Integrating Evidence-Based Learning in Engineering and Computer Science Gateway Courses

Dr. Xiang Zhao, Alabama A&M University

Dr. Xiang (Susie) Zhao, Professor in the Department of Electrical Engineering and Computer Science at the Alabama A&M University, has over 20 years of teaching experience in traditional on-campus settings or online format at several universities in US and aboard. Her teaching and research interests include numerical modeling & simulation, high performance algorithm design, data mining, and evidence-based STEM teaching pedagogies. Her recent research work has been funded by DOE, NRC, NASA and NSF, and generated over 50 journal and conference papers.

Dr. Showkat Chowdhury, Alabama A&M University

Dr. Showkat Chowdhury is a Professor in the Department of Mechanical Engineering at Alabama A&M University in Huntsville, AL. Dr. Chowdhury has extensive background in teaching undergraduate and graduate students in Mechanical Engineering, and performing research in the fields of Computational Fluid Dynamics, Pedagogy, Renewable Energy, Nano-Technology, Heat & Mass Transfer, and Combustion. He is managing multi-million dollar external research grants from NSF as PI. Previously, he worked as a Professor at Bangladesh University of Engineering & Technology (BUET) and at University of Brighton, U.K. He also worked in the Research Division of Corning Inc. He earned his Ph.D. and M.S. in Mechanical Engineering from Clarkson University, New York and B.S. in Mechanical Engineering from BUET.

Prof. Tamara Chowdhury, Alabama A&M University

Tamara Chowdhury is an Assistant Professor & Coordinator of Construction Management Program in the Department of Mechanical & Civil Engineering and Construction Management at Alabama A&M University in Huntsville, AL. Prof. Chowdhury has extensive background in teaching undergraduate students in the Department of Civil Engineering, Construction Management and conducting research. She also worked for a multinational research organization for many years. Prof. Chowdhury earned her MS in Civil engineering from Clarkson University, New York, USA and B.S. in Civil Engineering from Bangladesh University of Engineering & Technology.

Integrating Evidence-Based Learning in Engineering and Computer Science Gateway Courses

Abstract

Gateway Courses generally refers to the courses that are crucial for students to progress through their chosen majors. The successful completion of the gateway courses are necessary because these courses are mostly the prerequisites of other courses in the majors. However, many types of attritions in the STEM gateway courses lead to high failure rates.
To tackle this challenge, a team of STEM faculty members at Alabama A&M University (AAMU), a land-granted HBCU, has redesigned the gateway courses in computer science, mechanical engineering and construction management by replacing the lecture-dominated practices with evidence-based teaching pedagogies. In this study, two evidence-based pedagogies, problem-based learning and project-based learning have been implemented and tested in different levels of STEM gateway courses in the last three years. An assessment framework has been established to analyze the effect of the implemented pedagogies. Continuous assessment data have been collected and compared with the baseline data collected in the lecture-dominated same courses. Student surveys have been conducted and analyzed as well. Our study showed the evidence-based teaching practices fostered both the students' cognitive and non-cognitive skills. The DFW rates were also decreased in all semesters in all the targeted STEM gateway courses in this study. Based upon the success and lessons learned, our future work will expand and test the interventions in more gateway courses across STEM disciplines at AAMU, to enhance the minority student success, retention and graduation.

1. Introduction

STEM education is the gateway to prosperity for our ever-evolving technology-dependent society in the 21st century. To succeed in an increasingly integrated global, innovative-driven, and "labor-polarized" economy, the future prosperity of the U.S. depends in large measure on further development of STEM education, research, innovation, and entrepreneurship. "To succeed in today's information-based and highly technological society, all students need to develop their capabilities in STEM to levels much beyond what was considered acceptable in the past" [1]. STEM education must provide emerging scientists and engineers with innovative talents to energize the economic engines of the future.

A critical juncture in the undergraduate STEM education pathway is that majority of attrition occurs because students experience many academic challenges in gatekeeping courses [2]. An important factor to this failure is attributed to the lack of engaging pedagogy. The ingredients for success in STEM disciplines are the acquisition of knowledge and habits of mind; opportunities to put these into practice; a developing sense of competence and progress; motivation to be in, a sense of belonging to, or self-identification with the field; and information about stages, requirements, and opportunities. This study aims to improve the active learning and engagement of the students in their STEM gateway course by integrating the evidence-based teaching pedagogies, thereby pave the pathway for students to move toward their success in their future studies and careers. The rest of the paper is structured as follows: Section 2 provides a brief introduction to the evidence-based teaching pedagogical methodologies that have been adopted in this study. Section 3 describes the implementation approaches followed by the experimental results and discussion in Section 4. Section 5 presents the conclusions and future directions.

