An Intervention-Based Active-Learning Strategy to Enhance Student Performance in Mathematics

Sidhu, G. [1] Srinivasan, S.[2,3]
[1]School of Engg. Practice and Technology, McMaster University, Hamilton, Ontario, Canada
[2]Dept. of Mechanical Engg., McMaster University, Hamilton, Ontario, Canada
[3]Dept. Mechanical and Industrial Engg., Ryerson University, Toronto, Ontario, Canada

Corresponding Email: sidhugi@mcmaster.ca

ABSTRACT

Experiments were performed to study the effect of integrating an intervention strategy on student learning in an active learning environment in three different undergraduate mathematics courses. In these pedagogical experiments, the learning was measured via several subjective tests and the overall final grade for each course. For each course the comparison was made between two sections one receiving the material via traditional instruction (control section) and the second receiving the material via instruction based on the active learning strategy (experimental section). It was found that students taught using the latter approach performed significantly better in the tests and exams, reflecting a good understanding of the material.

Keywords: Active learning, engineering mathematics, intervention strategy; pedagogical experiments

DOI: 10.20961/ijpte.v%vi%i.19568

INTRODUCTION

Quality and affordable education is an immense challenge all over the world. Given that each student learns at a different pace and a different way, researchers have constantly explored the best methods to be adopted inside the classroom to enhance student learning (UNESCO, 2011; OECD, 2012). In pursuit of this objective, numerous pedagogical experiments have been performed by various researchers. Their works establish that there are alternative instruction techniques that are very effective in improving students learning and shaping them as life-long learners (Buck & Wage, 2005; Crouch & Mazur, 2001; Michael, 2006; Prince & Felder, 2007). An additional issue that requires attention is that students learn and retain the concepts for only a short period before and after the tests. Wage, Buck, Wright and Welch (2005) point out that students typically master only about 20% of the course contents that is taught to them in the class. Needless to say, there is lot of interest in developing strategies to deliver lectures in a way that maximizes student learning.

Of the several methods that have emerged, some of the most commonly employed techniques in the classroom include co-operative and small group learning (Springer et al., 1999; Wage et al., 2005; Prince, 2004), problem based learning (Capon & Kuhn, 2004; Kolb, 2015; Prince & Felder, 2006, 2007; Sidhu & Srinivasan, 2017, Centea & Srinivasan, 2015, 2016, 2017), active learning (Beichner et al., 2007; Freeman et al., 2007; Knight & Wood, 2005), inquiry-based learning (Lewis & Lewis, 2005; Prince & Felder, 2006), Challenge-based learning (Roselli & Brophy 2006), peer-led team learning (McCreary, Golde, & Koeske, 2006; Tien, Roth, & Kampmeier, 2001), and undergraduate research-based learning (Lopatto, 2004; Russell, Hancock, & McCullough, 2007).

Apart from teaching techniques, some investigations have advocated the use of computer-based active instruction (Beichner et al., 2007; Hoellwarth et al., 2005) to improve student learning. However, as noted by Butler, Marsh, Slavinsky and Baraniuk (2014), these approaches can either be too expensive, may require a significant amount of transformation, and may even place an enormous amount of work load on the instructors (Kirshner, Sweller, & Clark 2006).

More recently, studies have also used the principles of cognitive science to deliver lectures and have found success in improving student learning and retention (Deslauriers, Schelew, & Wieman, 2011; Butler et al., 2014, Srinivasan & Sidhu 2014, Sidhu & Srinivasan 2015, Srinivasan & Centea, 2015). For instance, Butler et al. (2014) have integrated cognitive science and technology in the classroom to improve student learning. Similarly, Deslauriers et al. (2011) have demonstrated that employing principles of cognitive psychology in a large section of physics classroom, improvements can be made in student learning.

From the above literature search, it is clear that there is a mixed response in the literature on these various teaching techniques. It can only be concluded that there is no single teaching methodology that is universally applicable to all courses and at all levels of education. In this research, we propose an enhanced active learning environment that is simple, effective and inexpensive, and one that facilitates the conceptual understanding, the quantitative problem solving skills as well as retention of the material by the student. Specifically, using intervention based strategies that incorporate the principles of cognitive science combined in an active learning environment, we present a strategy that facilitates better student learning and retention. The superior outcome is demonstrated by comparing the results of this methodology (Experimental section) with the performance of the students in traditional lecture setting (Control section) in three different undergraduate mathematics courses of an engineering program. In presenting our research, we clearly understand that the term learning is rather abstract and quite difficult to measure and quantify. Hence, without many options at this level, we resort to the performance of the students' scores in the tests and exams, and use this as a measure of learning.

