The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41936

Board 304: Improving Engineering Mechanics Self-efficacy by Focusing on Abstracting the Physical World as a Precursor to Analysis

Dr. Nigel Berkeley Kaye, Clemson University

Professor of Civil Engineering

Dr. Lisa Benson, Clemson University

Lisa Benson is a Professor of Engineering and Science Education at Clemson University, and the past editor of the Journal of Engineering Education. Her research focuses on the interactions between student motivation and their learning experiences. Her projects include studies of student perceptions, beliefs and attitudes towards becoming engineers and scientists, and their development of problem-solving skills, self-regulated learning practices, and epistemic beliefs. Other projects in the Benson group involve students' navigational capital, and researchers' schema development through the peer review process. Dr. Benson is an American Society for Engineering Education (ASEE) Fellow, and a member of the European Society for Engineering Education (SEFI), American Educational Research Association (AERA) and Tau Beta Pi. She earned a B.S. in Bioengineering (1978) from the University of Vermont, and M.S. (1986) and Ph.D. (2002) in Bioengineering from Clemson University.

Makayla Headley, Clemson University

I am a doctoral student in Engineering and Science Education. My research interest include engineering curriculum and accreditation.

Komal Rohidas Sonavane

Improving Engineering Mechanics Self-Efficacy By Focusing On Abstracting The Physical World As A Precursor To Analysis

Abstract

Sophomore level engineering mechanics classes typically have high rates of failure or withdrawal. Some explanations posited for this phenomenon include lack of student preparation, the difficulty of the material, ineffective instructional methods, and lack of context. Instructors and textbook authors attempt to overcome these issues with a range of pedagogical approaches such as math reviews, worked examples focused on problem solving processes, "real-world" problems, and active learning focused on physical understanding. However, the first step in the problem-solving process, abstracting the problem, is very often missing. At a fundamental level, engineers follow a four-step design process: (1) Describing or abstracting the physical world with diagrams, words, numbers, and equations (2) Analyzing their model (3) Designing something based on that analysis, and (4) Constructing the designed system. Sophomore mechanics classes traditionally focus on step (2) largely bypassing step (1), instead presenting students with drawings, numbers, and text and teaching them to apply appropriate equations.

The goals of this research are (1) to develop a sophomore-level mechanics class that flips the traditional approach by starting with the physical world application and focusing on developing students' ability to abstract as a precursor to analysis; and (2) to assess if this new approach improves student self-efficacy in basic mechanics. The hypothesis of the proposed research is that, by starting with abstraction, students will build a stronger connection between the physical world and the mechanics modeling. In turn, this will improve student's perceptions about their ability to solve engineering mechanics problems and their motivation to pursue careers as engineers in the future. The specific research questions we seek to answer are: (1) In what ways does teaching students how to abstract the physical world affect their self-efficacy to solve problems in a basic mechanics class? and (2) In what ways does showing students how to abstract the physical world into tractable engineering science problems affect their future-oriented motivation?

We are employing a mixed methods approach that combines quantitative survey data with observations, interviews, and course artifacts to address our research questions. The first phase of our research will establish baseline survey data from statics classes taught in a traditional lecture style that will be compared in future iterations of the course in which students engage in problem abstraction as the first step in the problem-solving process. Results will be presented on the baseline survey data assessing students' problem-solving self-efficacy and future oriented motivation. In addition to the baseline survey results, we will present example lesson plans, worksheets, class assessments, and an example physical model to illustrate how abstraction will be used in the classroom. Future directions for this project will also be discussed.

Introduction and literature review

This paper describes a work-in-progress that examines the potential for explicitly teaching problem abstraction in statics classes to improve students' self-efficacy and future-oriented motivation. The paper presents a brief overview of the backgrounds and motivation and then describes progress made in course development, instrument development, and baseline data from traditional statics classes.

Sophomore level engineering science courses, e.g. statics and dynamics, typically have high rates of failure or withdrawal (Min et al., 2011; Lord & Chen, 2014; Lord et al., 2017). Some explanations posited for this phenomenon include lack of student preparation, the difficulty of the material, poor pedagogy, and lack of context. Instructors and textbook authors attempt to overcome some of these issues with math reviews (Hibbeler 2007). worked examples that focus on problem solving processes (Beer et al. 2012), "real-world" problems (Miriam & Kraige 2007), active learning focused on physical understanding (Chan Hilton & Neupeaur 2013), and a range of other pedagogical approaches (Felder & Brent 2016). However, there is very often a step missing in the problem-solving process, namely the very first step of abstracting the real-world problem. At a fundamental level, engineers in the mechanics-based disciplines (e.g. civil and mechanical engineering), follow a four-step design process:

1) Abstracting/describing the physical world with diagrams, words, numbers, and equations
2) Analyzing their abstract descriptions to understand how the system works,
3) Designing something based on that analysis to solve a real-world problem, and
4) Constructing the designed system.

