a dramatic improvement in the students' skills with regard to the entire dynamics of the learning sessions, gaining a positive effect on their subsequent knowledge and problem-solving skills.

Problem Solving Confidence. Confidence in problem-solving abilities evaluates the students' self-assurance while engaging in problem-solving activities (Kim & Sin, 2007). Findings indicate that confidence has no significant impact on the perception of sources. The students who felt less confident while solving problems tended to have a rather negative perception of information sources in overall. Problem-solving confidence (Item 1) of Root Locus score "*When I make plans to solve a problem, I am almost certain that I can make them work*" between the control and the experimental groups. There was no statistically significant difference between the control *Mdn* =5 and the experimental groups *Mdn* = 5 in problem-solving confidence (Item 1) of Root Locus score, $U = 143.5$, $z = .66$, $p = .51$. For problem-solving confidence (Item 2) "*When given a new problem, I have confidence that I can solve it*", there was no statistically significant difference between the control *Mdn* =5 and the experimental groups *Mdn* =5, U = 121, $z = -.294$, and $p = .81$. In addition, the result of (Item 3) "*When given a new problem, I have confidence that I can solve it*" shows that there was no statistically significant difference between the control *Mdn* =5 and the experimental groups *Mdn*= 5 in students' self-perception of problem-solving confidence score of Root Locus score, U = 98.5, $z = -1.18$, $p = .27$.

The finding showed that there was no difference between the control group *Mdn* =15 and the experimental group *Mdn* = 14.50, *U* = 112, *z* = -.619, *p* = .564 in the average of students' self-perception of problem-solving confidence after conducting the SGP instructional practice seemed strange. However, previous study results by Wagner (2017) indicated that the SGP approach had a positive influence to improve problem-solving. Additional interest was expressed in the simple link established between competence in generating and solving problems. Wagner indicated that undergraduate students became more confident with identifying important problem based on what they needed to know to facilitate understanding the scope of their problem-solving skills. However, in the context of this research, sample size could possibly have played a role in this finding. Therefore, it is possible that the SGP instructional practice might have positively influenced students' self-perception of problem-solving confidence, as what the Wagner's study indicated in its results. More investigation is needed to further examine the interaction between students' confidence in problem-solving and their avoidant style. It may perhaps be interesting to find out if such connections are common in other populations; and if so, why.

Approach-Avoidance Style. Approach-Avoidance style evaluates a wide-ranging tendency of individuals to approach or avoid problem-solving activities (Kim & Sin, 2007). In this study, avoidance seemed to affect students' perception of information sources, specifically on 'accessibility' and 'accuracy,' which incidentally are obtained to be the two incredibly important measures for problem solving skills. In relation to the individual approach-avoidance style items, the students' self-perception of problem-solving approach-avoidance scores (Item1) *"When given a problem, I think about different ways of solving it"* showed there was no statistically significant difference between the control *Mdn* = 5 and the experimental *Mdn* = 5 groups, *U* = 115, *z* = -.53, *p* = .64. For (Item 2) *"When given a problem, I use a systematic* *method to solve the problem"*, the problem-solving approach-avoidance scores indicated that there was no statistically significant difference between the control *Mdn* = 5 and the experimental *Mdn* = 5 groups, *U* = 105, *z* = -.966, *p* = .402. However, the students' self-perception of problem-solving approach-avoidance scores for (Item 3) *"When given a problem, I usually first evaluate the problem to identify the important information"* were statistically significantly higher in the control (Mdn = 4.50) than the experimental *Mdn* = 6 groups, *U* = 73.5, *z* = -2.16, *p* = .04.

The control and experimental groups demonstrated no difference in terms of the average of their self-perception of approach-avoidance style. The test score was statistically significantly higher in the control group *Mdn* =16 than the experimental group *Mdn* = 14, *U* = 69.5, *z* = -2.237, *p* = .026. Whereas, for the purpose of assessing what students think about their own problem-solving skills, Gursen (2008) proposed that approach-avoidance style dimension among undergraduate groups was found to be significant (*p* < .05) after applying the instructional strategy. Students with a high avoidant style, in certain, would benefit from more practice that focuses on them of high-quality sources including real life application. However, the use of self-reports has received negative results from several researchers (e.g., Torff, & Tirotta, 2010). From this statement, it can say that the use of only a self-reported Likert scale made it difficult for the researcher to obtain some relevant information that could have shed more light on students' self-perception of their approach-avoidance style and SGP instructional practice of the participants.

Personal Control. Personal Control evaluates the degree to which students believe that they are in control of their emotions and behavior during problem-solving process (Kim & Sin, 2007). For the personal control (Item 1), "*When presented with a problem, I avoid jumping directly into the solution"*, the results indicated that test scores were statistically significantly higher in the control group *Mdn* = 4 than the experimental *Mdn* = 3.5 group, *U* = 52.5, *z* = -2.99, *p* = .003. Nevertheless, the students' self-perception of problem-solving personal control scores for (Item 2), *"When my first efforts to solve a problem fail, I become uneasy about my ability to solve the problem"*, were not statistically significantly different between the control *Mdn* = 3.5 and the experimental *Mdn* = 4 groups, *U* = 165, *z* = 1.46, *p* = .17. In addition, the students' self-perception of problem-solving personal control scores for (Item 3), "*When I work on a problem, I feel that I am not getting to the real solution"*, were not statistically significantly different between the control group Mdn = 4 and the experimental *Mdn* = 4 group, *U* = 148, *z* =.79, *p* = .47.

As the statistical results showed in the previous chapter, there was no significant difference between control and experimental group participants in the average of the self-perception of personal control (all three constructs put together). The students' scores were not statistically significantly different between the control group Mdn = 6 and the experimental group *Mdn* = 4.5, *U* = 115.5, *z* = -.487, *p* = .642. This result shows that the control group students scored higher than the experimental group. Nevertheless, a study by Yoo and Park (2015) compared the personal control test score of control and experimental groups in a clinical course to explore the effects of problem identification and whether or not students could "create their own knowledge and independently develop solutions, rather than refer to the knowledge imparted to them by educators or textbooks for problem-solving" (p. 166). The results showed that problem solving ability personal control indicated a significant improvement in the experimental group and deteriorated in the control group that received traditional activity. From Yoo's et.al findings, it can be inferred that more application of SGP instructional approach on the development of engineering students' problem-solving ability personal control needs to be implemented across different groups since this study did not find any significant difference in one-time application.

Research Question 3: Correlational Relationship Among Study Variables

Research Question 3: *Does a correlation exist between students' self-perception of problem-solving skills, conceptual knowledge, application knowledge, and their final score on the Root Locus concept?*

Researchers in the educational science field have found evidence to support the relationship that exists between knowledge gain and final learning outcomes after applying SGP instructional practice (Coppola & Pontrello, 2019; Weaver, 2020; Zulnaidi & Zamri, 2017). The current study investigated the correlational relationship between electrical engineering students who received the regular activity and the SGP activity (control vs experimental groups) in their problem-solving skills, conceptual knowledge, application knowledge to their final scores.

Problem-Solving Skills & Final Score. The data suggested that the SGP task instruction used did not significantly showed correlation between students' problem-solving skills and their final scores at $p = .55$. The computed effect size $r= 0.16$ was small. The results show that there was a weak correlation between final test scores and Approach-Avoidance Style (AAS), Personal Control, and Problem-Solving Confidence (PSC). This result means that there was no significant correlation between the regular and the SGP approaches; it implies that students did equally well using both the SGP and regular instructional strategies. However, Coppola and Pontrello (2019) indicated in their research study that the improvements in undergraduate chemistry program students' problem-solving skills and their learning outcomes have been described to result when they integrate student-generated activities for some of the difficult concepts. However, this implies that Coppola and Pontrello (2019) study is associated with the hypothesis of the current study, and that there is more room to explore the effect of SGP instructional strategy on students' problem-solving skills.

Conceptual Knowledge & Final Score. The results of the data analysis suggested that the SGP used did not show a significant correlation between students' conceptual knowledge and their final scores at $p = .90$. However, the effect size $r = .02$, small effect size revealed that there may be practical significance differences between the type of instructional strategy used. This result means that when students used SGP to complete the learning task, they demonstrated a higher understanding of Root Locus concept (higher scores) than when they used regular learning practice. A similar study by Bates, Galloway & McBride (2012) indicated that the use of SGP has a positive impact on the students' conceptual understanding in their learning activity. In line with Bates' et.al, study, it can say that the evidence in the present research regarding the hypothesis that expecting to get a significant finding. Therefore, it is possible that the SGP instructional practice might have significant correlation between students' conceptual knowledge and final score, as indicated in the Bates' et.al results.

Knowledge Application & Final score. The data indicated that the SGP task instructions used did not significantly affect students' knowledge application and their final score scores at $p = .38$. The computed effect size $r= 0.16$ was very small. This result means that there was no significant correlation between the regular and the SGP approaches. This implied that students did equally well using both the SGP and regular instructional strategies. Lee, Capraro, and Capraro (2018) reported that the SGP allowed students to connect their knowledge with their experiences or real-life concepts so that it created a better learning outcome. From this related finding it is clear that the application of the SGP learning would be effective in improving students' knowledge application.

Overall, there was no significant correlation between students' self-perception, conceptual knowledge, application knowledge and their final score on the Root Locus concept. Findings of the study should be generalized with caution, however, as the study was not based on a random or systematic sampling. The findings were not intended to be generalized to all students. By implication, both control and experimental electrical engineering students did not demonstrate a more advanced, strong correlation of their final score in all three dimensions. For these reasons the two groups were more likely to have similar learning outcomes in both the SGP and regular instructional practices. The data seemed to suggest that with more application of the SGP in long term, the result might possibly show a strong correlation.

Research Question 4: The Effect of Students' Performance During SGP on Study Variables

Research Question 4: *Which of the predictor variables (final test score, self-perception score, and conceptual knowledge score) are most influential in predicting students' performance during a SPG activity? Are there any predictor variables that do not contribute significantly to the prediction model?*

The statistical analysis that tested the interaction effect between students' performance during a SPG activity and (students' self-perception of problem-solving skills and conceptual knowledge) indicated that there was no significant interaction at $p < .05$. The multiple regression model showed statistically it did not significantly predict students' performance, $F(3\ 12) = 1.05$, $p = .376$, *adj.* $R2 = .14$. Hence, the results suggested that the type of learning task used in either regular or SGP instructional strategies had no different effect on students' performance during a SPG activity score. In essence, the finding indicates that the type of instructional strategy used does not influence the effect of the students' performance during a SPG activity and their score in (students' self-perception of problem-solving skills and conceptual knowledge). Hence, the used of the SGP did not create a unique effect on students' score.