MATERIALS

The three courses in which the experimental methods were applied are introductory differential calculus (M1), complex analysis (M2) and ordinary differential equations (M3). While M1 is a relatively easy course, M2 and M3 are more advanced and include difficult concepts that require considerable efforts to master. The course materials for each course are as follows:

Course Materials – M1

(1) Preparatory material: solving linear and quadratic equations and inequalities, functions, domain and range, conics, trigonometric functions and equations, exponential and logarithmic equations, matrices and arrays, determinants, Cramer's rule, vector dot and cross products.

(2) Differential calculus: limits, continuity, derivatives and rates of change, various rules of differentiation, higher order differentials, and applications of differential calculus (related rates and optimization).

Course Materials – M2

The topics covered in this course include:

(1) Complex numbers, complex planes, complex functions and mappings, limits and continuity, differentiability, analyticity, Cauchy-Reimann equations.

(2) Harmonic functions, Real integrals, complex integrals, Cauchy-Goursat theorem, Independence of path.

(3) Cauchy's integral Formulas, complex form of Greens theorem and sequences and series.

(4) Taylor series, Laurent series, residue theorem and its applications.

Course Materials – M3

This course focussed on the methods to solve ordinary differential equations (ODE) as well as the applications of ODE in problems involving physics. The specific topics covered include:

(1) (a) Integration: Improper, Double and Triple integrals. (b) Differentiation: Chain rule, Implicit, higher order partial differentials.

(2) Solution of ODE: Separation of variables, Bernoulli equation, Exact differential equation, Initial value problems, Reducible second order differential equation.

(3) Applications: Growth and decay, radioactive disintegration, Newton's Law, Torricelli's law, chemical mixtures and law of mass action.

(4) Solution of ODE: Characteristic equation, Variation of parameters, Undetermined coefficients, Inverse operators, and Euler's method.

METHODS

Each course was offered for 13 weeks and the class met twice a week for two hours. All lectures were delivered in a standard classroom equipped with white boards and a smart-podium. In each subject, the student performance in the course was evaluated based on term tests (evenly spaced throughout the term) and a comprehensive final exam. Table 1 summarizes the key aspects of each course and details of each course are further discussed in the respective *Course Materials* section.

In all three courses, the course material was delivered to the students in the control section via regular classroom lectures. Subsequently, the students were given problem sets that they can use to practice outside the classroom. In the experimental section of the courses, at the beginning of the term, the students were randomly divided into groups of 3-4. Every student was part of the same group for the entire term. Further, in this section, the students were given weekly reading assignments that they had to complete before joining the class. This was enforced via simple quizzes that the students had to solve before joining the classroom. Inside the classroom, following a short discussion for about 15% of the class-time, the students were assigned worksheets that they had to solve as a group. The worksheet containing anywhere from 5-15 questions, depending upon the topic, were drawn from the same pool of questions that was assigned to the control section.

By design, the worksheets incorporated an *intervention strategy*. Specifically, it involved the use of three key themes, namely, *Reinforcement*, *Spacing* and *Feedback*. A collective employment of these principles is motivated by their positive effect on learning and long-term retention of the material (Deslauriers et al., 2011). Specifically, the motivation behind the integration of these principles in the intervention strategy is their positive effect on learning and long-term retention of the material, which are as follows: (a) *Reinforcement*: By repeatedly recalling the concepts from the memory, the information is more permanently stored in the memory. (b) *Spacing*: To aid the retention of the material for a longer duration of time, the material must be practiced over a longer span of time. (c) *Instant Feedback*: An immediate corrective feedback can help in better understanding of the material more effectively. In all experimental sections, these principles were integrated into the course as follows: each worksheet contained a few questions from earlier topics. As a result, the students were expected to repeatedly recall the concepts, reinforcing them as the students solve the questions in the class.

To assist the students, the instructor and the teaching assistant were also available for them to seek clarifications or intermittent feedback as soon as they complete their problems. Thus, by the end of the class, the solutions to the questions were verified and corrective feedback was provided to every student in the class on a one-on-one basis.

Table 1: A summative description of the three courses.

	M1	M2	M3
Duration of Course	13 wks	13 wks	13 wks
# students	111[*,C], 104[*,E]	124[*,C], 114[*,E]	56[C], 34[E]
# of tests	2[C], 4[E]	4	3
Final exam	Comprehensive	Comprehensive	Comprehensive

*Students were divided into 2 sections.

