ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15573

The Engineering Education Assessment Process - A Signals and Systems Perspective

Dr. George E. Hassoun, Notre Dame University - Louaize, Lebanon

G. Hassoun received the Licence en Physique degree from the Lebanese University, Beirut, Lebanon, in 1982, the Mastère en Avionique diploma from ENSAE, Toulouse, France, in 1984, the M.S. degree in Aeronautical and Astronautical Engineering from the Ohio State University, Columbus, OH, in 1989, and the Ph.D. degree in Electrical Engineering from the University of Adelaide, South Australia, in 1996.

In 1997, he worked as a Senior Research Assistant at the University of New South Wales - Sydney, with the Satellite Navigation and Positioning Group, Department of Geomatic Engineering. In 1998, he joined the Avionics Group of the Air Operations Division DSTO – South Australia, as a Research Scientist.

Since 2001, he has been an Assistant Professor with the Electrical, Computer and Communication Engineering Department at Notre Dame University – Louaize, Lebanon. His research interests include control, avionics, navigation and guidance, optimization and estimation theories, in addition to aerospace applications. He is presently interested in the application of signals and systems theory to engineering education.

Dr. Hassoun is a current member of the American Society for Engineering Education.

The Engineering Education Assessment Process

A Signals and Systems Perspective

Abstract:

In this work in progress, a signal model is suggested for the knowledge acquired by engineering students during their study of a specific engineering subject, based on Signals and Systems theory. This model is illustrated using three courses typically taught in modern American-style engineering schools, namely Circuit Analysis, Signals and Systems, and Feedback Control Systems. Additionally, a signals-and-systems-based model is suggested for the assessment process that inputs the acquired knowledge signal, mentioned above, and produces the so-called assessed (engineering) knowledge signal. Based on the largely acknowledged continuous nature of the brain activity, the cumulative nature of the acquired subject-specific engineering knowledge, and the discrete nature of assessment schemes typically administered in engineering schools, it is argued that the acquired engineering knowledge could appropriately be modeled by a continuous-time signal, however the assessed engineering knowledge could be more realistically modeled by a discrete-time signal.

As such, the assessment process could then be modeled as a sampling process, where samples of the acquired knowledge signal are captured at various periods of time for the purpose of reconstructing a good image of the student acquired knowledge. It is reasoned that the perceived level of student learning does depend to a large extent on the successful reconstruction of the (continuous) acquired knowledge signal from the (discrete) assessed knowledge signal, i.e. in order for the evaluation of acquired knowledge to be satisfactory, the reconstruction process needs to be error-free!

Towards that end, Nyquist-Shannon’s sampling theorem is used to place a condition on the minimum assessment frequency, in order to avoid aliasing errors in the assessment/sampling process. Based on that theorem, a minimum of two samples (assessments) are necessary in the smallest period of the continuous signal (i.e. the acquired knowledge signal). Accordingly, and based in part on previous works in this domain, a preliminary figure of merit is suggested as a

necessary minimum assessment frequency, below which the assessment process, and consequently the validity of perceived learning may be questionable.

This work is in line with recent studies by educational experts/psychologists advocating the switch from a 2-or-3-assessment-per-semester assessment scheme to a more frequent assessment scheme. The present work seeks the feedback of the engineering education community regarding the validity and implications of the proposed models and the potential of benefiting engineering schools in their pursuit of quality education by drawing their attention not only to the quality (level) of their learning and assessment activities, but also to the frequency of these activities and to the importance of appropriately weighing each learning and assessment activity, including homework assignments and quizzes.

I – Introduction

When it comes to improving the effectiveness of engineering education, much research has been published and numerous methods and techniques have been suggested. Active Learning, for example, is a popular learning methodology advocating the initiation of classroom activities, such as group discussions, interactions and/or short quizzes, aiming to improve long-term knowledge retention [1]. Cooperative, Collaborative, and Problem-based Learning (PBL) are other methodologies that have been proposed to improve learning [2], [3], [4]. A more recent approach, the Flipped Classroom, proposes replacing the traditional classroom lecture by a team-based active classroom discussion session, following preparatory work outside the classroom [5]. Most of these suggested methodologies, however, focus on the modes and techniques of knowledge delivery. Other suggested methodologies focus on knowledge assessment and on the implicit relationship between assessment and learning. Scenario-based Assessment and Assessment Based on Learning Outcomes are two of these suggested methodologies [6], [7]. Most of these assessment-related approaches focus on the modes and techniques of assessment, without giving much attention to the frequency of assessment and its relationship to effective learning.