Refer to Figure 1 for a schematic diagram of this process. Sophomore mechanics courses primarily focus on step (2) largely bypassing step (1). Instructors present students with drawings, numbers, and text that describe the system and teach them to take those descriptions and apply the appropriate equations to analyze the system. By leaving out the first step, students lack the connection to the real world and the problem reduces to applied mathematics. This lack of connection has the potential to reduce students' connection with their chosen profession and, more importantly, reduces their motivation and self-efficacy in solving actual engineering problems. "The will to learn depends partly on how the problem solver interprets the problem-solving situation" (Mayer, 1998, p. 56).

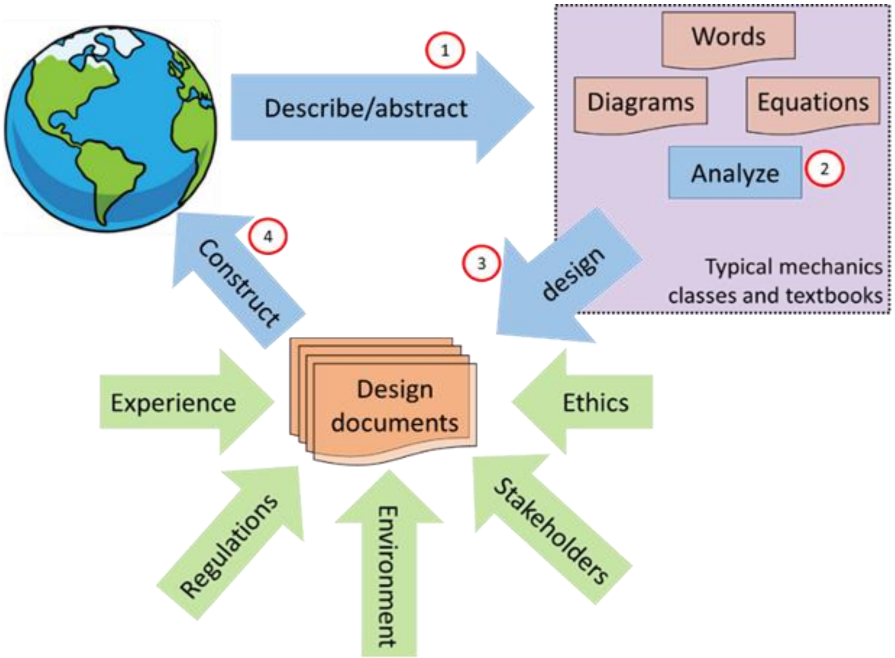

Figure 1. Schematic diagram of the engineering process starting with (1) abstracting the physical world, (2) analysis, (3) design, and then (4) constructing something in the physical world.

There is strong evidence that a lack of context within core engineering courses needs to be addressed to minimize mid-year student attrition in engineering programs (Lord et al., 2017). Engineering students take required foundational courses in science, math, and engineering, but content in these courses are often highly abstract with limited apparent connection to students' future professional goals. Students' limited perceptions of the usefulness and relevance of tasks in their courses leads to reduced academic motivation (Simons et al., 2004), which in turn can lead to attrition. Furthermore, students' problem-solving approaches are also linked to their academic motivation (Kirn & Benson 2015). To overcome this problem, several institutions have introduced sophomore year design courses (e.g. Sarasua et al., 2020; Nagel et al., 2012). While this approach provides students with context for their studies, it does not solve the problem of the highly abstract nature of foundational courses in basic math, science, and engineering. There remains a lack of connection between the physical world in which professional engineers work and the abstract world of first year and sophomore courses in math, science, and engineering science. Making that connection will require a new approach to teaching engineering science courses that starts with the physical world and explicitly addresses the process of abstracting the physical world into tractable engineering science problems. The hypothesis of the proposed research is that**,** by starting with abstraction, ***students will build a stronger connection between the physical world and mechanics modeling. In turn, this will improve student's perceptions about their ability to solve engineering mechanics problems and their future-oriented motivation.***