2. Review of evidence-based pedagogical methodologies

Teaching is an art of encouraging students to become active learners and awakening their enthusiasm to life-long learning. On the other hand, learning is a dynamic process in which both the teacher and students should actively participate, exchange views, and ask/answer questions in an engaging atmosphere [3]. It has been abundantly demonstrated that pedagogical methods that promote conceptual understanding through interactive engagement of students are far more effective than traditional didactic instructional methods. Almost all of the newly developed methods on teaching and learning have concentrated on student-centered, inquiry-based approaches [4]. These techniques are especially effective when structured in ways that address the preconceptions that STEM students bring to the classroom. Some strategies, such as Modeling Methods [5] and Just-in-Time-Teaching [6] have shown significant success and others, such as Process-Oriented Guided Inquiry Learning (POGIL) [7], Problem-Based Learning (PBL) [8], Project-Based Learning (ProjBL) [9] and Game-Based Learning (GBL) [10] have gained more prominence and national recognition in higher education.

One of the successful evidence-based designs for teaching science and engineering courses is the **Problem-Based Learning (PBL).** The earliest successful adoption of PBL is in medical education [11][12], but PBL was quickly infused into other STEM disciplines. PBL is a pedagogical model in which students are the center of the learning process. Students become the active learner who connect domain knowledge to real-world challenging problems, and work collaboratively toward their solutions. The instructor provides resources and mentorship to students on how to tackle the problem, not the solution directly. The major advantages of PBL include deepening students' critical thinking, stimulating students' interests in their areas of study, motivating students' problem solving and therefore engagement [13] [14][15]. However, the challenges do exist for the academically under-prepared student groups or when lack of appropriate tutor resources [16][17].

Project-Based Learning (ProjBL) is an instructional methodology that encourages students to learn and apply knowledge and skills through an engaging experience. It provides students the opportunities for deeper learning and for the development of important non-cognitive skills for college and career readiness. Students drive their learning by inquires, research and collaboration toward the completion of the projects. The role of the instructor shifts from a content-deliverer to a facilitator and mentor. Compared with PBL, students form a group and work more independently to complete the projects with the instructor providing support only when needed. Students are encouraged to make their own decisions about the project topics and how to complete [18][19]. One of the main goals of ProjBL is to engage students in deep learning throughout the full project life cycle [9].

3. Our Approaches

A team of faculty members in computer science, mechanical engineering and construction management at Alabama A&M University are implementing evidence-based instructional practices in three gateway courses in STEM curricula. Recognizing that it is essential to implement effective pedagogy in gateway courses where most attrition occur, this study has focused on: (1) redesigning three gateway courses in computer science, mechanical engineering and construction management by integrating evidence-based teaching strategies—problem-based learning (PBL) and project-based learning (ProjBL); (2) incorporating classroom and laboratory activities that require active student engagement, conceptual understanding, critical thinking, and problem-solving; and (3) conducting assessment and data analysis with statistical tools against the baseline data. This section mainly describes the details on the implementation of evidence-based teaching in selected STEM gateway courses.

Innovative, evidence-based instructional practices are critical to transforming the conventional undergraduate instructional landscape into a student-centered learning environment. This study seeks transformational change and quality improvement in instructional practices driven from research concerning effective STEM pedagogy that typically incorporates classroom or laboratory activities that require active student engagement, conceptual understanding, critical thinking, and problem solving. Figure 1 shows the logic model that has been established and applied in this study.

In fall 2016, faculty catalysts in the project team selected three different levels of gateway courses in STEM disciplines to integrate the evidence based teaching: CS102 – Introduction to Programming I, ME425 – Design of Machine Elements, and CMG250 – Construction Estimating. The reason is that the project team intended to test how various pedagogies are effective in different levels of STEM courses and how students respond to those pedagogies. Continuous study were conducted on the same courses (taught by the same instructors) between fall 2016 and fall 2019. Due to the course offering and assignment constrains at the university, the CS102 course was taught with PBL pedagogy in Fall 2016, Fall 2017 & Fall 2019, and compared with the baseline data of Spring 2014 (without PBL). The ME425 course was taught with ProjBL pedagogy in Spring 2018 & Spring 2019, and compared with the baseline data of Spring 2017 (without ProjBL). The CMG250 course was taught with ProjBL pedagogy in Spring 2018 & Spring 2019, and compared with the baseline data of Spring 2017 (without ProjBL).The student learning outcomes for each course remain the same for the purpose of comparison and the obligation of the program accreditation.