In a similar study, Spier-Dance, Mayer-Smith, Dance & Khan (2005) resulted that the value of using SGP with undergraduate science students as an approach for promoting conceptual understanding. The researchers assessed students' performances on a final exam question for evidence of depth of conceptual understanding as well as knowledge application. They concluded that the students who generated their own analogies performed much better on the exam and showed a high level of conceptual understanding, as compared to the regular instructional method. There are several reasons that could be responsible for the differences in findings between the Spier-Dance et al.'s study and the current study. These reasons may include the small sample size of the present work and the short-term application of the study. Spier-Dance et al.'s study was conducted with four sections of an introductory chemistry course, while the present work used only one section of an electrical engineering course. Therefore, the smaller sample size of the present study may have been responsible for the no significant interaction effect between the performance during a SPG activity and the participants' final test, self-perception, and conceptual knowledge used by undergraduate students in performing the learning task. Therefore, it is possible that the SGP instructional practice might have positively influenced students' final test scores, self- perception, and conceptual knowledge test scores as indicated in the literature review results.

Limitations and Future Research

Several reasons could explain why the SGP group performed similarly with the traditional group. First, a good sample size can be a useful tool in litigation, yet should be implemented with care. By recognizing the strengths and weaknesses of statistical sampling, it can bring this tool to take in the appropriate settings and defend its use or evaluate poorly conducted sampling efforts. A larger sample size would help to determine if a particular outcome is a true finding. In some cases, a type II error may occur, where the hypothesis is incorrectly accepted and no difference between the study groups is reported. Because of the Covid-19 global pandemic impact, fewer students participated in this study. Large sample sizes are important, especially in order to report the effect on significant differences found between groups in the study. Eng (2003) stated that "in a study comparing two groups of individuals, the power (sensitivity) of a statistical test must be sufficient to enable detection of a statistically significant difference between the two groups if a difference is truly present" (p. 310). This study used less than a minimum sample size, and as such, this small sample size could possibly explain why a confirmatory factor analysis was not considered as an additional statistical test in this research. Again, with a small sample size, the findings would not have the needed statistical power to be utilized as a basis to discuss the findings reported by other researchers with larger sample sizes.

Second, the use of only short-term application of the SGP instructional strategy made it difficult for the researcher to find a statistically significant difference between the study groups. Long-term research application has been a key means for being able to understand how the instructional strategy could make positive differences, mostly as a result of learning outcomes change. If the use of long-term application could have lasted at least one semester, the integration of the SGP instructional strategy that included more practice problems for different electrical engineering concepts into the regular curriculum, the participants would have had more time to acquaint themselves with this type of learning and instructional delivery. The possible confounding variable of resistance to the instructional strategy that caused students unfamiliarity toward the SGP could have been eliminated. For future research, it is important to plan the appropriate length of time for the study application to explore more outcome of SGP approach. This study further suggested that long-term SGP intervention would potentially show significant differences between the study groups. The current study concludes that long-term interventions would be more effective at students learning outcomes than short-term interventions.

Self-reported data may also vary from measured or experimental data. In this study, the use of only a self-reported Likert scale with a limited sample size made it difficult for the researcher to obtain some relevant information, which could have shed more light on students' self-perception of their problem-solving skills and SGP instructional practice of the participants. The use of self-reports has received negative results from several researchers (e.g., Torff, & Tirotta, 2010). For example, using a PSI self-reported survey would have brought out relevant questions for control and experimental participants to respond. However, for future study, the PSI self-report questionnaire has been examined as one of the most widely used measurement strategies in science education. It consists of a set of professionally written questions used for explaining problem solving skills. In both in research and practice, this study recommends that the key steps to use PSI self-report questionnaires in a large sample size.

Lastly, although this study did not report a significant difference between the SGP and the traditional group, there appears to be a difference between the mean scores among the two groups. Hence, it can be implied that SGP has the potential to promote knowledge utilization and problem-solving skills among engineering students. This potential benefit occurs because SGP enables students to connect and relate classroom concepts to real-world problems, and as a result contextualizing their learning. The findings of this study are significant for engineering instructors who intend to promote knowledge application and problem-solving skills in their teaching. Also, SGP is a constructivist learning approach and the results from this study suggest that it may offer alternative instructions to the traditional teacher-centered approach, thereby helping instructors better prepare their students for their future workplace challenges. The preparation of the faculty to deliver SGP would be consider as part of a future investigation.

Conclusion

This research study examined the effects of the SGP instructional strategy used in an undergraduate electrical engineering course to determine students' abilities to enhance conceptual knowledge and problem-solving skills in real problem lab activities. The need for this study was to improve students' abilities to function well in the future workplace environment. The study also investigated whether there were relationships between students' skills in SGP and their problem-solving skills, conceptual, and application knowledge of an electrical engineering concept.

This investigation employed a quantitative approach using a within-subject design with pre-post testing. A single group of participants experienced both the regular and SGP instructional strategy. This study's independent variables were the type of instructional strategy– traditional class instruction and the SGP approach. The dependent variables were the students' learning outcomes. This study used a knowledge test (pre and post) to test students' conceptual knowledge, a problem-solving inventory (PSI) survey to assess students' self-perception of problem-solving skills, and a problem identification rubric to assess students' knowledge application in the SGP activity.

The study revealed limited differences in the two groups (control vs experimental) responses of their conceptual knowledge, knowledge application abilities, and self-perception of problem-solving skills. The test scores in knowledge areas did not have a statistically significant relationship overall with the study variables. Further investigation on the connections between these study variables and the SGP instructional strategy is needed. Continued research could provide a more insightful depiction of the effects of this approach on students' development of conceptual knowledge, knowledge application, and problem-solving skills in electrical engineering concepts.

From the result of the applying student-generated problems instructional strategy, it could be beneficial if included as part of the teaching curriculum. Student-generated problems can be implemented in various ways. The problems generated by students can be utilized for practice, or alternatively can be integrated into exams or quizzes. It can benefit students by stimulating interest in the engineering subjects covered and helping them connect the learning concepts to topics for which they are passionate. This approach also allows students to participate more in the evaluation of their own learning when these problems are used in a future workplace. The Student-Generated Problems approach has been demonstrated to help students that put a thoughtful effort into the creation of learning process.

APPENDICES

Appendix A: Instruments

Student-Generated Problems Rubric

Criteria	Exceed Expectations 5	Met Expectations 3	Needs Improvement 1	Point
Description of the Target concept(s)	• The concept is clear described, explained, AND well defined. • the explanation of the concept is accurate, complete, AND concise.	• The concept is clear described, explained, OR well defined. • The explanation of the concept is accurate, complete, OR concise.	• Only the term of the concept is presented. • No description or explanations are given.	
Description of the problem (issue, symptoms, etc.)	• The description of the problem context is clear AND complete. • The description of the main problem (issues or symptoms, root causes of the problem, etc.) is clear AND complete. • The goal of the problem solving is clearly defined.	• The description of the problem context is clear OR complete. • The description of the main problem (issues or symptoms, root causes of the problem, etc.) is clear OR complete. • The goal of the problem solving is vaguely defined.	• The description of the problem context is unclear OR incomplete. • The description of the main problem (issues or symptoms, root causes of the problem, etc.) is unclear OR incomplete. • The goal of the problem solving is absent.	
Analysis of the cause of the problem	• Logical analysis of the root cause of problem is clearly presented with no errors.	• Analysis of the root cause of problem is presented with 1-2 errors.	• Analysis of the root cause of problem is not logical and poorly presented with multiple errors.	
The rationale of how the target concept(s) are needed for solving the problem	• The rationale is logical, with no missing links in the reasoning • The explanation is accurate, clear, AND concise	• The rationale is logical, but with 1-2 missing links in the reasoning • The explanation is inaccurate, unclear, OR unconcise	• The rationale is logical, but with more than 2 missing links in the reasoning • The explanation is inaccurate, unclear, AND unconcise	
Authenticity of the problem	• The problem identified is a real world everyday o professional problem • The problem could be solved in multiple ways	• The problem identified is a real world everyday or professional problem • The problem could be solved in only one way	• Textbook type of problems	
Possible Problem Solution	• Multiple competing solutions are presented • The solutions are clearly explained with how the target concept(s) are applied • Evaluations of the competing solutions are presented.	• One single solution is presented • The solutions are clearly explained with how the target concept(s) are applied	• One or no solution is presented • The explanation for how the concept(s) is (are) applied in the solution is inaccurate or unclear.	

Appendix B

The Problem-Solving Inventory

P. Paul Heppner, Ph.D.

Directions: People respond to personal problems in different ways. The statements on this inventory deal with how people react to personal difficulties and problems in their day-to-day life. The term "problems" refers to personal problems that everyone experiences at times, such as depression, inability to get along with friends, choosing a vocation, or deciding whether to get a divorce. Please respond to the items as honestly as possible so as to most accurately portray how you handle such personal problems. Your responses should reflect what you actually do to solve problems, not how you think you should solve them. When you read an item, ask yourself: Do I ever behave this way? Please answer every item.

Read each statement and indicate the extent to which you agree or disagree with that statement, using the scale provided. Mark your responses by circling the number to the right of each statement.

1. Strongly Agree
2. Moderately Agree
3. Slightly Agree
4. Slightly Disagree
5. Moderately Disagree
6. Strongly Disagree

1. When a solution to a problem has failed, I do not examine why it didn't work.
2. When I am confronted with a complex problem, I don't take the time to develop a strategy for collecting information that will help define the nature of the problem.
3. When my first efforts to solve a problem fail, I become uneasy about my ability to handle the situation.
4. After I solve a problem, I do not analyze what went right and what went wrong.
5. I am usually able to think of creative and effective alternatives to my problems.
6. After following a course of action to solve a problem, I compare the actual outcome with the one I had anticipated.
7. When I have a problem, I think of as many possible ways to handle it as I can until I can't come up with any more ideas.
8. When confronted with a problem, I consistently examine my feelings to find out what is going on in a problem situation.
9. When confused about a problem, I don't clarify vague ideas or feeling by thinking of them in concrete terms.
10. I have the ability to solve most problems even though initially no solution is immediately apparent.
11. Many of the problems I face are too complex for me to solve.
12. When solving a problem, I make decisions that I am happy with later.
13. When confronted with a problem, I tend to do the first thing that I can think of to solve it.