[C] Control section.

[E] Experimental section.

The students in the experimental section also had access to the practice problem sets given to the control section and were encouraged to pursue these problems outside the class and return to the classroom with the solutions in the following week. The fact that the students were able to solve several problems in class encouraged them to pursue the few remaining problems outside the classroom and most students returned with solution to other questions

Data Collection:

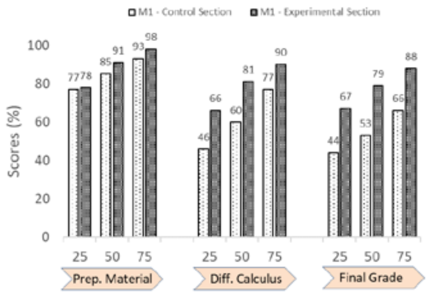
In the course M1, in both sections, the student learning was evaluated using term tests. Specifically, the control section was tested on the above material over two term tests, whereas the experimental section was tested on the same concepts over four term tests. For the control section, Test 1 was based on the preparatory material and Test 2 covered the topics of differential calculus. On the other hand, for the experimental section, the student learning on the preparatory material was measured via Tests 1 and 2, whereas Tests 3 and 4 gave a measure of their learning of differential calculus. Each test was for a duration of one hour. All the tests were equally weighted towards the final grade of the student. The term test on the preparatory material had around four questions and tests on the differential calculus had four questions each.

In the courses M2 and M3, students in both sections were taught the same topics and their learning was measured via four term tests and a comprehensive final exam. The students were given a one hour term test once every three weeks, immediately after the predetermined set of topics for the respective tests were taught in the class. Specifically, the students were tested in topics (1)-(4) listed in the course materials subsection above in the four term tests, respectively.

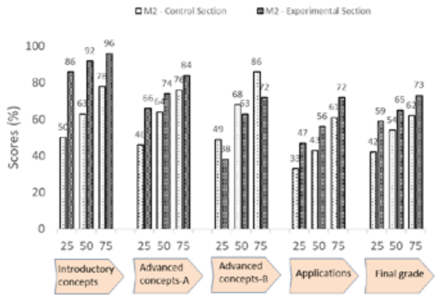
In all three courses, the final exam was comprehensive and the duration of the exam was three hours in which the students had to answer about twelve questions.

RESULTS AND DISCUSSION

The percentile scores of the term tests and the final course grade of the students in M1 and M2 are presented in Figures 1a and 1b, respectively. The average scores and the course grade are also shown in Fig. 2. As seen in Fig. 1a, in M1, in the first test, the performance of the students in the control as well as the experimental sections is nearly the same. In fact, the average scores of the students in these tests are 82% and 87% for the control and experimental section, respectively (c.f. Fig. 2a). This is expected because most of the material in this test was a review of their advanced high-school concepts which the students are expected to know well.



(a)



(b)

Fig. 1. The 25th, 50th and 75th percentile scores of the students in (a) Introductory Differential Calculus (M1) and (b) Complex Analysis (M2).

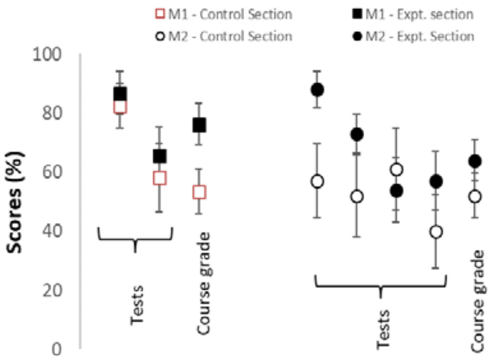


Fig. 2. Average scores of the students in the control and experimental sections of M1 and M2.

The difference in the performance of the students between the two sections is more pronounced in the second test that focuses on the new material, i.e., differential calculus. While the average score of the student is about 58% in the control section, in the experimental section the average score was about 66% (mean of 78% and 54% in tests 3 and 4, respectively). The sharp decline of the average in the 4th test of the experimental section is due to the fact that students were aware that only the top 3 tests were considered. As a result, several students appeared for the test only to take note of the types of questions, returning blank tests and focusing on other subjects instead. Taking note of this, if we consider only the performance on the 3rd test as an indicator of the students' performance in the differential calculus part of the course, 75% of the students in the experimental section had a score of over 66% whereas in the control section, nearly 25% of the students had a failing grade (c.f. Fig. 1a).