Paced Active Learning (PAL) is one variant of Active Learning that looks at the importance of increasing the frequency of assessment, as part of a more comprehensive educational approach incorporating two other techniques, namely Regularly Assessed Performance (RAP) and

Computer Assisted Presentation (CAP). However, PAL addresses the issue of assessment frequency in a rather informal and empirical fashion [8].

Other studies have suggested that administering frequent, low-stakes exams has the potential of improving learning effectiveness while reducing dishonest behavior. These studies partly originated in the cognitive psychology field [9], [10].

The present work, however, looks at the issue of assessment frequency from a mathematical/Signals and Systems perspective. Given the measurability and continuity of acquired engineering knowledge, in addition to its cumulative nature, this knowledge is first modeled as a continuous-time signal and the assessment process is modeled as a sampling system, where assessment outcomes are simply seen as discrete samples of the continuous acquired engineering knowledge signal. Because these samples are normally captured with the purpose of reconstructing the acquired engineering knowledge, a minimum sampling/assessment frequency is required to validate the reconstruction process, based on Nyquist-Shannon's sampling theorem.

As such, engineering assessments are seen as processes designed to check whether a certain path has been followed rather than whether a certain point in time has been reached. Towards that end, some of the limitations of individual assessments (points in time) are stated, including breadth and depth limitations, coverage limitations, and circumstantial limitations.

Since Nyquist-Shannon's sampling theorem uses ideal sampling to address the question of sampling frequency, and because ideal sampling is based on the so-called unit impulse function, the widely accepted one-or-two-hour exam is suggested as a practical approximation of the unit impulse function. Under this assumption, it is argued that an adequately weighted homework assignment could also be considered as a practical approximation of the unit impulse function, provided a high ethical standard is adhered to. This brings up the issues of ethics and plagiarism in modern engineering schools, and the need to formally systemize acceptable approximations of the unit impulse function, perhaps by assigning appropriate weights for each of the widely known assessment activities, such as exams, homework assignments, quizzes, and projects, as part of modeling the learning assessment process.

Finally, it is suggested that the modeled knowledge assessment/sampling system could be complemented by two other systems, one preceding it, designated as the student learning system, and another one following it, and called the learning evaluation system. More importantly, the knowledge assessment system could be used to close the learning loop of the student, who may use the assessment output to "correct the error" between the desired engineering knowledge signal and his/her acquired engineering knowledge signal. As part of this engineering knowledge modeling exercise, a signal noise could be added to the combined model to account for potentially misleading information received by the student. Towards that end, the engineering education community is kindly solicited to give feedback on a number of issues including:

1. The soundness and validity of the proposed models of the acquired engineering knowledge signal, the assessed knowledge signal, and the learning assessment process.
2. If the models are acceptable, what are the implications of the results suggested in this work on the currently adopted engineering education assessment schemes in various parts of the world, in terms of evaluation accuracy and validity?
3. Given the increasing engineering educators' workloads and the varying scales of student plagiarism in contemporary engineering schools, would it be realistic to switch from an assessment scheme consisting of 2-to-3 major assessments per semester to a more frequent assessment scheme, reaching one formal exam per week as suggested in this work? And would it be possible to rely on the rapidly emerging online learning management systems to facilitate this task?

II – Modeling Acquired Engineering Knowledge

Given the nature and characteristics of engineering knowledge disseminated in modern engineering schools, and the way in which the human brain learns and retains information, it is hereby suggested that, despite being abstract rather than physical, engineering knowledge could be modeled by a continuous-time (or simply continuous) signal [11]. This model is largely based on the following three properties:

1. **Engineering Knowledge is Measurable**

   In an engineering education environment, knowledge measurement is one of the most commonly performed tasks. A knowledge measurement is performed every time a test, quiz, or homework assignment is graded, a project is rated, a presentation is evaluated, or a GPA is calculated! This grading/evaluation process is actually a way of quantifiably measuring the level of acquisition of specialized engineering knowledge at a certain point in time, in comparison with the desired knowledge level. As stated in Section IV, the smaller the "error" between the acquired and the desired knowledge, the higher is the grade. Since, by definition, a signal is a model of a measurable variable, we can simply state that specialized engineering knowledge could be modeled by a signal. It could be argued, however, that knowledge measurement may differ from one engineering school/institution to another or even from one engineering instructor/educator to another; accordingly, it may not be reversible or repeatable. As a matter of fact, this argument highlights the need to identify and standardize a "unit of specialized engineering knowledge measurement", if applicable; however, it doesn't make specialized engineering knowledge less of a signal! As with any other signal, measurement standardization is not a precondition for the definition of a signal. Moreover, for a specific engineering school, with a clearly defined evaluation policy (preferably using effective evaluation tools such as rubrics), the measurement of specialized engineering knowledge readily becomes a fairly reversible and repeatable routine.