14. Sometimes I do not stop and take time to deal with my problems, but just kind of muddle ahead.
15. When considering solutions to a problem, I do not take the time to assess the potential success of each alternative.
16. When confronted with a problem, I stop and think about it before deciding on a next step.
17. I generally act on the first ideal that comes to mind in solving a problem.
18. When making a decision, I compare alternatives and weigh the consequences of one against the other.
19. When I make plans to solve a problem, I am almost certain that I can make them work.
20. I try to predict the result of a particular course of action.
21. When I try to think of possible solutions to a problem, I do not come up with very many alternatives.
22. When trying to solve a problem, one strategy I often use is to think of past problems that have been similar.
23. Given enough time and effort, I believe I can solve most problems that confront me.
24. When faced with a novel situation, I have confidence that I can handle problems that may arise.
25. Even though I work on a problem, sometimes I feel like I’m groping or wandering and not getting down to the real issue.
26. I make snap judgements and later regret them.
27. I trust my ability to solve new and difficult problems.
28. I use a systematic method to compare alternatives and make decisions.
29. When thinking of ways to handle a problem, I seldom combine ideas from various alternatives to arrive at a workable solution.
30. When faced with a problem, I seldom assess the external forces that may be contributing to the problem.
31. When confronted with a problem, I usually first survey the situation to determine the relevant information.
32. There are times when I become so emotionally charged that I can no longer see the alternatives for solving a particular problem.
33. After making a decision, the actual outcome is usually similar to what I had anticipated.
34. When confronted with a problem, I am unsure of whether I can handle the situation.
35. When I become aware of a problem, one of the first things I do is try to find out exactly what the problem is.

PSI SELF-SCORING SHEET

Instructions:

Scoring the PSI is a matter of summing the responses to each item (1-6) for each of the three factors. The times constituting each factor are listed below.

1. The first step is to transfer your answers (1-6) for the inventory to each of the corresponding blanks on this scoring sheet.

2. Second, note that some items are worded negatively, and scoring of these items must be reversed. These items are indicated by asterisks and are followed by an equal sign (=) and an additional blank. Thus, for these items, reverse the numbers in the following fashion on all of those items which have additional blanks.

   1 = 6

   2 = 5

   3 = 4

   4 = 3

   5 = 2

   6 = 1

3. Third, simply sum the responses together for each factor (being careful to add any reversed number). Record the factor score.

4. Finally, add the three factor scores for the PSI total score. Do not add the three filler items in any way.

Self-Scoring the PSI

Factor one: Problem Solving Confidence

5. _____
10. _____
11.* _____ = _____
12. _____
19. _____
23. _____
24. _____
27. _____
33. _____
34.* _____ = _____
35. _____

FACTOR 1 SCORE _____

Factor two: Approach-Avoidance Style

1.* _____ = _____
2.* _____ = _____
4.* _____ = _____
6. _____
7. _____
8. _____
13.* _____ = _____
15.* _____ = _____
16. _____
17.* _____ = _____
18. _____
20. _____
21.* _____ = _____
28. _____
30.* _____ = _____
31. _____

FACTOR 2 SCORE _____

Factor three: Personal Control

3.* _____ = _____
14.* _____ = _____
25.* _____ = _____
26.* _____ = _____
32.* _____ = _____

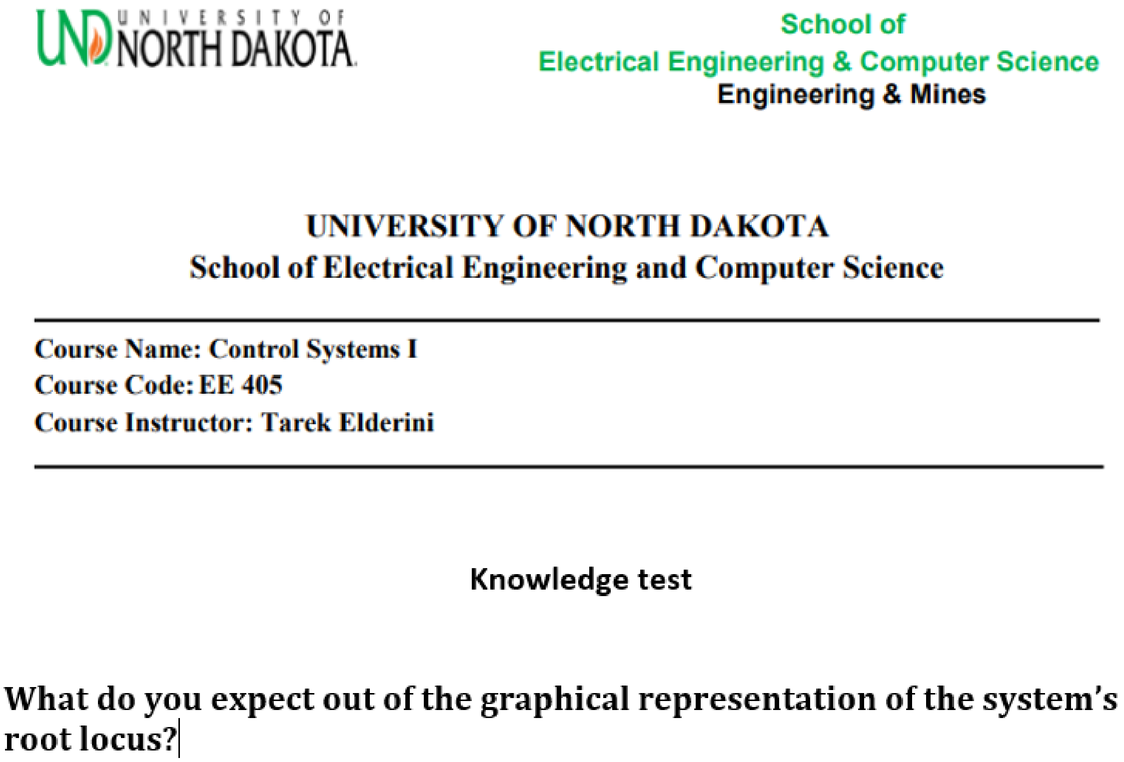
FACTOR 3 SCORE _____

Filler items (Do Not Include in Scoring)

9. _____
22. _____
29. _____

TOTAL PSI SCORE _____

Appendix C: Knowledge Test



School of
Electrical Engineering & Computer Science
Engineering & Mines

UNIVERSITY OF NORTH DAKOTA
School of Electrical Engineering and Computer Science

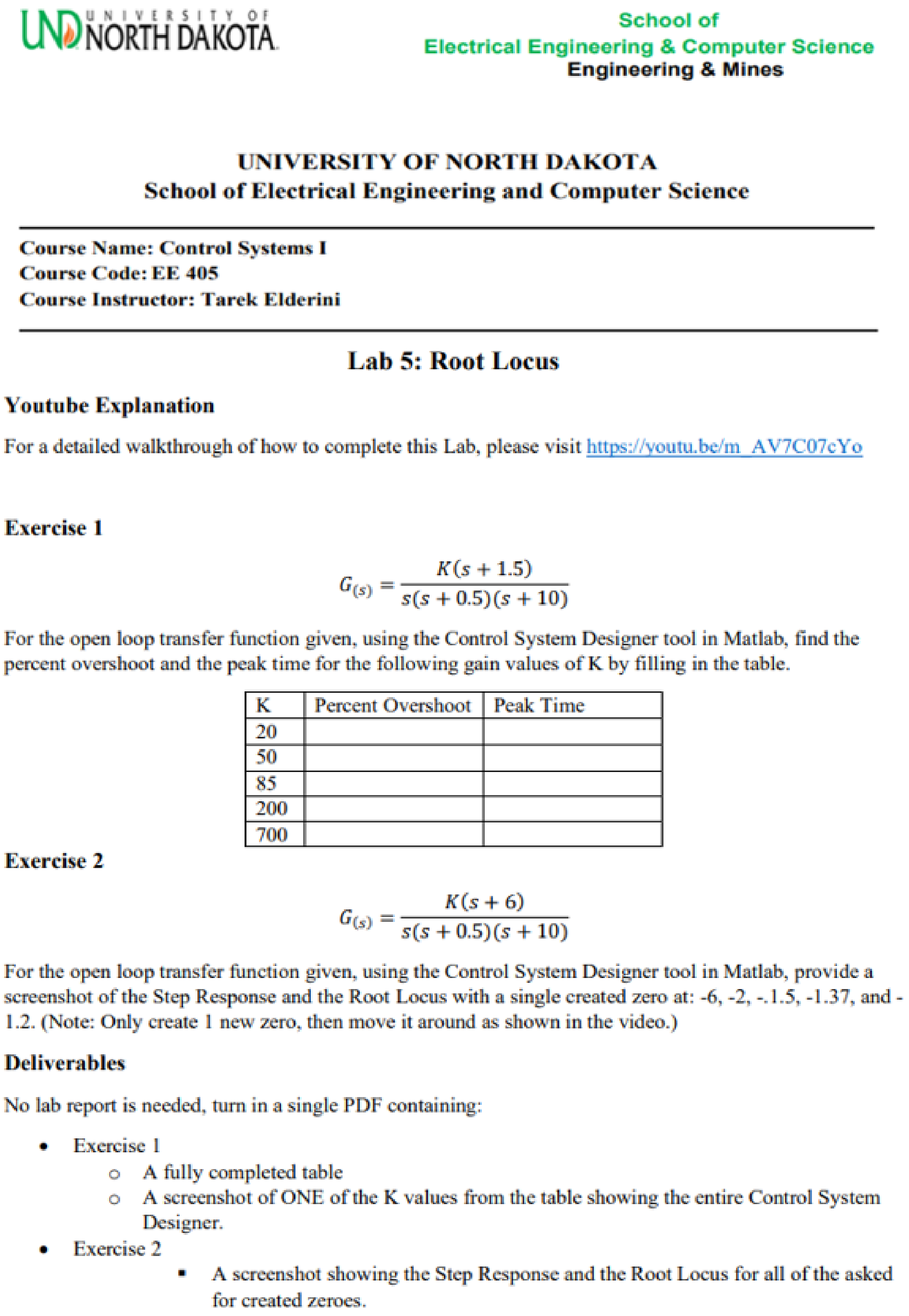
Course Name: Control Systems I
Course Code: EE 405
Course Instructor: Tarek Elderini

Knowledge test

What do you expect out of the graphical representation of the system's root locus?

Appendix D: Application Knowledge Test

Sample of Regular Activity Question & Report



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Course Instructor: Tarek Elderini

Lab 5: Root Locus

Youtube Explanation

For a detailed walkthrough of how to complete this Lab, please visit https://youtu.be/m_AV7C07cYo

Exercise 1

$$G_{(s)} = \frac{K(s + 1.5)}{s(s + 0.5)(s + 10)}$$

For the open loop transfer function given, using the Control System Designer tool in Matlab, find the percent overshoot and the peak time for the following gain values of K by filling in the table.

K	Percent Overshoot	Peak Time
20		
50		
85		
200		
700		

Exercise 2

$$G_{(s)} = \frac{K(s + 6)}{s(s + 0.5)(s + 10)}$$

For the open loop transfer function given, using the Control System Designer tool in Matlab, provide a screenshot of the Step Response and the Root Locus with a single created zero at: -6, -2, -.1.5, -1.37, and -1.2. (Note: Only create 1 new zero, then move it around as shown in the video.)

Deliverables

No lab report is needed, turn in a single PDF containing:

- Exercise 1
  - A fully completed table
  - A screenshot of ONE of the K values from the table showing the entire Control System Designer.
- Exercise 2
    - A screenshot showing the Step Response and the Root Locus for all of the asked for created zeroes.