In the final exam of this course, the questions based on the differential calculus topics were significantly more than the questions on the preparatory material. As a result, the performance of both sections was similar to their performance in the second term test. Put differently, the statistics of the final course grade in both sections closely follow the student performance on the second term test.

An interesting observation in Fig. 2 for this course is that the average final course grade improves by about 10% from the term test on the topics of differential calculus in the experimental section to approximately 76%. On the other hand in the control section, during the same period, the final course grade decreases by about 5% to approximately 54%. This is clear evidence of the fact that by employing the reinforcing and spacing strategy, the students in the experimental section are able to improve upon their learning, retain the material and perform better in the final exam. On the other hand, without these strategies, the students in the control section are unable to retain the material as time progresses.

As in M1, in M2 the performance of the students in the experimental section is better than their peers in the control section. This is clearly reflected in the percentile scores shown in Fig. 1b as well as the average scores in Fig. 2. In the first test, covering elementary principles of complex analysis, the experimental sections average score was about 30% higher. In the subsequent test on advanced concepts and the applications of complex integral theorems, these students average grade was about 20% and 17% higher in the respective tests.

In the third test focusing on *advanced integral theorems*, there is a sharp decline in the student performance in the experimental section. This can be attributed to the fact that the experimental section was taking a test in another subject within a day of this test. This could have resulted in a severe under preparation for this test. This is also expected because the students often attempt to maximize their grades by optimally distributing their time between the subjects (Love & Kotchen, 2010). For the same reason, given their falling grades, the students on the control section in all likelihood invested more of their time for this test to improve their grades. This resulted in their best performance. Interestingly, the control section performed the best in this test. Nevertheless, since only the best three tests are taken into consideration, the experimental sections was about 10% higher than the average final grade of the control section.

While the new measures/strategies paid good dividends in the experimental section, as in the control section, the average performance of the class gradually decreased with each test (c.f. Fig. 2). A major reason for this is that the students are faced with increasingly difficult and challenging topics in each test. Another factor that contributes to this trend is that the students are aware that only the three best tests are considered towards their final grade. Thus, closer to the end of the term, knowing that their performance in the course is not going to improve any further, the students will optimize their time to improve their performance in other courses that have deadlines closer to the end of the term. This is consistent with the resource allocation strategy postulate of Love and Kotchen (2010).

From Fig. 2 it is important to note that, similar to M1, in this course too, the students in the experimental section were able to reverse this falling trend after the 3rd term test, reaching a final course grade of about 64%. This indicates that as time progresses, the intervention strategies enables to reinforce and promote a better understanding of the concepts in the experimental section. Without such strategies, in the control section, the average performance of the student through the course is nearly stagnant.

Table 2: Effect size of each term test and the course grade in M1 and M2

Course	**Test**				**Final Course Grade**
	1	**2**	**3**	**4**	
M1	0.29	0.36	-	-	1.55
M2	1.56	0.95	-0.28	0.75	0.83

To obtain a quantitative estimate of the improvements due to the new teaching methodology, an effect size was calculated and is reported in Table 2. As is evident in this table, the students in the experimental section improved in their learning and retention throughout the course. Eventually, by the end of the course, we notice an effect size of about 1.55 in M1. This value closely agrees with the findings of Bloom (1984) in which he reported an effect size of about 1.2 when strategies to reinforce concepts are used in the classroom.

Finally, although in both courses, the new teaching methodology enhanced the student performance, the effect size in M2 is only about 0.83. This is nearly half the drastic improvement found in M1 (effect size = 1.55) and can be attributed to the fact that M2 is significantly more challenging than M1, requiring much longer duration to master.

Effect of variation of population

To investigate the possibility of bias due to different populations in the control and experimental sections in the above two courses, in the ensuing paragraphs we present our findings for a similar experiment conducted with the same population in the ordinary differential equations course (M3). For this, the intervention strategy was employed in the experimental section only during weeks 7 and 8, to teach the application of the ODE solution methods to solve problems. No such strategy was employed in the control section.

In solving the application problems, the student has to formulate the ODE for the problem, state the necessary initial/boundary conditions, relate the differential equation to an appropriate solution method, apply the solution method and obtain the final solution. On the other hand, in the other tests, an ODE was given to the students along the necessary initial/boundary conditions, and the student has to apply an appropriate solution strategy and obtain the final solution. Thus, the application problems are significantly more challenging than the problems of the latter type.