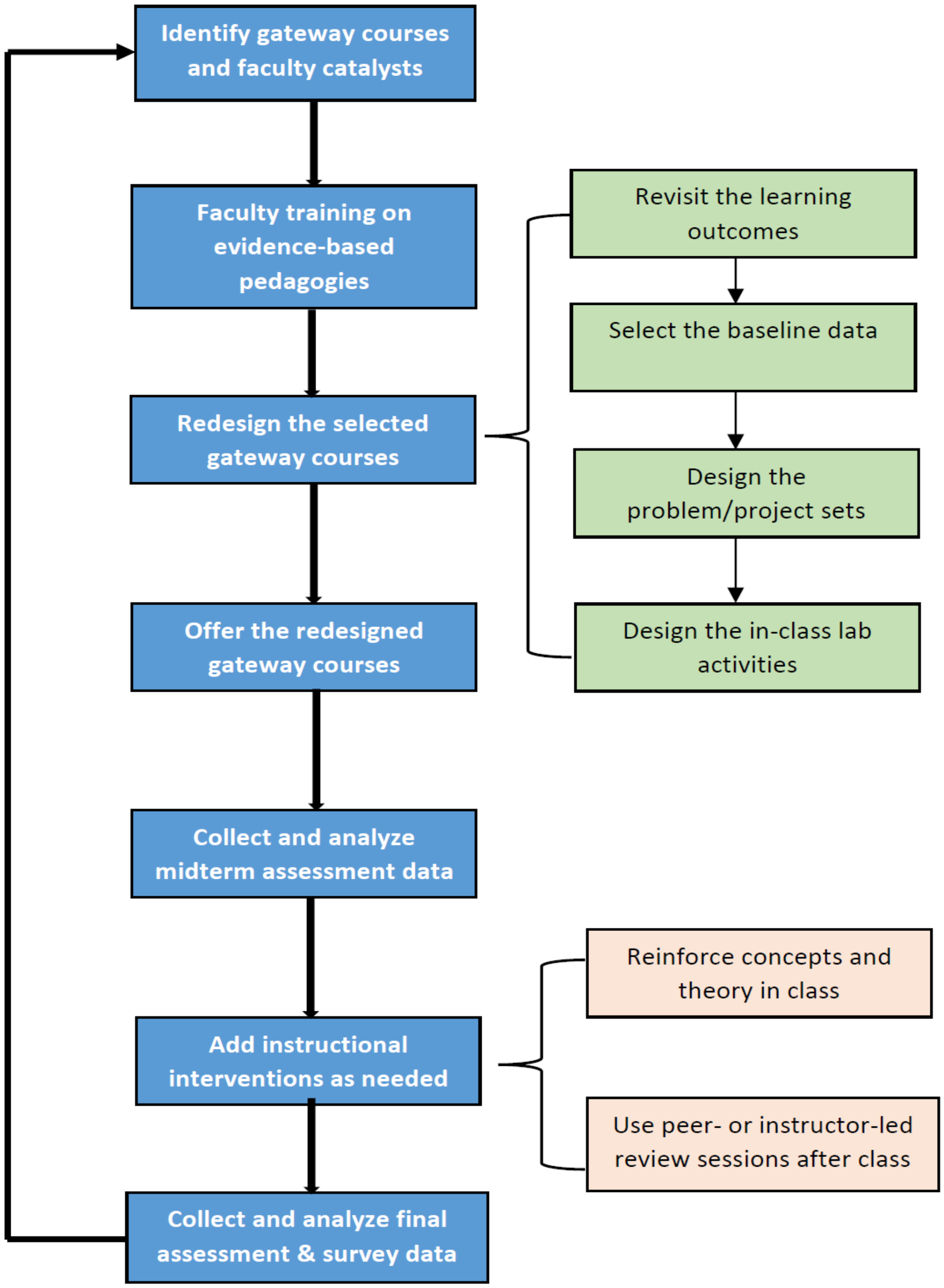

Figure 1. The logic model

After faculty catalysts received training on how to apply various evidence-based teaching pedagogies, they redesigned the selected courses and integrated evidence-based teaching pedagogical approaches. To help students get motivated and become interested in programming as soon as they encounter the computer science major courses, a revised student-centered “hybrid” PBL was implemented in CS102-‘Introduction to Programming I’. The difference between this hybrid PBL with traditional PBL practices in computer science education [20] is: The amount of instructor’s lecture time was increased at the beginning in order to help students get sufficient pre-requisite knowledge and skills before they can start the independent problem-solving. This is due to the fact that most of students in CS102 do not have any programming experience. Most of them are freshmen who are not familiar with the terminology in computer science and even the computer lab environment. Therefore, problem sets and laboratory materials are carefully designed by gradually increasing the difficulty levels. This is important for promoting the development of problem-solving and critical-thinking skills and prevent students from feeling lost. All questions are designed surrounding the outcomes in CS102 meanwhile simulating the real-world scenarios and requirements.

ME425 has been identified as one of the most challenging design courses in the Mechanical Engineering major. It requires students’ deep engagement and comprehensive skills for problem solving, design of mechanical systems and components that need to integrate all the knowledge students have assimilated through various courses in their major for professional success. ProjBL pedagogy has been adopted and implemented in ME425. This engaged pedagogy aims to help students enhance their cognitive, non-cognitive and critical thinking skills through engineering design tasks.

CMG250 has been identified as one of the most critical courses in the Construction Management major. ProjBL has been adopted and implemented for CMG250 course. In this course an independent project is assigned to each student to calculate the estimation of a building project. The students work on the project with their peers with necessary guidance from the instructor. The project aims to improve students’ study habits, and enhance their abilities for systematic planning and problem solving.

The midterm assessments have been conducted to monitor the students’ progress and performance, followed by an immediate adjustment of the instructor’s intervention as needed. For example, from the midterm survey and exam, students in CS102 demonstrated weaker understanding on some concepts and skills such as using variables and arithmetic expressions. The instructor added in-class lab times to reinforce the related concepts and after class peer-tutoring.