University of North Dakota
Department of Electrical Engineering

EE 405L Control Systems Laboratory

Lab # 5: Root Locus

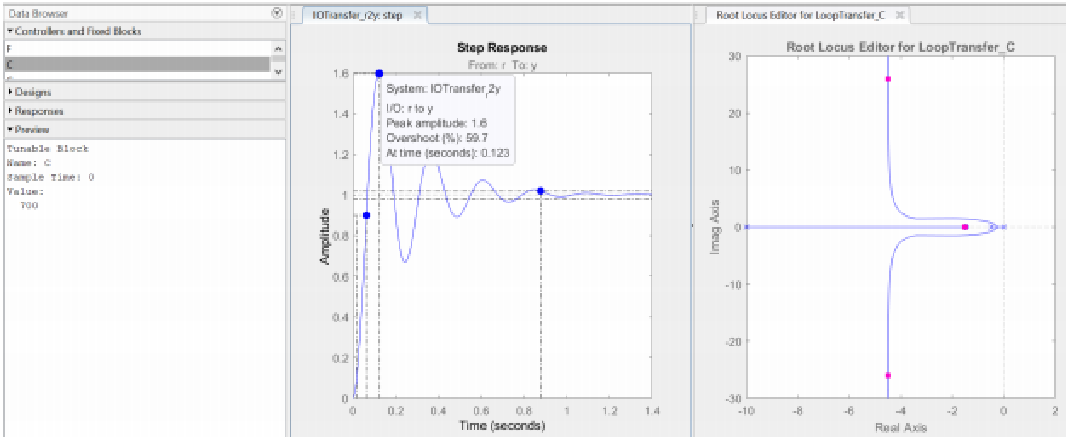
Submitted By: *Gildo Heringer Silva*
Bryce Gruber

Exercise 1:

$$G_{(s)} = \frac{K(s+1.5)}{s(s+0.5)(s+10)}$$

For the open loop transfer function given, using the Control System Designer tool in Matlab, find the percent overshoot and the peak time for the following gain values of K by filling in the table.

K	Percent Overshoot	Peak Time
20	18.4	1.18
50	20.4	1.2
85	25.9	1.26
200	39.4	1.39
700	59.7	1.6



```
Tunable Block
Name: C
Sample Time: 0
Value:
  700
```

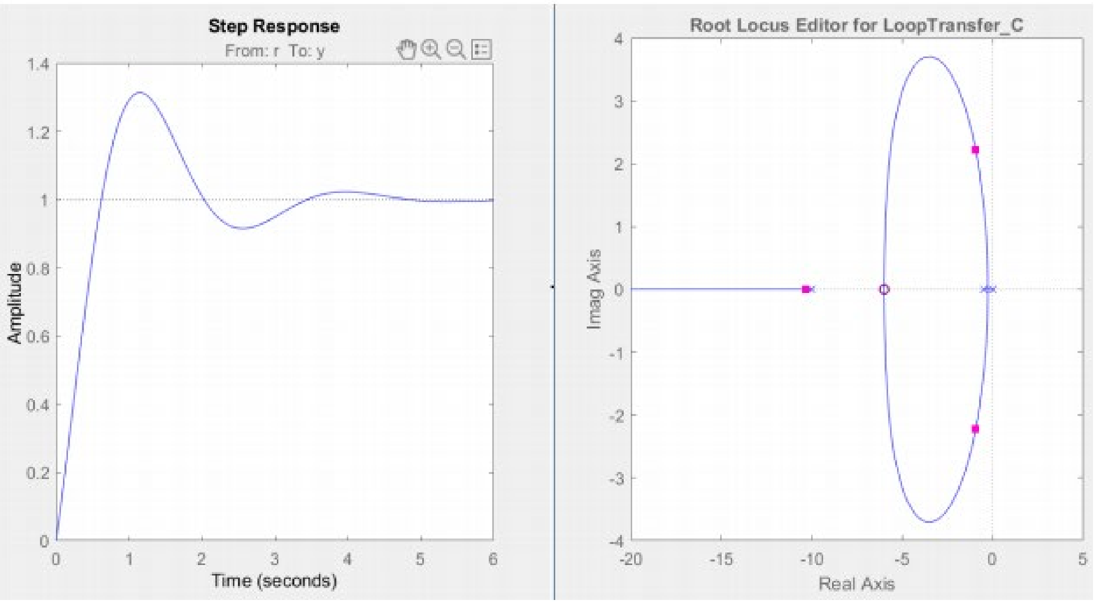
System: IOTransfer_r2y
I/O: r to y
Peak amplitude: 1.6
Overshoot (%): 59.7
At time (seconds): 0.123

Exercise 2:

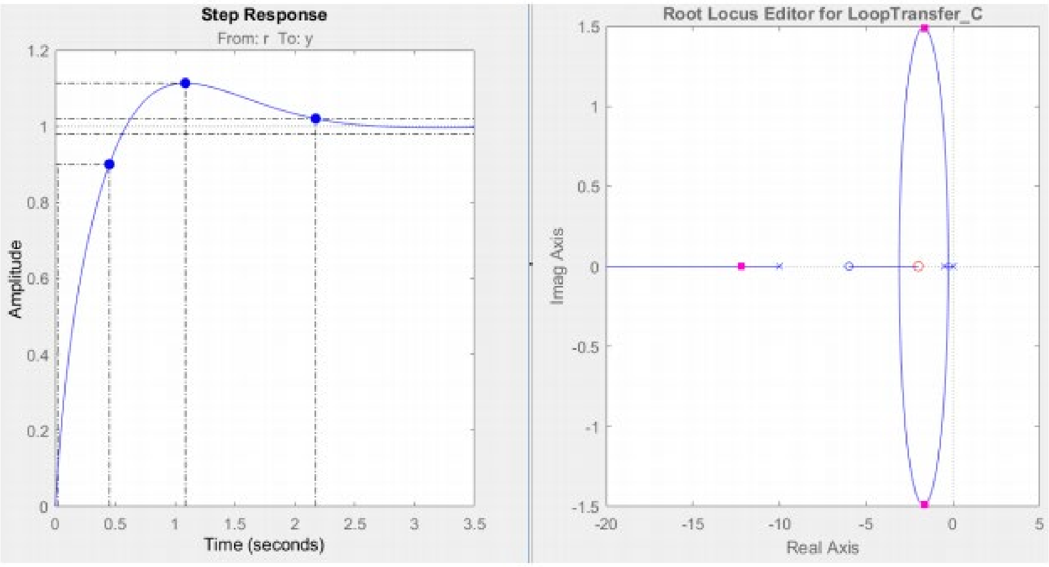
$$G_{(s)} = \frac{K(s+6)}{s(s+0.5)(s+10)}$$

For the open loop transfer function given, using the Control System Designer tool in Matlab, provide a screenshot of the Step Response and the Root Locus with a single created zero at: -6, -2, -.1.5, -1.37, and - 1.2. (Note: Only create 1 new zero, then move it around as shown in the video.)

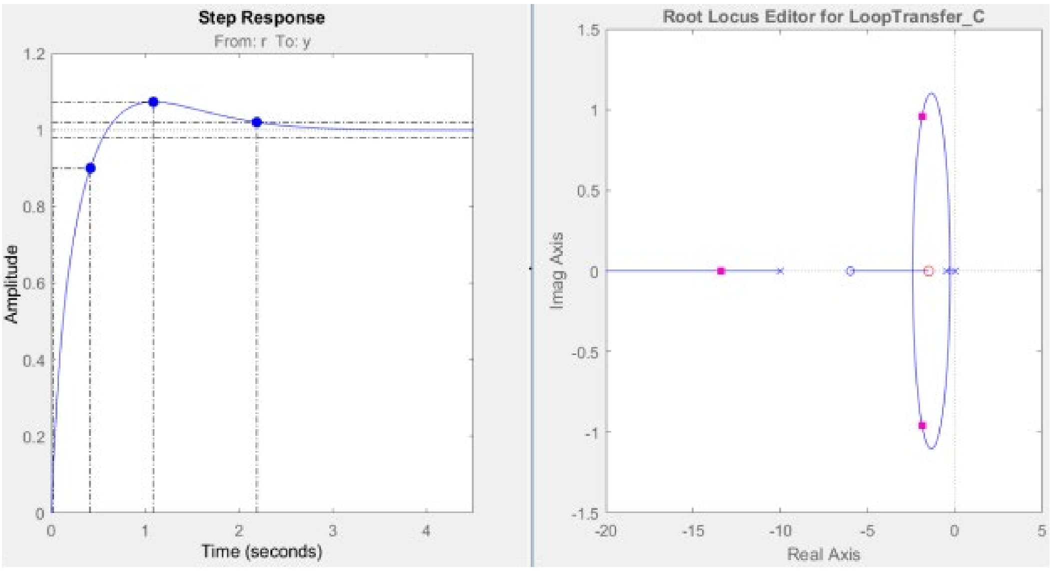
Results for single created zero at: -6:



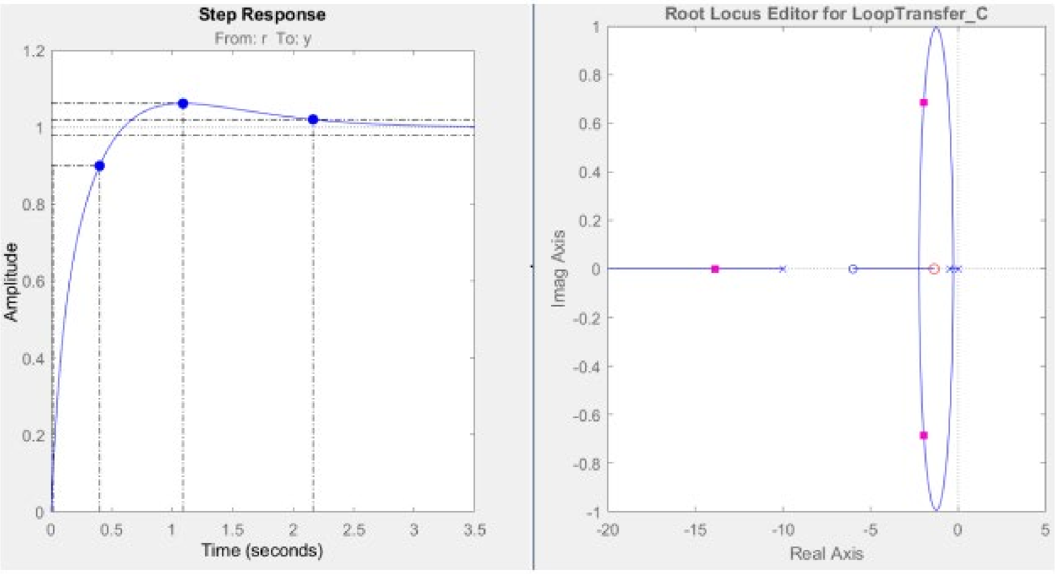
Results for single created zero at: -2:



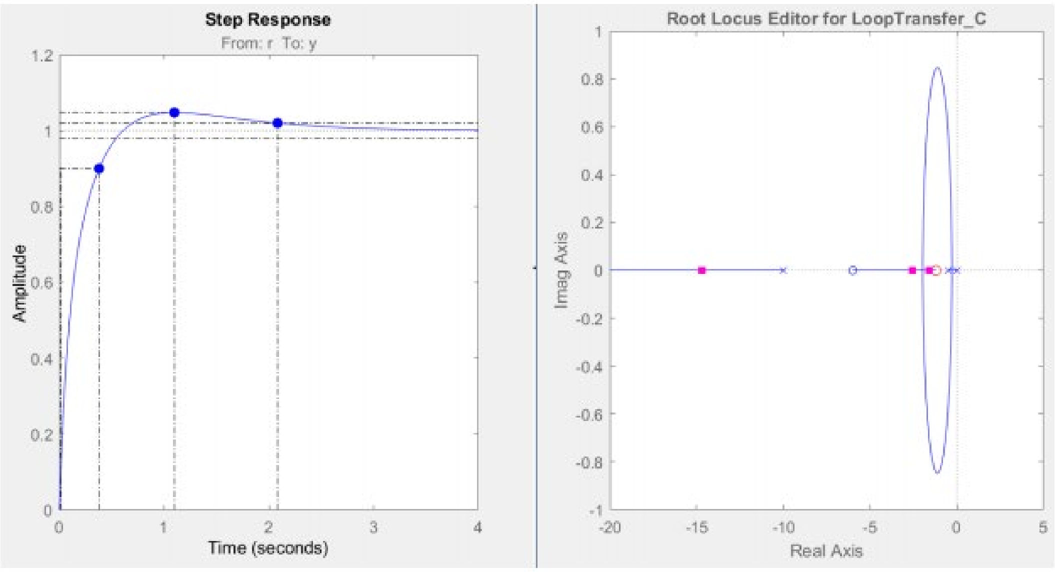
Results for single created zero at: -1.5:



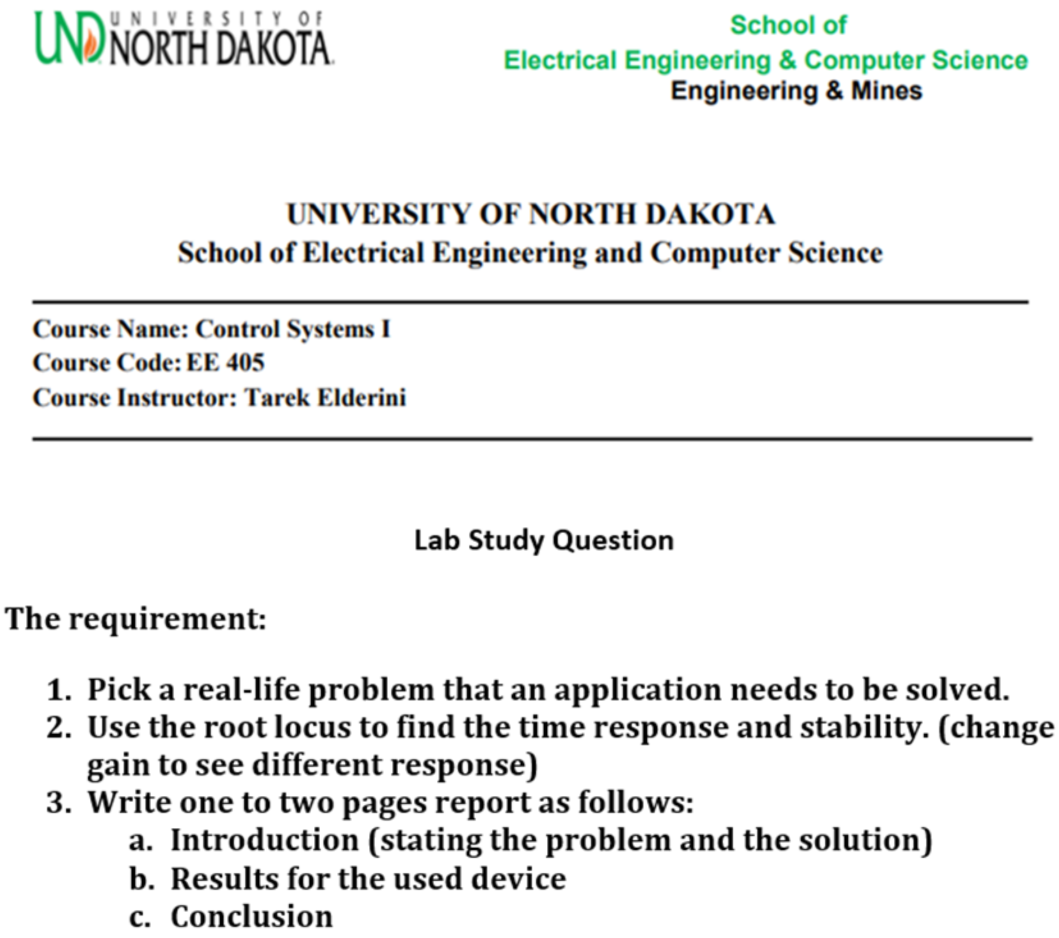
Results for single created zero at: -1.37:



Results for single created zero at: -1.2:



Sample of SGP Activity Question & Report



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Lab Study Question

The requirement:

1. **Pick a real-life problem that an application needs to be solved.**
2. **Use the root locus to find the time response and stability. (change gain to see different response)**
3. **Write one to two pages report as follows:**
    a. **Introduction (stating the problem and the solution)**
    b. **Results for the used device**
    c. **Conclusion**

04/22/2021

Introduction

A vehicle's response to the variations of the road would be uncomfortable and dangerous without a suspension system to absorb these sudden changes, or shocks. Thus, shock absorbers were invented, and this report will inspect a common configuration of such a system. A transfer function will be developed, and from it a root locus will be used to produce a timed response.

Case study

The vehicle to be evaluated is known as the "Golden Car", which behaves more like a tank and is used to test the ability for a new road or bridge to withstand extreme conditions. One fourth of this car's suspension is represented in Figure 1:

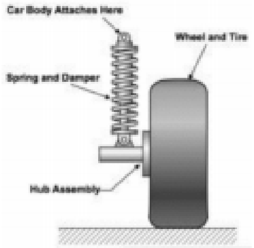


Figure 1: ¼ Golden Car's Suspension

A more mathematically useful representation of this system is shown in Figure 2:

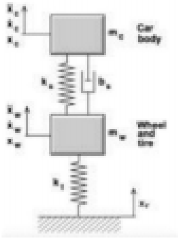
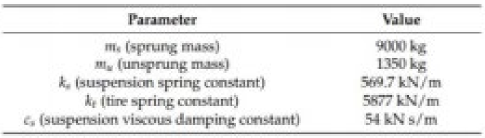


Figure 2: ¼ Golden Car's Suspension

The parameters for the Golden car are shown in Table 1:



Parameter	Value
m_s (sprung mass)	9000 kg
m_u (unsprung mass)	1350 kg
k_s (suspension spring constant)	569.7 kN/m
k_t (tire spring constant)	5877 kN/m
c_s (suspension viscous damping constant)	54 kN s/m

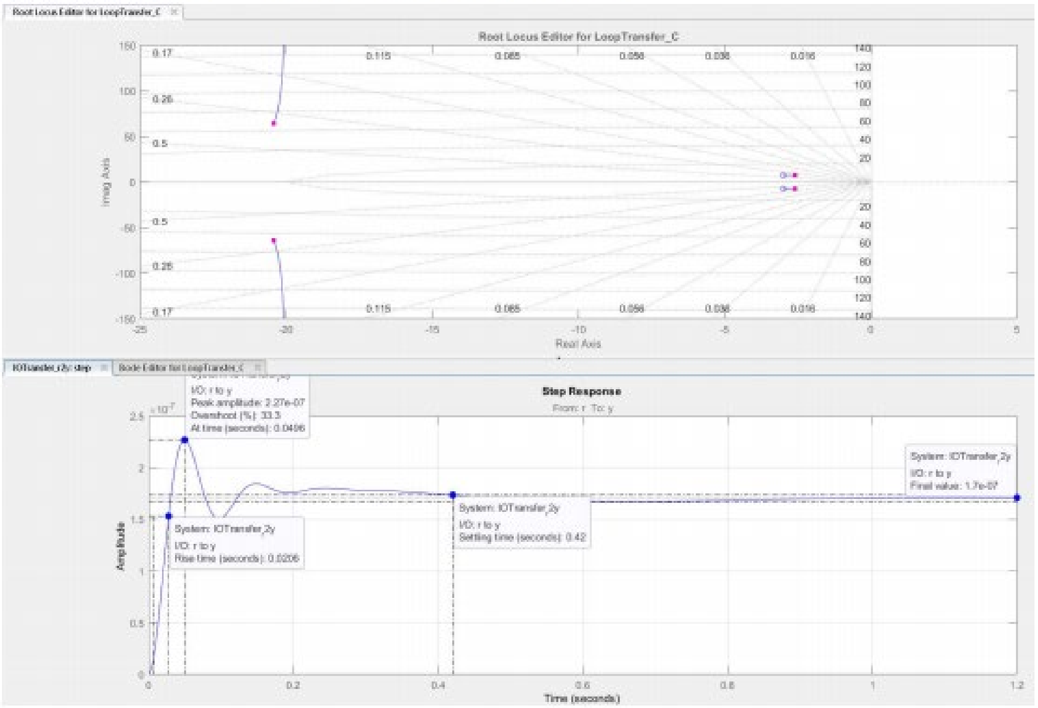
Table 1: ¼ Golden Car's Suspension Parameters

The corresponding Open Loop Transfer Function was found (with Appendix A containing work performed) and is shown in Figure 3:

```
                   9000 s^2 + 54000 s + 569700
  ------------------------------------------------------------------
  1.215e07 s^4 + 5.589e08 s^3 + 5.879e10 s^2 + 3.174e11 s + 3.348e12
```

Figure 3: ¼ Golden Car's Suspension Transfer Function

The root locus and its step response were then created in Matlab to witness the system's behavior, beginning with a K value of 1. The K value is the gain parameter, which is the ratio of system output versus input. These are shown in Figure 4:



I/O: r to y
Peak amplitude: 2.27e-07
Overshoot (%): 33.3
At time (seconds): 0.0496

System: IOTransfer_r2y
I/O: r to y
Rise time (seconds): 0.0206

System: IOTransfer_r2y
I/O: r to y
Settling time (seconds): 0.42

System: IOTransfer_r2y
I/O: r to y
Final value: 1.7e-07

Figure 4: System response with K=1

This suspension system was found to be stable and predictable for a wide range of gain values, therefore large gain values were used to witness substantial changes in behavior between configurations. Figure 5 shows the system for when K=3.71e10:

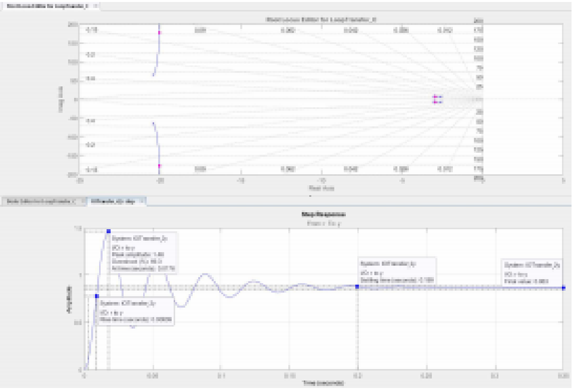


Figure 5: System response with K=3.71e10

A final value of K=1e10 was used and bot the Step Response and Root Locus are shown shown in Figure 6:

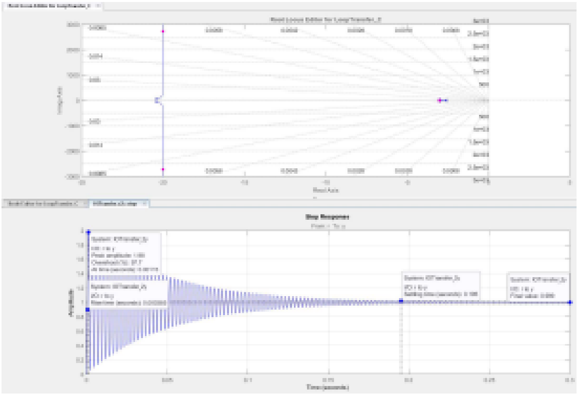


Figure 6: System response with K=3.71e10

Results

Table 1 shows the timed responses for each of the K values for each system:

K Value	Peak Overshoot in %	Rise time in s	Settling Time in s
1	33.3	0.0206	0.42
3.71E+07	69.3	0.00639	0.199
1.00E+10	97.7	0.000385	0.195

Table 1: Comparison of Values

The lower the system gain, the lower the peak value, as well as lower oscillations. Rise time is also lower, and with extreme gain values, the rise time is quite abrupt. The relationship is invers for settling time however, with a longer settling time for a smaller gain.

Conclusions

The Root Locus shows that this system is stable for all values of K, as there are no poles on the right-hand side of the imaginary axis. The higher the gain values, the settling time much shorter but the initial impact (overshoot) followed but high intensity oscillations makes this system more appropriate for systems with a gain certainly lower that 3.71e7, but a wide range of gains should be comfortable below this level.

Without a suspension system, the behavior of the car when navigating bumps would be as abrupt as a step function, which would damage the passengers, as well as the car. This suspension system has shown itself to be successful in lessening the impact of a disturbance while remaining stable, as well as settling to the final value in a reasonable time across a wide range of gains, solving the problem of a bumpy road.

References

Mascio, Loprencipe, Moretti, Puzzo, Zoccali. (2017, June). Bridge Expansion Joint in Road Transition Curve: Effects Assessment on Heavy Vehicles

Appendix E: Problem-Solving Skills Survey

Consent to Participate

Project Title: Using Student-Generated Problems (SGP) as an Instructional Strategy to Enhance Undergraduate Engineering Students' Knowledge Application Ability and Problem-Solving Skills.
Principal Investigator: Sameera Algarni
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Department: Teaching, Leadership & Professional Practice

Research Advisor: Dr. Woei Hung
Phone/Email Address: woei.hung@und.edu
Department: Teaching, Leadership & Professional Practice

What should I know about this research? Someone will explain this research to you. Taking part in this research is voluntary. Whether you take part is up to you. If you don't take part, it won't be held against you. You can take part now and later drop out, and it won't be held against you If you don't understand, ask questions. Ask all the questions you want before you decide.

How long will I be in this research?
Your participation in the study will last for one physics lab activity. You will need to attend the lab times in a week schedule in Zoom platform. Time will take about an hour to attend the activity.

Why is this research being done?
The purpose of this study is to examine the effect of student-generated problems (SGP) activity in an undergraduate engendering lab on students' knowledge application ability and problem-solving skills.

What happens to me if I agree to take part in this research? You will be randomly assigned to one of the groups in this study. You will be provided a link to complete the problem-solving inventory survey (PSI), filled before the day of the experiment. If you are assigned to the SGP group, you will be doing the following, otherwise, you will be doing the regular lab work. You will go into groups of 2 students to work on the Student-Generated-Problem (SGP) activity, and during the SGP activity, you will use the concept learnt in the class to generate relevant problems and provide possible solutions. PI will attend your lab section during the intervention in zoom. After the SGP activity, you will be asked to write a lab report individually. You will then be asked to complete a post-PSI survey. Your score on one of the assignments will be collected and analyzed.

Could being in this research hurt me?
There are no foreseeable risks to you in participating in this research beyond those experienced in everyday life.

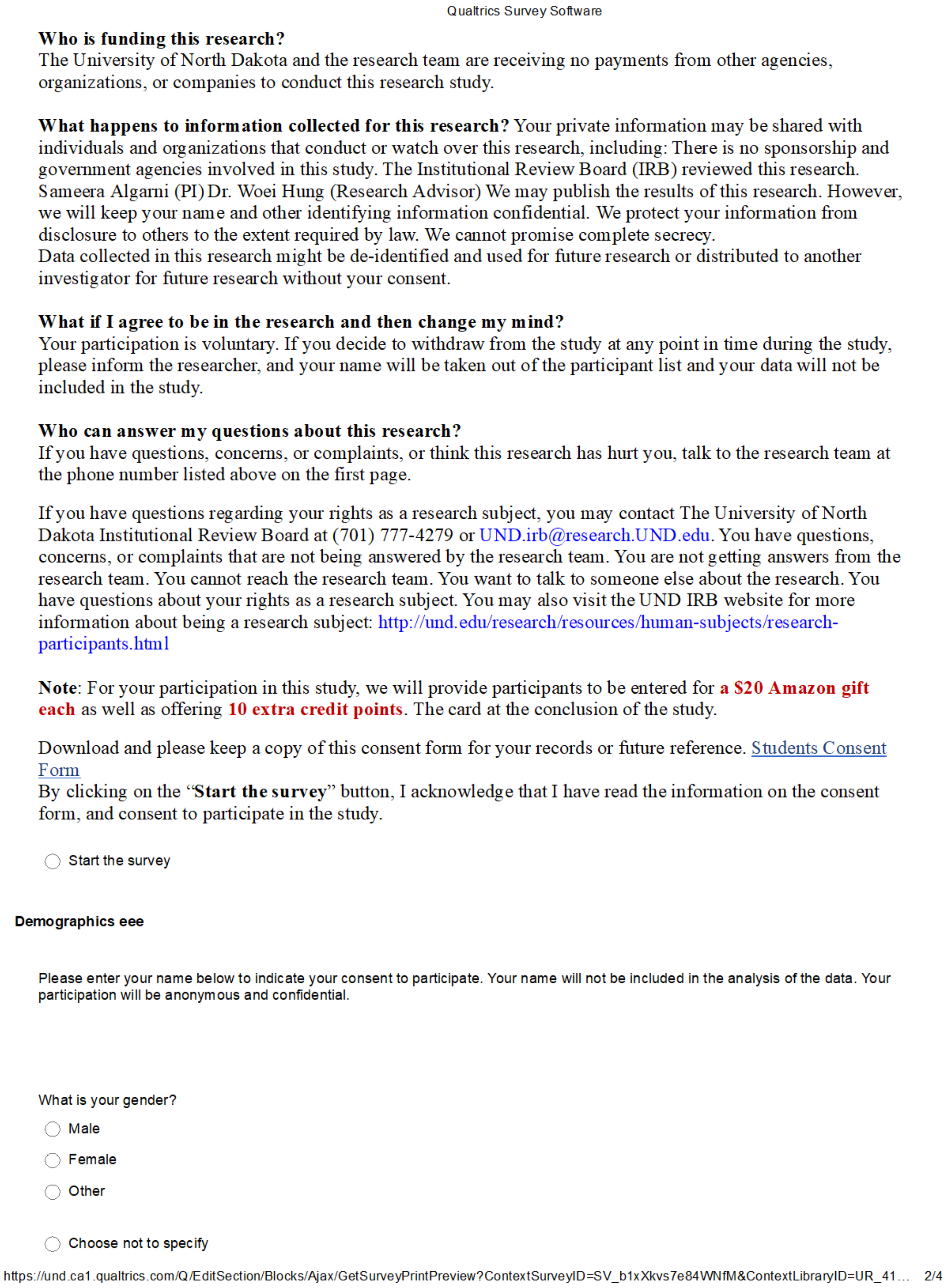
Will being in this research benefit me?
We hope that the knowledge gained through your participation will assist us in better understanding enhancing students' knowledge application and problem-solving skills.

How many people will participate in this research?
32 undergraduate students will take part in this study at the University of North Dakota.

What other choices do I have besides taking part in this research?
This study is to examine the effect of an instructional practice that will be implemented in this class as part of the regular lab activities. If you decide not to participate, we will not include your course data in the study.

Will it cost me money to take part in this research?
You will not have any costs for being in this research study.

Will I be paid for taking part in this research?
You will be entered in **20 Amazon gift cards** at the conclusion of the study.
Your professor will also offer **10 extra credit points** for your participation in the research. If you choose not to participate in the research, you will be offered other opportunities to earn extra credit.



Who is funding this research?
The University of North Dakota and the research team are receiving no payments from other agencies, organizations, or companies to conduct this research study.

What happens to information collected for this research? Your private information may be shared with individuals and organizations that conduct or watch over this research, including: There is no sponsorship and government agencies involved in this study. The Institutional Review Board (IRB) reviewed this research. Sameera Algarni (PI) Dr. Woei Hung (Research Advisor) We may publish the results of this research. However, we will keep your name and other identifying information confidential. We protect your information from disclosure to others to the extent required by law. We cannot promise complete secrecy.
Data collected in this research might be de-identified and used for future research or distributed to another investigator for future research without your consent.

What if I agree to be in the research and then change my mind?
Your participation is voluntary. If you decide to withdraw from the study at any point in time during the study, please inform the researcher, and your name will be taken out of the participant list and your data will not be included in the study.

Who can answer my questions about this research?
If you have questions, concerns, or complaints, or think this research has hurt you, talk to the research team at the phone number listed above on the first page.

If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at (701) 777-4279 or UND.irb@research.UND.edu. You have questions, concerns, or complaints that are not being answered by the research team. You are not getting answers from the research team. You cannot reach the research team. You want to talk to someone else about the research. You have questions about your rights as a research subject. You may also visit the UND IRB website for more information about being a research subject: http://und.edu/research/resources/human-subjects/research-participants.html

Note: For your participation in this study, we will provide participants to be entered for **a $20 Amazon gift each** as well as offering **10 extra credit points**. The card at the conclusion of the study.