A comparison of the performance of the students in the four term tests of M3 course in the control and experimental section is presented in Fig. 3. As seen in this figure, in Tests 1, 3 and 4, the student performance in either section is similar.

The fluctuation in the average scores are within the standard deviations of the respective sections, indicating the effect of difference in the population is negligible. On the other hand, there is a significant difference in the performance of the students between the two sections in the third test, where the intervention strategy was applied to the experimental section. More precisely, the experimental section performed nearly 2 letter grades better than the control section. From this data, it is clear that the intervention strategy has a significant effect on the student performance and that a variation in the population sample has a minimal effect. In other words, it is safe to conclude that the improved performance of the students in the experimental sections of M1 and M2 can be directly attributed to the new intervention strategy and that the effect of population variance is negligible.

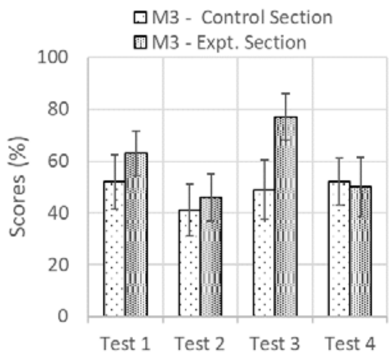


Fig. 3. Performance of the students *Ordinary Differential Equations* (M3)..

SUMMARY AND CONCLUSIONS

In this study, we present an inexpensive and easy to implement active learning strategy to enhance student learning and retention. Specifically, we demonstrate the use of an intervention-based active learning strategy to enhance student learning in three undergraduate engineering mathematics courses, namely, differential calculus (M1), complex analysis (M2) and ordinary differential equations (M3).

The course materials were delivered to the students in the control sections using a traditional lecture format. On the other hand, in the experimental sections, the new strategy was employed in the respective experimental sections as follows: The students were assigned weekly reading assignments and had to take a quiz before joining the classroom. Inside the classroom, majority of the lecture time (>85%) was replaced with group-problem solving sessions. Specifically, in these sessions, students were divided into small groups where they collectively solved worksheets containing several problems (some questions from earlier topics to recall and reinforce the concepts). The instructor and a qualified teaching assistant were available to elucidate the concepts for the students throughout the class time, providing an instantaneous feedback on their solutions. At the end of the class, the students were given take-home practice problem sets to master the concepts.

On comparing the performance of the students from either sections on several term tests and the average course grades, it was found that:

(1) Student learning improves by employing the intervention strategy in conjunction with active learning methodologies inside the classroom.
(2) While the dividends are much higher in easier courses (e.g. Differential calculus, effect size of 1.55), a relatively lower but significant gains are achieved in more challenging courses (e.g. complex analysis, effect size =0.83).
(3) The experiments in the third course establish that the gains recorded in the other courses are due to the intervention strategy combined with an active learning environment, and that the effect of variation of population is insignificant.

Based on these findings, it can be concluded that by integrating three key themes, namely, *reinforcement*, *spacing* and *instant feedback*, we can significantly enhance the learning and retention of the topics. Specifically, by participating in the quiz before the class, solving the worksheets in the class and doing homework outside the class, the concepts can be continuously reinforced over a long duration to enhance student learning. The instantaneous feedback in the online quizzes and the worksheets in the classroom ensure that the concepts are well received by the students, all these measures collectively promoting academic achievement.

REFERENCES

Beichner, R. J., Saul, J. M., Abbott, D. S., Morse, J. J., Deardorff, D. L., Allain, R. J., Bonham, J. W., Dancy, M. H., & Risley, J. S. (2007). *The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project*. http://www.compadre.org/Repository/document/ServeFile.cfm?ID=4517&DocID=183

Bloom, B. S. (1984). The 2-Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring", *Educational Researcher, 13*, 4-16.

Buck, J. R., & Wage, K. E. (2005). Active and Cooperative Learning in Signal Processing Courses. *IEEE Signal Processing Magazine, 22*(2), 76–81.

Butler, A. C., Marsh, E. J., Slavinsky, J. P. & Baraniuk, R. G. (2014). Integrating Cognitive Science and Technology Improves Learning in a STEM Classroom. *Educ. Psychol. Rev., 26*, 331-340.

Capon, N., & Kuhn, D. (2004). What's So Good About Problem-Based Learning? *Cognition and Instruction, 22*(1), 61–79.

Centea, D. & Srinivasan, S. (2015). Problem Based Learning in the Conceptual Design of Hybrid Electric Vehicles ", IJCLEE 2015, International Joint Conference on the Learner in Engineering Education, Donostia - San Sebastian, Spain.