Lastly, the student exit survey and final exam were conducted to evaluate and assess the outcomes of the adopted teaching strategies. All students were required to participate in the survey in addition to the final exam. The experimental results are presented in Section 4.

4. Results and discussion

This section summarizes the experimental results obtained from this study. A comparative study was also accomplished to verify the effectiveness of the methodologies using the base line data.

CS102-“Introduction to Programming I” has been chosen as one of the STEM pilot courses because it is the first programming course and also the pre-requisite of many other core course in the computer science curriculum at AAMU. Underperforming students in CS102 are very likely to struggle or fail in other courses afterwards. Therefore, CS 102 has been considered as a critical gateway course in computer science. Table 1 lists the students learning outcomes and corresponding assessment methods. The same eight outcomes were assessed in fall 2016-fall 2019.

Table 1. The Course Learning Outcomes of CS102

Topic Areas	**Learning Outcome**	**Assessment Method**
Ch.1. Overview of Programming and Problem Solving	1. Understand the concepts of algorithm, computer program, high-level programming language, flow charts, and the brief history of C++.	Homework/ Tests
Ch.1. Overview of Programming and Problem Solving	2. Understand the major components of computers and how they work together.	Homework/ Labs/Tests
Ch.1. Overview of Programming and Problem Solving	3. Be able to enter, edit, compile, link, troubleshoot and run C++ programs.	Homework/ Labs/Tests
Ch. 2. C++ Syntax and Semantics, and the Program Development Process	4. Understand the structure of a C++ program and how to use different types of variables and constants.	Homework/ Labs/Tests
Ch.3. Numeric Types, Expressions, and Output	5. Understand the arithmetic operators and how to write and evaluate arithmetic expressions.	Homework/ Labs/Tests
Ch.3. Numeric Types, Expressions, and Output Ch.4. Program Input and the Software Design Process	6. Understand and be able to use standard I/O, file I/O, and library functions in C++ programs.	Homework/ Labs/Tests
Ch.5. Conditions, Logical Expressions, and Selection Control Structures	7. Understand the logical operators and how to write and evaluate logical expressions	Homework/ Labs/Tests
Ch.5. Conditions, Logical Expressions, and Selection Control Structures Ch.6. Looping Ch. 9. Additional Control Structures	8. Understand and be able to use basic control structures (selection and looping) in C++ programs	Homework/ Labs/Tests