Download and please keep a copy of this consent form for your records or future reference. Students Consent Form
By clicking on the "**Start the survey**" button, I acknowledge that I have read the information on the consent form, and consent to participate in the study.

○ Start the survey

Demographics eee

Please enter your name below to indicate your consent to participate. Your name will not be included in the analysis of the data. Your participation will be anonymous and confidential.

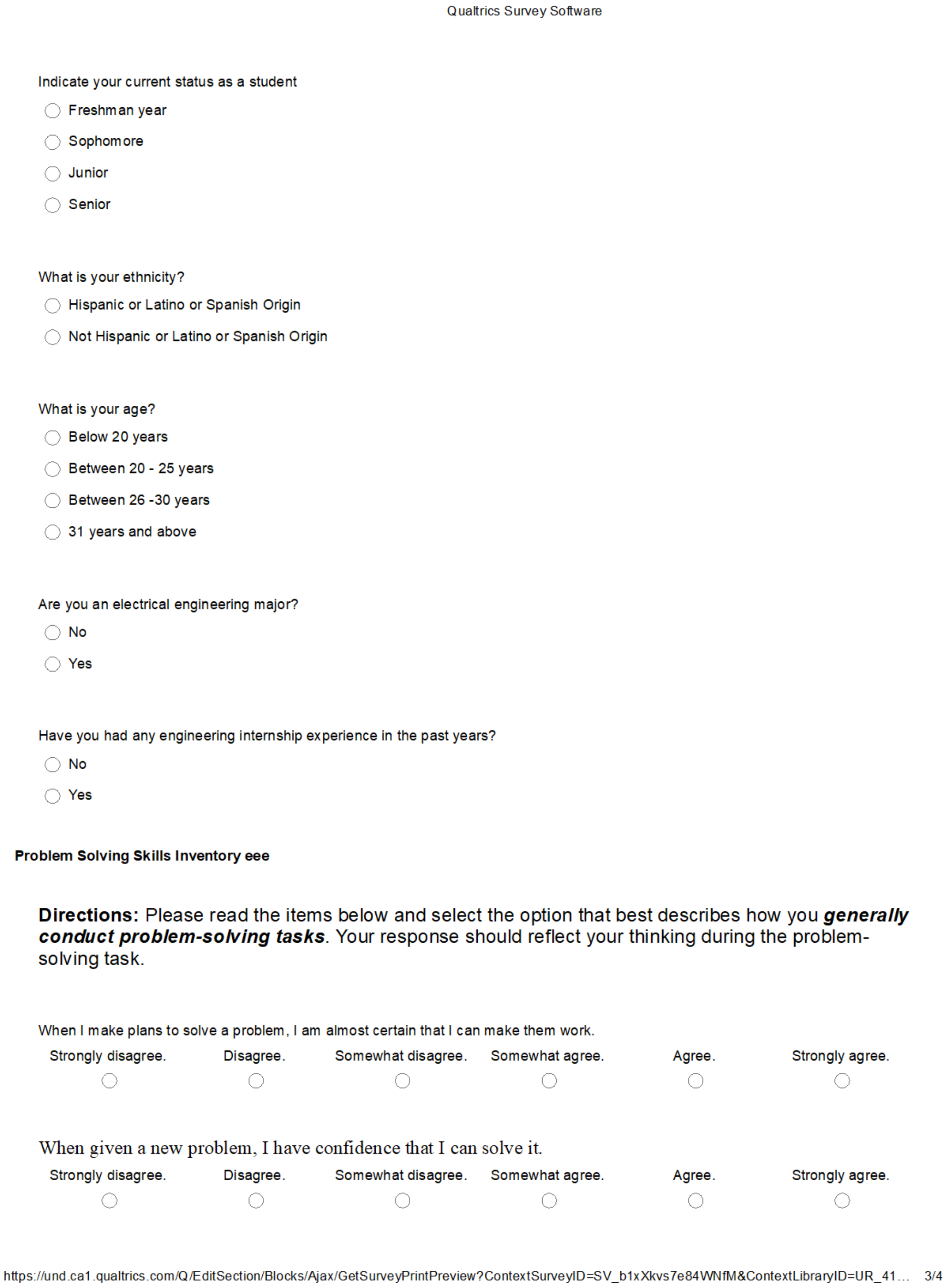
What is your gender?

○ Male

○ Female

○ Other

○ Choose not to specify



Indicate your current status as a student

○ Freshman year

○ Sophomore

○ Junior

○ Senior

What is your ethnicity?

○ Hispanic or Latino or Spanish Origin

○ Not Hispanic or Latino or Spanish Origin

What is your age?

○ Below 20 years

○ Between 20 - 25 years

○ Between 26 -30 years

○ 31 years and above

Are you an electrical engineering major?

○ No

○ Yes

Have you had any engineering internship experience in the past years?

○ No

○ Yes

Problem Solving Skills Inventory eee

Directions: Please read the items below and select the option that best describes how you ***generally conduct problem-solving tasks***. Your response should reflect your thinking during the problem-solving task.

When I make plans to solve a problem, I am almost certain that I can make them work.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When given a new problem, I have confidence that I can solve it.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When I become aware of a problem, one of the first things I do is try to find out exactly what the problem is.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When given a problem, I think about different ways of solving it.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When given a problem, I use a systematic method to solve the problem.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

Directions: Please read the items below and select the option that best describes how you **generally conduct problem-solving tasks**. Your response should reflect your thinking during the problem-solving task.

When given a problem, I usually first evaluate the problem to identify the important information.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When presented with a problem, I avoid jumping directly into the solution.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When my first efforts to solve a problem fail, I become uneasy about my ability to solve the problem.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When I work on a problem, I feel that I am not getting to the real solution.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

Problem Solving Skills Inventory EE

Directions: Please read the items below and select the option that best describes how you conduct problem-solving tasks. Your response should reflect your thinking during the problem-solving task relating to **Student-Generated Problems (SGP) lab activity in Graphical Representation: Root Locus** using the scale provided.

The SGP task helped me to make a problem-solving plan that will almost certainly work.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

The SGP task makes me feel confident that I can solve new problems using the same method.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

The SGP task helped me to think firstly about what exactly the problem is.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

The SGP task helped me to think firstly about what exactly the problem is.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

The SGP task enabled me to think systematically during the problem-solving process.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

Directions: Please read the items below and select the option that best describes how you conduct problem-solving tasks. Your response should reflect your thinking during the problem-solving task relating to **Student-Generated Problems (SGP) lab activity in Graphical Representation: Root Locus** using the scale provided.

The SGP task helped me to first evaluate the problem to identify the important information.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When presented with a problem, I avoid jumping directly into the solution.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

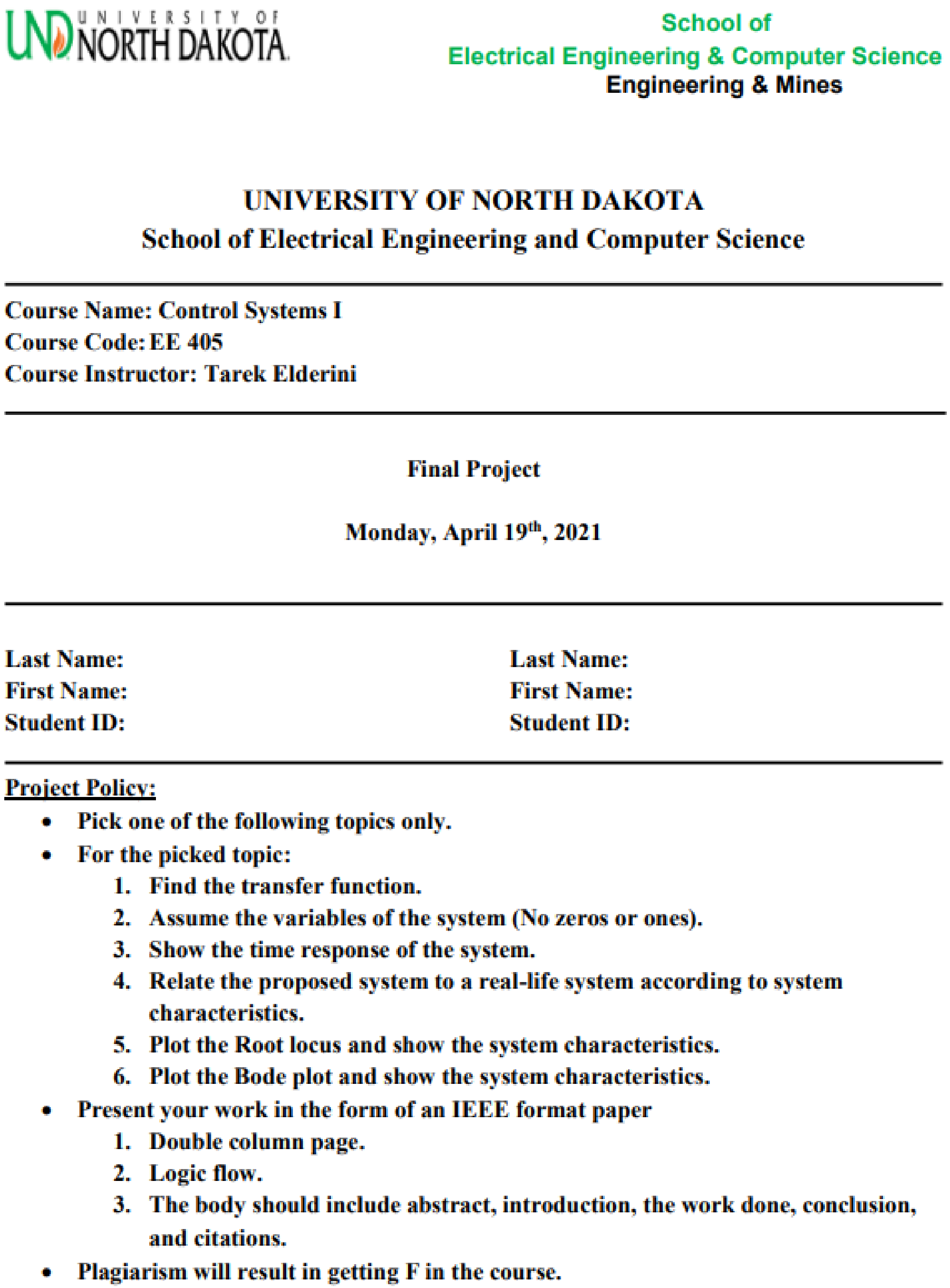
When my first efforts to solve a problem fail, I become uneasy about my ability to solve the problem.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

When I work on a problem, I feel that I am not getting to the real solution.