The goal of this research is to test this hypothesis by developing a sophomore level mechanics course in which the focus of instruction begins with the step of abstracting the physical world into diagrams, numbers, words, and equations. We will build the newly designed course around a physical model of a small urban area that has cultural relevance to civil engineering students at our institution (Jordan et al., 2019). In each class, the students will examine a component of the physical model and learn how to develop a mechanics-based model of its behavior. The students will also interact physically with and observe the behavior of the components of this model. We will assess the effects of this approach on student motivation and self-efficacy using a set of quantitative and qualitative assessment tools. Starting with abstraction will promote self-efficacy as students will:

1. Develop a stronger mental connection between the physical world and theoretical mechanics models. In the course, the students will take a physical system and develop a mechanics-based model to analyze. This forces students to focus on the connection between the physical model and the mathematical model. This prevents students using the plug-and-chug approach of throwing equations at the numbers.
2. Understand the basic analysis assumptions by physically experiencing the behavior of different components. There are many assumptions made in undergraduate engineering science courses. These are often introduced by explaining how they are incorporated into mathematical models with limited justification. For example, in statics there are three basic types of supports namely roller, pin, and built-in. Each can support different types of loads. Having students start with a physical model of each support type, establishing their behavior, and then abstracting that behavior into a model will create a stronger mental connection to the modeling assumptions applied to structural supports.
3. Learn terminology from seeing the different types of mechanical components and connections rather than from text and diagrams. There is often an underlying assumption in mechanics courses that students have a common language. This is rarely the case and making such an assumption places students with less background in engineering at a disadvantage. The approach proposed will enable the instructor naturally to introduce terminology as the students explore the physical model. This teaching of terminology will aid student enculturation into their chosen profession by learning the language of that profession in the context of the physical world around them.

Theoretical frameworks

This study draws on two main theoretical frameworks: future-oriented motivation and self-efficacy. Prior research on engineering student motivation has found that time-related factors are relevant in the context of academic performance (Husman & Lens, 1999; Miller & Brickman, 2004; Tabachnik et al., 2008), particularly for engineering students (Husman et al., 2007; Kirn & Benson 2015). Future-oriented theories included in this study are future time perspective and future possible selves. We also draw from self-efficacy theory to address students' beliefs about their ability to complete steps when solving engineering mechanics problems, which allows us to deepen our understanding of their perceptions of how the future relates to their problem-solving skills. These frameworks shape our study design, data collection, and analysis.

Future Time Perspective (FTP) theory posits that the distance into the future of student goals paired with their perceived usefulness (i.e., perceived instrumentality) of a related task in the present will influence student actions in the present (Husman & Lens, 1999). FTP research has shown that students who have stronger academic motivations often have stronger or more detailed perceptions of the future and its impact on their academic goals, which correlates to improved persistence, and performance on academic tasks (Husman & Lens, 1999).

Future Possible Selves (FPS) theory examines students' goals in terms of who they want to become ideally (ideal self), who they think they can become (attainable self), or who they want to avoid becoming (avoided self) (Markus & Nurius, 1986). Research applying FPS theory has shown that students with differing perceptions of their future will pursue goals differently: students with ideal selves are more likely to persist when faced with challenges or difficulties in their lives (Pizzolato, 2006). Being future-oriented or working to develop perceptions of future possible selves has been shown to increase interest and efficacy to succeed in school (Oyserman et al., 2007), and can influence self-regulatory behaviors (Oyserman et al., 2004), knowledge building (Hilpert et al., 2012), and perceptions of themselves in the present (Husman & Lens, 1999; Markus & Nurius, 1986).

Self-efficacy was defined by Bandura (1986) as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (p. 391). An individual's self-efficacy for attaining a specific outcome will influence the amount of effort they put into attaining that outcome and their enactment of coping strategies in the face of adversity (Bandura, 1977). Specific to our study context, increased engineering self-efficacy beliefs are predictive of improved learning and understanding in introductory engineering courses (Hutchison et al., 2006).

Together, these theories help inform the connections students make between the present and the future and support our exploration of the interactions between students' perceptions of their present coursework and future career goals. These connections can be made in both directions, as choices in the present activities can be seen to influence the future, and future goals can be seen to influence present activities.