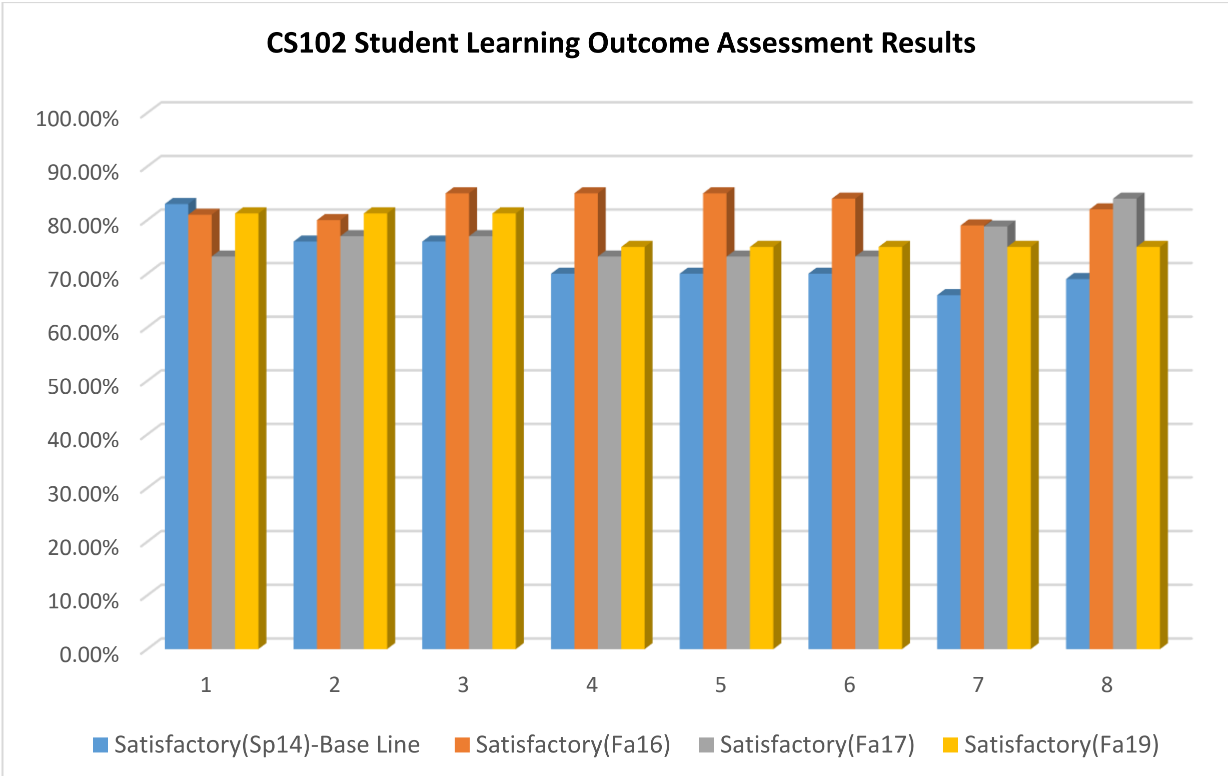

Figure 2. Comparison of the student assessment results based on eight *course-level* learning outcomes (the horizontal axis) in CS102. Note: "Satisfactory" here and in other tables below refers to a pre-determined program-level threshold, which indicates the percentage of students who meet the requirements in the assessment.

Figures 2 includes the comparison of the CS102 student assessment results between the base line data in spring 2014(without PBL) and the data in fall 2016-2019 (with PBL). The same course learning outcomes are used. It has been observed that the percentage of "Satisfactory or above" students was slightly decreased over the first learning outcome and fluctuated over the second one in CS102. One important factor contributed to this is that majority of the students in CS102 were first-semester freshmen, who needed longer registration settlement and lab/classroom/dorm acquaintance period. Therefore, those students were not fully ready or engaged at the first couple of weeks when the first two outcome are mainly assessed. It is very promising that after this "start-up" process was over, the students' performance were improved over other learning outcomes, although those learning outcomes demand more deep thinking and problem solving skills than the first two outcomes. This verifies the effectiveness of the hybrid student-centered PBL methodology on students' learning and engagement. The lessons learned from our study is: when PBL is implemented in freshman-level courses, instructors should allocate no less than 40% of class time to introduce concepts and foundational skills at the "start-up" stage, and then guide students into the "semi-independent" self-exploration with examples. Eventually, students get powered up and drive to the fully-independent problem solving.