2. **Engineering Knowledge is Continuous**

One of the most salient features of human brains is their continuous activity [12]. Brains do work relentlessly, even during deep sleep, when information stored in the short memory is transitioned to one or more long-term storage areas [13]! This means that, when engineering knowledge is first captured by an engineering student, it does not die out suddenly, under normal circumstances. The knowledge level may increase or decrease with time, at different time rates with different persons; at times, it may even remain the same. But normally, knowledge does not abruptly appear and then reappear at other instants of time. Once it is captured, i.e. once it crosses the immediate memory, information normally follows a continuous path, typical of each individual. In this context, most of us have experienced, first hand, the progress of information, as it travels through our brains, up from simple exposure to familiarity to intimate knowledge (skill) to expertise, or down from familiarity, to vague remembrance, to oblivion. For the average engineering student, in particular, engineering knowledge does not jump up suddenly from familiarity to expertise, for example, nor does it fall down abruptly from familiarity to oblivion. This is part of our human nature. As such, the signal that models specialized engineering knowledge could justifiably and realistically be considered as a continuous signal rather than a discrete signal.

3. Engineering Knowledge is Cumulative

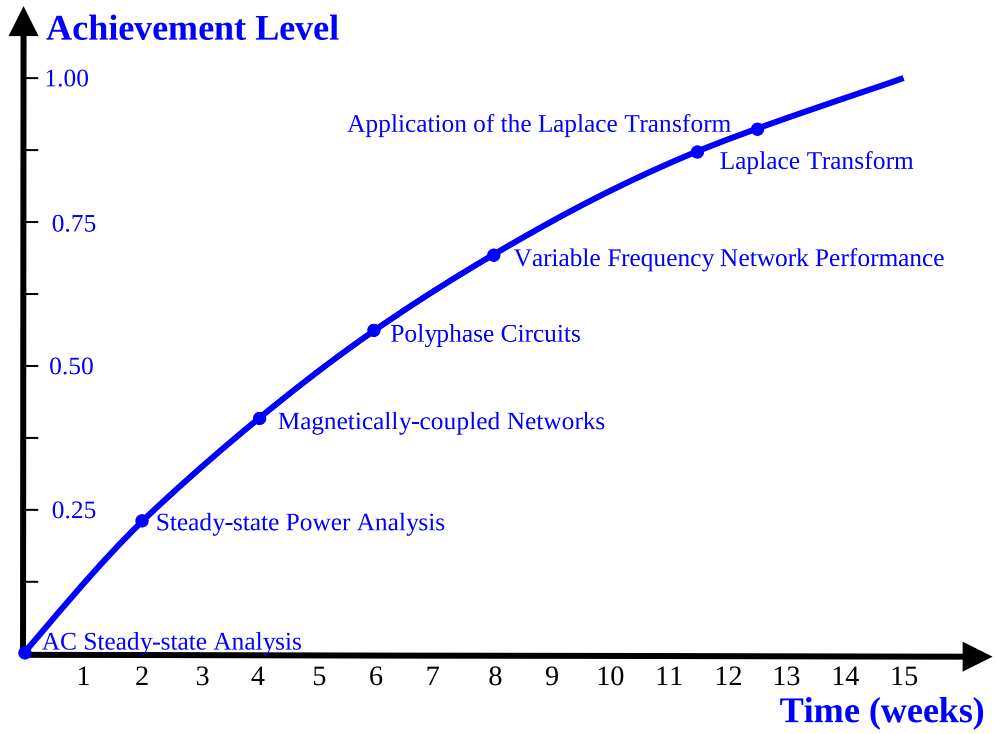

Figure 1 – Possible continuous signal model for the acquired knowledge associated with the Advanced Circuit Analysis course.