Centea, D. & Srinivasan, S. (2016). A Comprehensive Assessment Strategy for a PBL Environment. International Journal of Innovation and Research in Educational Sciences, Vol. 3, issue 6, pp 364-372.

Centea, D. & Srinivasan, S. (2017). Enhancing Student Learning Through Problem Based Learning. 6th International Research Symposium on PBL (IRSPBL), Bogota, Colombia.

Crouch, C.H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970–977.

Deslauriers, L., Schelew, E. & Wieman, C. (2011). Improving Learning in a Large-Enrollment Physics Class. *Science, 332*, 862-864.

Freeman, S., O'Connor, E., Parks, J. W., Cunningham, M., Hurley, D., Haak, D., Dirks, C., & Wenderoth, M. P., (2007). Prescribed Active Learning Increases Performance in Introductory Biology. *Cell Biology Education, 6*, 132–139.

Hoellwarth, C., Moelter, M. J., & Knight, R. D. (2005). A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms. *American Journal of Physics, 73*(5), 459–462.

Kirshner, P. A., Sweller, J. & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does not Work: An Analysis of the Failure of the Constructivist, Discovery, Problem-Based, Experiential and Inquiry-Based Teaching. *Educational Psychologist, 41*, 75-86.

Knight, J. K., & Wood, W. B. (2005). Teaching More by Lecturing Less. *Cell Biology Education, 4*, 298–310.

Kolb, D. A. (2015). *Experiential Learning: Experience as the Source of Learning and Development* (2nd ed.). Pearson Education, Inc.

Lewis, S. E., & Lewis, J. E. (2005). Departing from Lectures: An Evaluation of a Peer-Led Guided Inquiry Alternative. *Journal of Chemical Education, 82*(1), 135–139.

Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First Findings. *Cell Biology Education, 3*, 270–277.

Love, D. A. & Kotchen, M. J. (2010). Grades, Course Evaluations and Academic Incentives. *Eastern Economic Journal, 36*, 151-163.

McCreary, C. L., Golde, M. F., & Koeske, R. (2006). Peer Instruction in the General Chemistry Laboratory: Assessment of Student Learning. *Journal of Chemical Education, 83*(5), 804–810.

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education, 30*, 159–167.

OECD. (2012). *Education at a glance 2012. OECD indicators*. Paris: OECD.

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education, 93*(3), 223–231.

Prince, M. J., & Felder, R. M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. *Journal of Engineering Education, 95*(2), 123–138.

Prince, M., & Felder, R. (2007). The Many Faces of Inductive Teaching and Learning. Journal of College Science Teaching, 36(5), 14–20.

Roselli, R. J., & Brophy, S. P. (2006). Effectiveness of Challenge-Based Instruction in Biomechanics. *Journal of Engineering Education, 95*(4), 311–324.

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of Undergraduate Research Experiences. *Science, 316*, 548–549.

Sidhu, G. & Srinivasan, S. (2015). An Intervention-Based Active Learning Strategy Employing Principles of Cognitive Psychology. CEEA15, Proceedings of Canadian Engineering Education Associate (CCEA15) Conference, Hamilton, Canada.

Sidhu, G., Srinivasan, S. & Centea, D. (2017). Implementation of a Problem Based Learning Environment for First Year Engineering Mathematics", 6th International Research Symposium on PBL (IRSPBL), Bogota, Colombia.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, *69*(1), 21–51.

Srinivasan, S. & Centea, D. (2015). Applicability of Principles of Cognitive Science in Active Learning Pedagogies ", IJCLEE 2015, International Joint Conference on the Learner in Engineering Education, Donostia - San Sebastian, Spain.

Srinivasan, S. & Sidhu, G. (2014). Technology and Intervention-Based Instruction for Improved Student Learning. ICEER2014 International Conference on Engineering Education and Research, Hamilton, Canada.

Tien, L. T., Roth, V., & Kampmeier, J. A. (2001). Implementation of a Peer-Led Team Learning Instructional Approach in an Undergraduate Organic Chemistry Course. *Journal of Research in Science Teaching*, *39*(7), 606–632.

UNESCO Institute for Statistics (UIS). (2011). *Global Education Digest 2011*. Montreal: UIS.

Wage, K. E., Buck, J. R., Wright, C. H. G., & Welch, T. B. (2005). The Signals and Systems Concept Inventory. *IEEE Transactions on Education*, *48*(3), 448–461.