Student assessment data on program-level outcomes for ME425 and CMG250 in Tables 2 and 3 also confirmed the constant improvement after the ProjBL has been integrated into the courses (Mechanical Engineering and Construction Management Programs in the University directly assess the program-level outcomes instead of course-level outcomes) over two years. The third year (2020) implementation is still undergoing.

Table 2. Assessment Data vs. *Program-Level* Learning Outcomes for ME425 with Project Based Learning
Learning Outcome: “An ability to design a system, component or process to meet desired needs”.

Semester	Satisfactory	Unsatisfactory
Spring 2017 (Base line data, no ProjBL)	88%	12%
Spring 2018 with ProjBL	96%	4%
Spring 2019 with ProjBL	100%	0%
Average(Spring 2018-Spring 2019)	98%	2%

Table 3. Assessment Data vs. *Program-Level* Learning Outcomes for CMG 250 with Project Based Learning.
Learning Outcome: “Create construction project cost estimates”.

Semester	Satisfactory	Unsatisfactory
Spring 2017 (Base line data, no ProjBL)	87%	13%
Spring 2018 with ProjBL	100%	0%
Spring 2019 with ProjBL	100%	0%
Average(Spring 2018-Spring 2019)	100%	0%

Tables 4-6 contains the comparison of the student grade data including ABC rate and DFW (W: withdraw) rate for the three selected courses. With the implementation of the PBL pedagogy during fall 2016-2019, the DFW rates of CS102 all decreased significantly compared with the base line data (without PBL). On average, the DFW rates in CS102 dropped from 41% to 23% over three years. With the implementation of the ProjBL pedagogy, the average DFW rates in ME425 and CMG250 also dropped by 17% and 5%, respectively. The assessment data shows that the effectiveness of the pedagogies on the student retention in each course is affirmative and consistent during this study.

Table 4. Student Grades for CS102 Introduction to Programming with Problem Based Learning

Semester	ABC Rate	DFW Rate
Spring 2014 (Base line data, no PBL)	58 %	41 %
Fall 2016 with PBL	78 %	22 %
Fall 2017 with PBL	78 %	22%
Fall 2019 with PBL	75%	25%
Average(Fall 2016-Fall 2019)	77%	23%

Table 5. Student Grades for ME425 Design of Machine Elements with Project Based Learning

Semester	ABC Rate	DFW Rate
Spring 2017 (Base line data, no ProjBL)	81%	19%
Spring 2018 with ProjBL	96%	4%
Spring 2019 with ProjBL	100%	0%
Average(Spring 2018-Spring 2019)	98%	2%

Table 6. Student Grades for CMG 250 Construction Estimating with Project Based Learning

Semester	ABC Rate	DFW Rate
Spring 2017 (Base line data, no ProjBL)	95%	5%
Spring 2018 with ProjBL	100%	0%
Spring 2019 with ProjBL	100%	0%
Average(Spring 2018-Spring 2019)	100%	0%

In addition to the formal assessment, student surveys have been conducted to provide the evaluation and feedback in three selected courses. Student participate rates are 92% to 100% for all the courses. The student survey summary in Table. 7 showed the feedback on PBL implemented in CS102 are highly positive. For example, majority of the students agreed PBL "improved my interest for active participation in computing" and "improved my confidence in solving problems". In addition, majority of the students agreed this implementation "helped me practice the critical thinking skills such as analyzing problems, gathering & evaluating info and applying knowledges". Similar positive feedback on ProjBL are also obtained from the surveys in ME425 and CMG250 and summarized in Tables 8 and 9, respectively.