Project objectives

We aim to strengthen connections students make between coursework and the physical world by empowering students to start with the generalized skill of problem definition and scoping as they work with physical models in a foundational engineering course. This work is guided by two main research questions:

1. In what ways do teaching students how to abstract the physical world affect their self-efficacy in a basic mechanics course, and to what extent do students build direct connections

between the physical world they live in with the mechanics models they will use in their studies?
2. In what ways do showing students how to abstract the physical world into tractable engineering science problems affect their future-oriented motivation, and to what extent do students make connections between what they learn and the physical world they will work in upon graduation?

Course development

The course being developed is a new version of an existing statics class. This is a foundational mechanics class taught to sophomore students in civil, environmental, biosystems, biomedical, and industrial engineering. Approximately 5-600 students take the class each year in sections of roughly 40 students. The class has an existing syllabus that lists the topics that are required to be taught. However, the instructional team has flexibility in determining the order the topics are covered and the method of instruction.

The pedagogical approach we will take is to introduce students to physical models of actual objects they encounter in their regular lives and then lead them through the process of abstracting the physical object into an engineering problem and then solving that problem. Therefore, theory will only be introduced as it is needed to solve a particular problem. This requires re-working of the typical class progression of introducing forces as vectors and then looking at equilibrium. Instead, we begin with equilibrium and introduce forces and vectors as needed to solve a problem.

Each class period will have a detailed lesson plan that will include the following:
1. Motivation: Students will be given a choice of items to examine in the model urban area each of which can be used as a launch pad for the topic of the day.
2. Question: Students will be prompted to ask questions about the selected model item. Questions will be open-ended to allow students the space to explore. For example, if the item were a traffic light supported by two cables the instructor could ask “what are some of the engineering considerations that would go into design this item?”
3. Focus: The instructor would focus the discussion toward a particular question related to the topic of the day. From the previous example, the question might be “how strong do the cables need to be to support the traffic light?” The students would then discuss how they might answer this question.
4. Abstraction: The students would identify a particular component or system to analyze (guided by the instructor) and discuss how to represent it on paper. This would include the first two steps in the seven-step problem solving PROCESS rubric developed by Grigg and Benson (2015), which will be adapted as needed to fully capture problem abstraction:
    i. **P**roblem definition – identify parameters, constraints, assumptions, and outcomes.
    ii. **R**epresentation and **O**rganization – sketch the problem showing all problem parameters; identify equations, parameters, variables etc.

5. Problem solving process: The students will then solve the remainder of the problem posed by the instructor following the last five steps in the PROCESS rubric. It is only at this stage that the instructor would introduce the relevant theory for that day's class.
    iii. **C**alculations – manipulate equations, show working, establish solutions.
    iv. **E**valuate **S**olution – Check for accuracy and units; indicate final answer, check for reasonableness, and justify.
    v. **S**elf-assessment – Rate comfort with your understanding of the problem and solution.
6. Repeat: The first time through the instructor would lead the class through the entire PROCESS For each further iteration the instructor would stop at earlier steps in the PROCESS until the students were able to complete a full analysis using the instructor as a resource for answering questions.

For example, in an early class students will be given images of cable-supported traffic lights and a simple physical model of the same object (see figure 2). They will examine the question "How strong do the cables need to be to support a traffic light?" Students will be guided through a discussion breaking down the problem with questions like "How heavy is a typical traffic light?", "What do we mean by 'how strong'?", and "what sorts of forces can a cable support?" Only then will theory and modeling assumptions be introduced. After introducing the required theory, the students will take measurements from the model, draw appropriate diagrams, and solve for the tensions in the cables.

Figure 2. Images of cable-supported traffic lights (top) and an analogous model of a weight supported by cables (bottom).

The two primary differences between this course structure and the more common approach to teaching engineering mechanics are:

1. The problem is presented as a physical model and the students must abstract the physical model into a tractable engineering mechanics problem.
2. The theory needed to solve the problem is only introduced as needed, i.e. once the problem has been abstracted. This places the physical model and abstraction process at the center of the course rather than as an example to illustrate the theory.

The class will be organized into four modules covering equilibrium at a point, equilibrium of rigid bodies, structures, and internal forces. The final module on internal forces will include a basic introduction to stress distributions in bending as a motivation for covering second moment of area, a topic that is usually covered in statics classes but rarely is provided a meaningful context or motivation.