One of the most characteristic properties of engineering knowledge is its mainly systematic, progressive, and cumulative structure. In modern engineering schools, this knowledge is typically organized into various sequences of logically-threaded modules/chapters, each of which being typically a pre-requisite for the subsequent ones. To study advanced circuit analysis (Figure 1), for example, the notion of phasors is first covered in the AC Steady-state Analysis module. Without the notion of phasors, most of the other modules could not simply be covered. Also, Polyphase Circuits is another module in which the notion of complex power is used. This latter notion is typically addressed in a previous module, Steady-state Power Analysis. Although this cumulative, modular property is not a required condition for signal continuity, it does significantly facilitate the task of modeling acquired knowledge by a continuous signal. Figure 2 and Figure 3 illustrate two possible continuous signals modeling two typical undergraduate engineering courses, namely Signals and Systems and Feedback Control Systems, respectively.

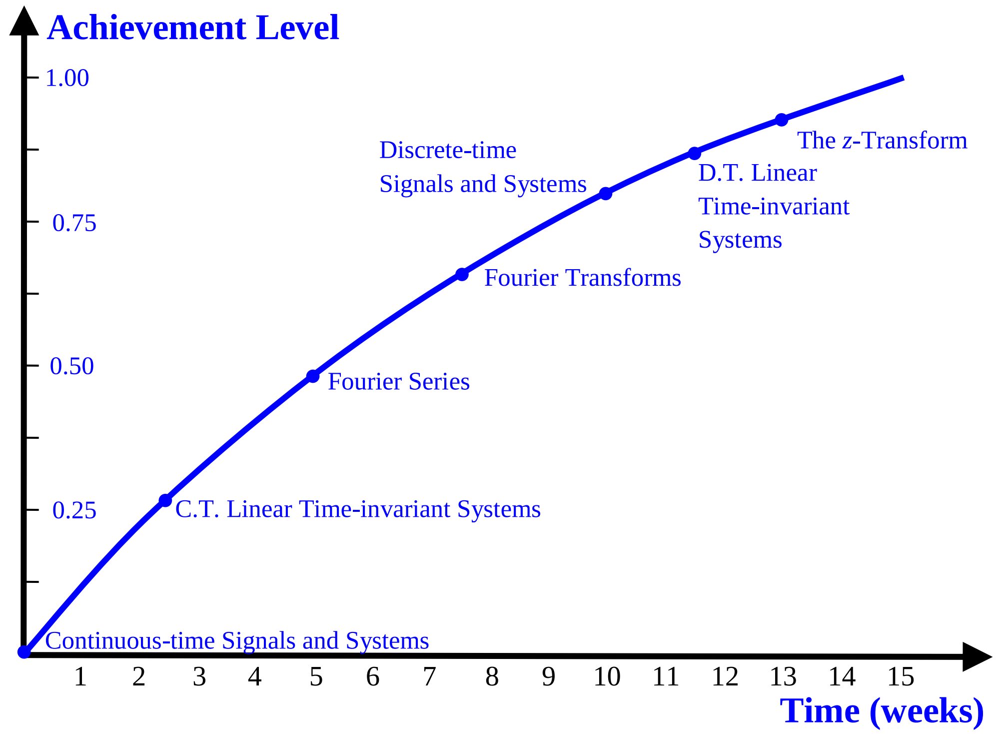

Figure 2 – Possible continuous signal model for the acquired knowledge associated with the Signals and Systems course.