Table 7. CS102 Student Survey Summary (Followed by the Survey Question Sample)

SQ	Fall 2016				Fall 2017				Fall 2019			
	Strongly agree	Agree	Disagree	Strongly Disagree	Strongly agree	Agree	Disagree	Strongly Disagree	Strongly agree	Agree	Disagree	Strongly Disagree
#1	50%	38%	6%	6%	60%	30%	5%	5%	50%	33%	17%	0%
#2	50%	38%	6%	6%	40%	30%	15%	15%	50%	33%	17%	0%
#3	63%	25%	6%	6%	30%	30%	15%	25%	50%	17%	25%	8%
#4	56%	25%	6%	13%	40%	40%	5%	15%	58%	25%	9%	8%
#5	38%	50%	6%	6%	60%	20%	5%	15%	50%	42%	8%	0%
#6	63%	25%	6%	6%	55%	30%	5%	10%	58%	25%	9%	8%
#7	63%	25%	6%	6%	35%	40%	15%	10%	50%	33%	9%	8%

Student Survey Questions Course: CS102 with Problem-Based Learning Pedagogy
1. Working for the given problems in this course helped me gain knowledge in C++ programming. 2. My experience in solving the given problems helped me improve my study habits such as reviewing materials, completing my work on time, discussing with my peers, etc. 3. Working for the given problems improved my interest for active participation in computing. 4. The given problems in this course broadened my view on how computer programming can help my career or future study. 5. The problem-based learning approach improved my confidence in solving problems. 6. Working for the given problems helped me practice the critical thinking skills such as analyzing problems, gathering & evaluating info and applying knowledges. 7. This course encouraged me to be more of an “active learner” compared to other courses I take.

Table 8. ME425 Student Survey Summary (Followed by the Survey Question Sample)

Survey Questions	**Spring 2018**				**Spring 2019**			
	Strongly agree	Agree	Disagree	Strongly disagree	Strongly agree	Agree	Disagree	Strongly disagree
#1	64%	36%	0%	0%	68%	32%	0%	0%
#2	64%	36%	0%	0%	65%	32%	3%	0%
#3	55%	41%	4%	0%	54%	43%	3%	0%
#4	55%	36%	9%	0%	54%	43%	3%	0%
#5	60%	36%	4%	0%	57%	43%	0%	0%
#6	50%	45%	5%	0%	51%	46%	3%	0%
#7	55%	41%	4%	0%	52%	43%	5%	0%

Student Survey Questions Course: ME425 with Project-Based Learning Pedagogy
1. Working for the project in this course, helped me to gain knowledge in mechanical engineering design. 2. My experience in this project helped me to improve my study habits such as reviewing materials, completing my work on time, discussing with my peers, etc. 3. Working for the project helped me to improve my interest for active participation. 4. The course project experience enhanced my ability for systematic planning in problem solving. 5. The project-based learning approach improved my confidence in solving engineering problems. 6. Working in a group for the design project helped me to improve teamwork skills. 7. This course encouraged me to be more of an “active learner” compared to other courses I take.

Table 9. CMG250 Student Survey Summary (Followed by the Survey Question Sample)

Survey Questions	Spring 2018				Spring 2019			
	Strongly agree	Agree	Disagree	Strongly disagree	Strongly agree	Agree	Disagree	Strongly disagree
#1	76%	24%	0	0	77%	23%	0	0
#2	67%	33%	0	0	73%	27%	0	0
#3	86%	14%	0	0	87%	13%	0	0
#4	80%	20%	0	0	90%	10%	0	0
#5	87%	13%	0	0	88%	12%	0	0

Student Survey Questions

Course: CMG 250 with Project-Based Learning Pedagogy

1. Working for the project in this course, helped me to gain knowledge in building estimating.
2. My project experience helped me to improve my study habits such as reviewing materials, completing my work on time, discussing with my peers, etc.
3. Working for the project helped me to improve my interest for active participation in the calculation process.
4. The project experiences enhanced my abilities for systematic planning in problem solving (organization skill).
5. The project-based learning approach improved my confidence in solving problems.

5. Conclusions and future work

This study has established and tested our logic model for evidence-based practice in three different-level STEM gateway courses successfully at AAMU. The student assessment results indicated the effectiveness of the evidence-based instructional practices, especially in prompting deep thinking, problem solving and improving engagement and retention. In addition, positive feedback has been obtained from the student survey data on those courses. This study also confirmed the existing engagement challenges among the undergraduate students in various STEM majors. Future study will be focused on implementing the evidence-based pedagogies PBL and ProjBL in more STEM gateway courses and continuously verify their effectiveness on engaging students and developing the critical skills for success. The broader impact of this study is twofold. First, data generated through assessment and evaluation will support the theoretical rationale that systematic change in STEM education must include the student-centered pedagogies that motivate the students to be active learners. Secondly, dissemination of the results of this work is expected to provide a model for institutional implementation of evidence-based practices at colleges or universities of similar size and/or student body demographics as AAMU, a land-granted minority serving university.