Research methodology

The research plan will employ a mixed methods approach to assess outcomes related to students' self-efficacy for engineering mechanics problem solving and their future-oriented motivation. This task will have four assessment components, all within the context of engineering mechanics concepts: problem-solving self-efficacy, future-oriented motivation, problem-solving skill development, and connections between physical models, problem abstraction, and real-world applications.

In this paper we report on research activities undertaken during the first six months of the project. Specifically, we are collecting baseline data on students' problem-solving self-efficacy for students in an existing sophomore-level statics course that is taught through the civil engineering program. Problem-solving self-efficacy data were collected using a previously tested survey (Kirn & Benson 2015). These data will allow us to make comparisons for students in the course prior to and after implementing physical models. The survey data was cleaned and self-efficacy construct scores were calculated. Averages and standard deviations were calculated for each construct and compared for students based on major (civil engineering majors vs. non-majors).

Preliminary results

Baseline survey data from students in the existing statics course was analyzed to calculate student self-efficacy in the different components of the PROCESS problem solving method. Data was broken out based on whether the student was a civil engineering major. Non-civil engineering majors consisted of students in environmental, biosystems, industrial, and bioengineering. A summary of these data is presented in Table 1. While there are small differences in reported rates, no statistical analysis was conducted to establish if the differences were significant. This analysis is reserved until a larger data set is collected over the coming semesters.

Table 1. Mean and standard deviation for each measure of problem-solving self-efficacy.

	Civil Engineers (*n*=34)		**Non-Civil Engineers (*n*=36)**	
	Mean	Standard Deviation	Mean	Standard Deviation
Problem definition (/100)	81.6	9.0	83.3	10.4
Representation & Organization (/100)	82.0	10.1	82.6	12.0
Calculations (/100)	87.3	10.0	84.6	11.1
Evaluate Solution (/100)	87.9	8.4	83.0	13.9
Self-assessment (/100)	84.8	9.6	75.5	19.0

Future work

We are establishing baselines for comparisons of student attitudes, motivation and problem-solving skills before and after the implementation of our new course. We are developing activities and timelines for the new course to incorporate important aspects of problem abstraction such as developing problem statements from physical models. Future work includes collecting another round of problem-solving self-efficacy data and data on students' future-oriented motivation in the existing statics course. We will collect student solutions to a problem on an exam in the existing statics course that includes drawing a representation of the problem (for example, a free body diagram), calculations at some level of complexity (for example, a truss or frame). The problem will be selected with the intention of giving students in the new course the same problem on an exam in the new course. We will regrade student solutions using appropriate components of the PROCESS rubric (Representation and Organization, Calculations, and Evaluate Solution). Not all elements of the PROCESS rubric can be compared because students in the existing course are not instructed or prompted to develop and demonstrate specific skills like problem definition or assessing their self-confidence in completing the problem. We will also survey students who have completed the existing statics course to share their interests in physical contexts related to the concepts they learned about. This will inform our selection of physical models for the model-based course and provide culturally relevant contexts for the new course.

References

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*, 191-215.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice Hall.

Beer, F., Johnston, E. R., & Mazurek, D. (2012). *Vector Mechanics for Engineers: Statics* (10th edition). McGraw Hill.

Chan Hilton, A. B., & Neupauer, R. M.(Eds.). (2012) *H2OH Classroom demonstrations for water concepts*. American Society of Civil Engineers.

Felder, R. M. & Brent, R. (2016). *Teaching and Learning STEM: A Practical Guide* (1st edition). Jossy-Bass.

Grigg, S., & L. Benson. (2015). Promoting Problem-solving Proficiency in First-year Engineering: PROCESS Assessment. Proceedings of the ASEE 2015 Annual Conference, Seattle, WA.

Hibbeler, R. C. (2007). *Engineering Mechanics Statics* (11th edition). Pearson.

Hilpert, J. C., Husman, J., Stump, G. S., Kim, W., Chung, W. T., & Duggan, M. A. (2012). Examining students' future time perspective: Pathways to knowledge building. *Japanese Psychological Research*, *54*(3), 229–240. https://doi.org/10.1111/j.1468-5884.2012.00525.x

Husman, J., & Lens, W. (1999). The role of the future in student motivation. *Educational Psychologist, 34*(2), 113–125. https://doi.org/10.1207/s15326985ep3402

Husman, J., Lynch, C., Hilpert, J. & Duggan, M.A. (2007). Validating measures of future time perspective for engineering students: Steps toward improving engineering education. In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Honolulu, HI.