Strongly disagree.	Disagree.	Somewhat disagree.	Somewhat agree.	Agree.	Strongly agree.
○	○	○	○	○	○

Appendix F: Final Exam Question



School of
Electrical Engineering & Computer Science
Engineering & Mines

UNIVERSITY OF NORTH DAKOTA
School of Electrical Engineering and Computer Science

Course Name: Control Systems I
Course Code: EE 405
Course Instructor: Tarek Elderini

Final Project

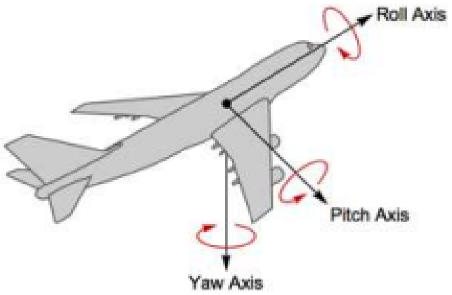
Monday, April 19th, 2021

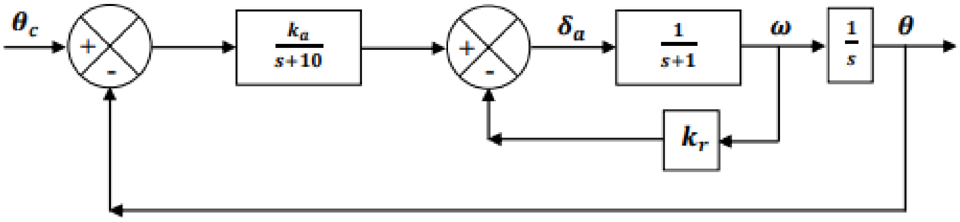
Last Name:	**Last Name:**
First Name:	**First Name:**
Student ID:	**Student ID:**

Project Policy:

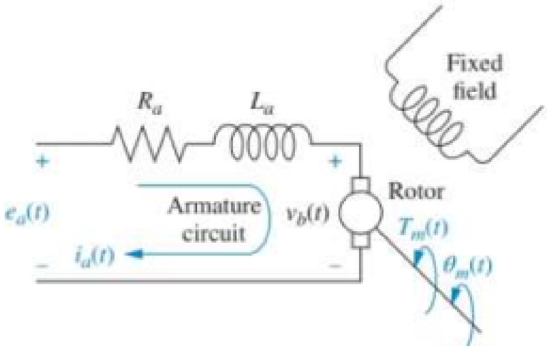
- **Pick one of the following topics only.**
- **For the picked topic:**
  1. **Find the transfer function.**
  2. **Assume the variables of the system (No zeros or ones).**
  3. **Show the time response of the system.**
  4. **Relate the proposed system to a real-life system according to system characteristics.**
  5. **Plot the Root locus and show the system characteristics.**
  6. **Plot the Bode plot and show the system characteristics.**
- **Present your work in the form of an IEEE format paper**
  1. **Double column page.**
  2. **Logic flow.**
  3. **The body should include abstract, introduction, the work done, conclusion, and citations.**
- **Plagiarism will result in getting F in the course.**

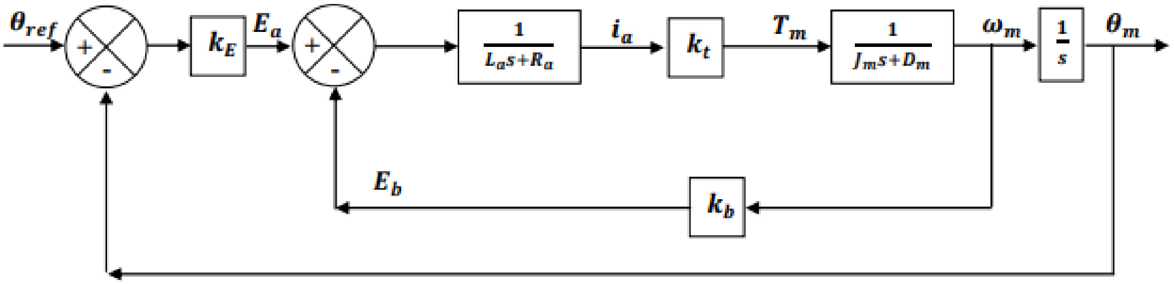
System 1. Aircraft Pitch Control Loop:



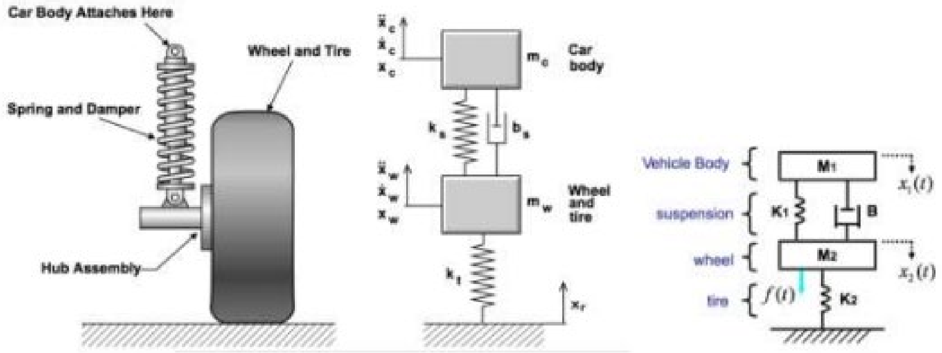


System 2. DC motor:



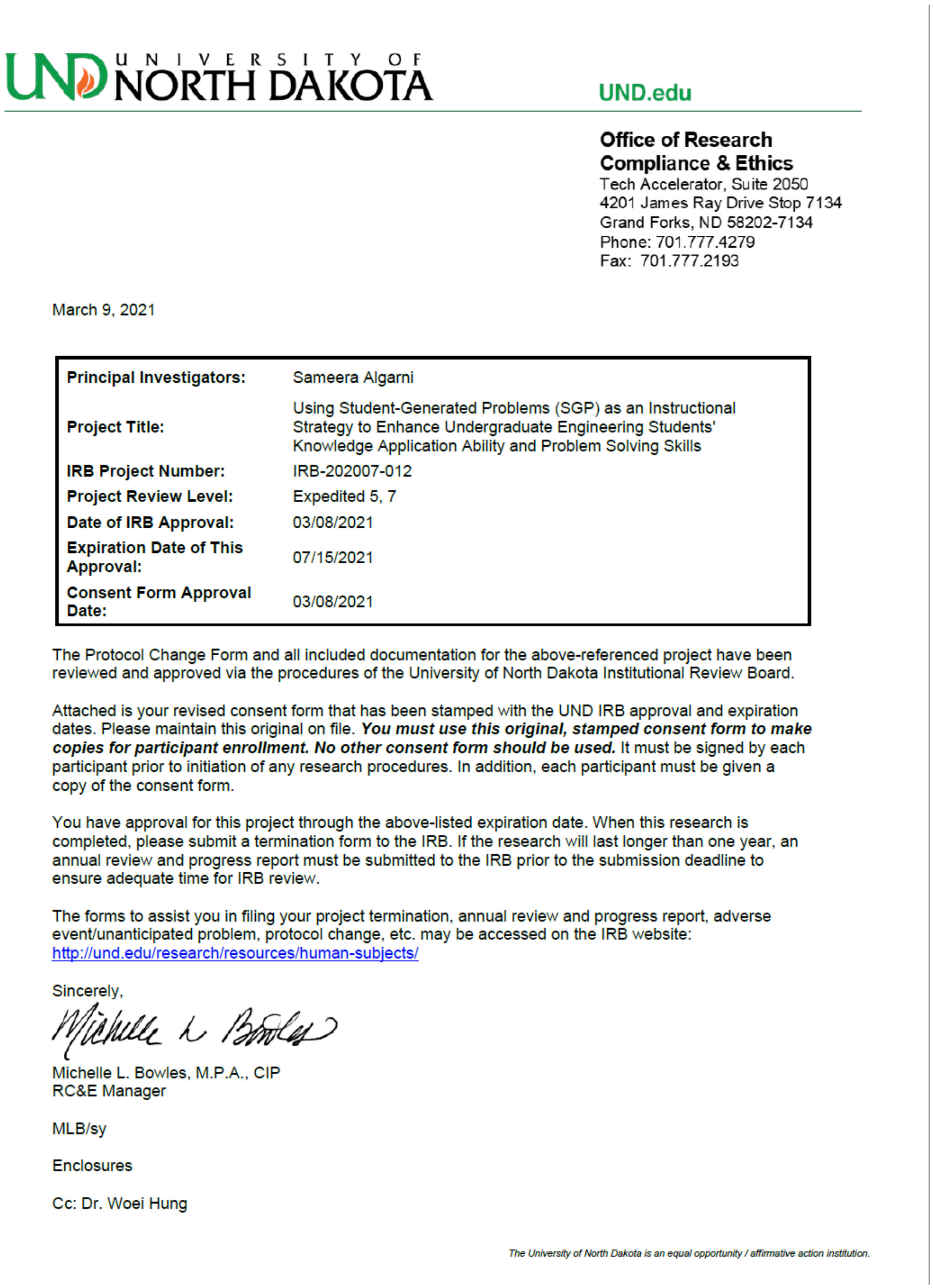


System 3. Simplified model for the suspension system of a quarter of a car



Transfer function = $\frac{X_2}{F}$

Appendix G: IRB Approval



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4201 James Ray Drive Stop 7134
Grand Forks, ND 58202-7134
Phone: 701.777.4279
Fax: 701.777.2193

March 9, 2021

Principal Investigators:	Sameera Algarni
Project Title:	Using Student-Generated Problems (SGP) as an Instructional Strategy to Enhance Undergraduate Engineering Students' Knowledge Application Ability and Problem Solving Skills
IRB Project Number:	IRB-202007-012
Project Review Level:	Expedited 5, 7
Date of IRB Approval:	03/08/2021
Expiration Date of This Approval:	07/15/2021
Consent Form Approval Date:	03/08/2021

The Protocol Change Form and all included documentation for the above-referenced project have been reviewed and approved via the procedures of the University of North Dakota Institutional Review Board.

Attached is your revised consent form that has been stamped with the UND IRB approval and expiration dates. Please maintain this original on file. ***You must use this original, stamped consent form to make copies for participant enrollment. No other consent form should be used.*** It must be signed by each participant prior to initiation of any research procedures. In addition, each participant must be given a copy of the consent form.

You have approval for this project through the above-listed expiration date. When this research is completed, please submit a termination form to the IRB. If the research will last longer than one year, an annual review and progress report must be submitted to the IRB prior to the submission deadline to ensure adequate time for IRB review.

The forms to assist you in filing your project termination, annual review and progress report, adverse event/unanticipated problem, protocol change, etc. may be accessed on the IRB website: http://und.edu/research/resources/human-subjects/

Sincerely,

Michelle L Bowles

Michelle L. Bowles, M.P.A., CIP
RC&E Manager

MLB/sy

Enclosures

Cc: Dr. Woei Hung

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