Acknowledgment

This study has been supported by the S-STEM program of National Science Foundation (NSF) and MSEIP program of Department of Education (DOEd). The authors greatly appreciate the support and encouragement from the NSF and DOEd program officers and university colleagues.

References

1. Chang, M. J., Cerna, O., Han, J., & Sáenz, V. The contradictory roles of institutional status in retaining underrepresented minorities in biomedical and behavioral science majors. *The Review of Higher Education*, 31(4), 433-464 (2008).
2. Cohen, D. K. Teaching Practice: Plus ÇA Change. In: Contributions to Educational Change: Perspectives on Research and Practice, National Society for the Study of Education series on Contemporary Issues, edited by P Jackson, pp. 45(1988).
3. Armstrong, S. J. & Fukami, C. (Eds.), *Experiential Learning Theory: A Dynamic, Holistic Approach to Management Learning, Education and Development*, Handbook of Management Learning, Education and Development. London: Sage Publications (2008)
4. Karl A. Smith, "Inquiry-Based Cooperative Learning, Sigma Xi Conference Proceedings, Reshaping Undergraduate Science and Engineering Education: Tools for Better Learning, p. 53 (1999)
5. David Hestenes, Modeling Methodology for Physics Teachers, Proceedings of the International Conference on Undergraduate Physics Education(College Park, August (1996)
6. Gavrin, L,"Using Just-in-Time Teaching in the Physical Sciences" in *Just-in-Time Teaching: Across the Disciplines, Across the Academy*, Simkins S, and Maier M (Eds.), Sterling, VA: Stylus Publishing. (2010)
7. J. J. Farrell, R. S. Moog, J. N. Spencer "A Guided Inquiry Chemistry Course.". *J. Chem. Educ.* **76** (4): 570–574 (1999)
8. http://www.learning-theories.com/problem-based-learning-pbl.html
9. Veselov, G.E., Pljonkin, A. P., and Fedotova, A.Y., Project-based learning as an effective method in education, Proceedings of the 2019 International Conference on Modern Educational Technology, pp 54–57 (2019) https://doi.org/10.1145/3341042.3341046
10. Kickmeier-Rust, M.D., Albert, D, Micro-adaptivity: protecting immersion in didactically adaptive digital educational games. *Journal of Computer Assisted Learning*, 26, 95-105.(2010)
11. Barrows, H. S., and Tamblyn, R.N., Problem-Based Learning: An Approach to Medical Education, New York: Springer, 1980
12. Boud, D, and Felleti, G., The Challenge of Problem-Based Learning, New York: St. Martin's Press, 1991.
13. Tiwari, A., Lai, P., So, M., and Yuen, K. 2006. A comparison of the effects of problem-based learning and
lecturing on the development of students' critical thinking. *Med. Educ. 40*, 6, 547–554.
14. Walker, A. and Leary, H. 2009. A problem based learning meta analysis: Differences across problem
types, implementation types, disciplines, and assessment levels. *Interdiscipl. J. Prob.-Based Learn. 3*, 1,
12–43.
15. Strobel, J. and Van Barneveld, A. 2009. When is PBL more effective? A meta-synthesis of metaanalyses comparing PBL to conventional classrooms. *Interdiscipl. J. Prob.-Based Learn. 3*, 1, 44–58.

16. Carrero, E., Gomar, C., Penzo, W., and Rull, M. 2007. Comparison between lecture-based approach
and case/problem-based learning discussion for teaching pre-anaesthetic assessment. *Euro. J. Anesthesiol.*
24, 12, 1008–1015.
17. Kirschner, P. A., Sweller, J., And Clark, R. E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educ. Psychol. 41*, 2, 75–86.
18. Bell, S., Project-Based Learning for the 21st Century: Skills for the Future, The Clearing House, 83:2, 39-43, (2010) DOI: 10.1080/00098650903505415
19. Krauss, J. and Boss, S., Thinking Through Project-Based Learning: Guiding Deeper Inquiry, Corwin Press(2013)
20. O'Grady, M., Practical Problem-Based Learning in Computer Education, *ACM Transactions on Computing Education*, Vol. 12(3), 2012, pp 1–16.