Hutchison, M. A., Follman, D. K., Sumpter, M., & Bodner, G. (2006). Factors influencing the self-efficacy beliefs of first-year engineering students. *Journal of Engineering Education, 95*(1), 39. doi.org/10.1002/j.2168-9830.2006.tb00876.x

Jordan, S.S., Foster, C.H., Anderson, I.K., Betoney, C.A., & Pangan, T.J.D. (2019). Learning from the experiences of Navajo engineers: Looking toward the development of a culturally responsive engineering curriculum. *Journal of Engineering Education, 108*(3), 355– 376. https://doi.org/10.1002/jee.20287

Kirn, A., & Benson. L. (2015). Engineering Students' Perceptions of the Future: Exploratory Instrument Development, Proceedings of the ASEE 2015 Annual Conference, Seattle, WA.

Lord, S., & Chen, J. (2014). Curriculum Design in the Middle Years. In A. Johri & B. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 181-200). Cambridge: Cambridge University Press. doi:10.1017/CBO9781139013451.014

Lord, S., Berger, E., Kellam, N., Ingram, E., Riley, D., Rover, D., Salzman, N., & Sweeney, J. (2017). Talking about a Revolution: Overview of NSF RED Projects. Paper presented at the ASEE Annual Conference and exposition, Columbus, OH.

Markus, H., & Nurius, P. (1986). Possible selves. *American Psychologist, 41*(9), 954–969. https://doi.org/10.1037//0003-066X.41.9.954

Mayer, R. E. (1998). Cognitive, metacognitive, and motivational aspects of problem solving. *Instructional Science, 26*(1), 49–63. doi.org/10.1023/A:1003088013286

Miller, R. B., & Brickman, S. J. (2004). A Model of Future-Oriented Motivation. *Educational Psychology Review*. *16*(1), 9–33. https://doi.org/10.1023/B:EDPR.0000012343.96370.39

Min, T., Zhang, G., Long, R. A., Anderson, T. J., & Ohland, M. W. (2011). Nonparametric Survival Analysis of the Loss Rate of Undergraduate Engineering Students. *Journal of Engineering Education, 100*(2), 349–373.

Miriam, J. L., & Kraige, L. G. (2007). Engineering Mechanics Statics (6th edition). Wiley.

Nagel, R. L., Pierrakos, O., Nagel, J. K., & Pappas, E. C. (2012). On a client-centered, sophomore design course sequence. ASEE Annual Conference and Expo, San Antonio, TX.

Oyserman, D. Bybee, D., Terry, K. & Hart-Johnson, T. (2004). Possible selves as roadmaps. *Journal of Research in Personality, 38*(2), 130–149. https://doi.org/10.1016/S0092-6566(03)00057-6

Oyserman, D., Brickman, D., & Rhodes, M. (2007). School Success, Possible Selves, and Parent School Involvement. *Family Relations*, *56*, 479–489. DOI:10.1111/j.1741-3729.2007.00475.x.

Pizzolato, J. E. (2006). Achieving college student possible selves: navigating the space between commitment and achievement of long-term identity goals. *Cultural Diversity & Ethnic Minority Psychology*, *12*(1), 57–69. https://doi.org/10.1037/1099-9809.12.1.57

Sarasua, W., Kaye, N. B., Ogle, J. H., Benaissa, M. N., Benson, L. Putman, B. J., & Pfirman, A. L., (2020). Engaging Civil Engineering Students Through a “Capstone-like” Experience in their Sophomore Year. American Society for Engineering Education Annual Conference and Exposition. Montreal, Quebec, Canada.

Simons, J., Dewitte, S., & Lens, W. (2004) The role of different types of instrumentality in motivation, study strategies, and performance: Know why you learn, so you’ll know what you learn! *British Journal of Educational Psychology*, *74*, 343–360.

Tabachnik, S. E., Miller, R. B., & Relya, G. E. (2008). The Relationships Among Students’ Future-Oriented Goals and Subgoals, Perceived Task Instrumentality, and Task-Oriented Self-Regulation Strategies in an Academic Environment. *Journal of Educational Psychology, 100*(3), 629–642. DOI: 10.1037/0022-0663.100.3.629.