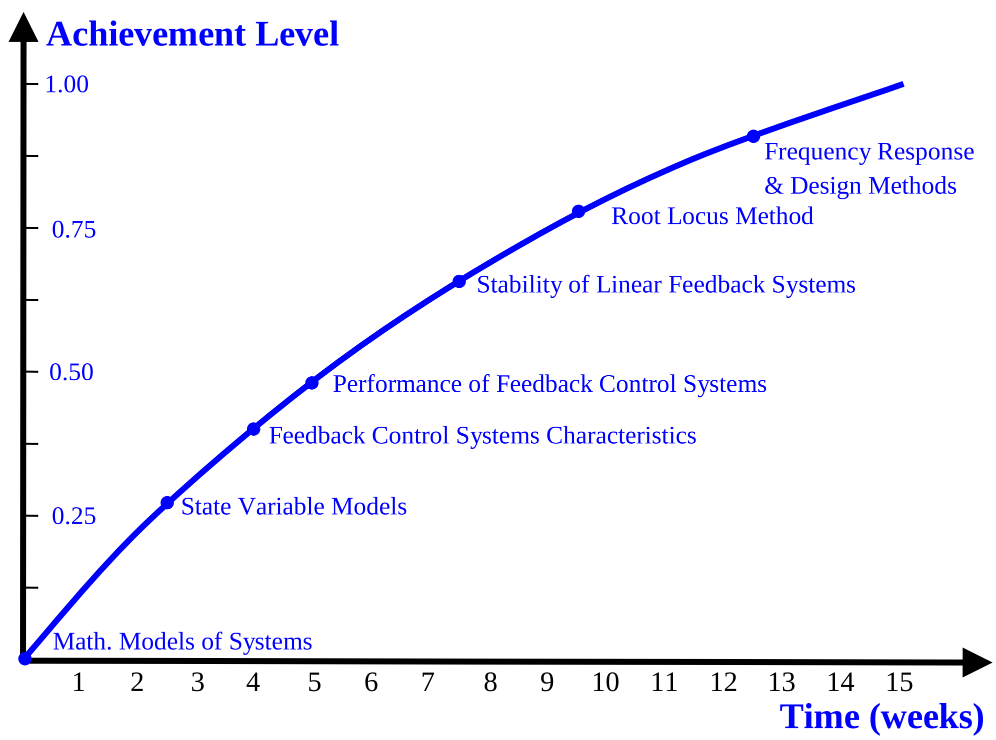

Figure 3 – Possible continuous signal model for the acquired knowledge associated with the Feedback Control Systems course.

It is important to note, however, that the task of modeling the acquired engineering knowledge by a continuous signal should not be affected by the exact sequence of course modules, by their corresponding achievement levels, or by the overall shape of the waveform. Figure 4 depicts a possible model for an introductory Electric Circuits course. The unconventional waveform associated with the course, the possible reshuffling of its various modules, or the possible alteration of its shape does not make the signal less continuous! What is important in this context is the need to use the entire signal, and not just some samples of it in the evaluation process, as outlined in Section IV.

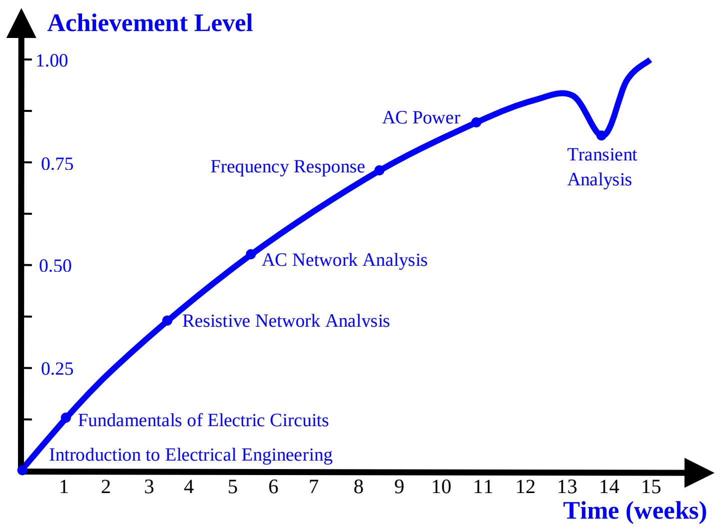

Figure 4 – Possible continuous signal model for the acquired knowledge associated with the Electric Circuits course.

With regard to the cumulative/scaffolding property of the engineering knowledge signal, it may be interesting to note that this property is not only largely prevalent at the engineering course level, but also at the engineering program level as well. Figure 5 depicts a partial view of the suggested course sequence of the Electrical Engineering program at Notre Dame University – Louaize (NDU).

In this view, the suggested electrical engineering courses for five consecutive semesters, including two summer sessions, are shown. Courses located on a continuous horizontal line are offered during the same semester/session, and courses located at lower levels, are prerequisites of courses located at upper levels to which they are connected, while hashed lines indicate co-requisites. A quick examination of Figure 5 illustrates the cumulative/scaffolding nature of this largely typical engineering program.

III – Assessment Process as a Sampling System

In an engineering education environment, it is well known that student performance is typically evaluated using various forms of assessments, namely exams, quizzes, homework assignments, project reports, classroom presentations, etc. However, not all of what was said above about acquired engineering knowledge is applicable to assessed engineering knowledge:

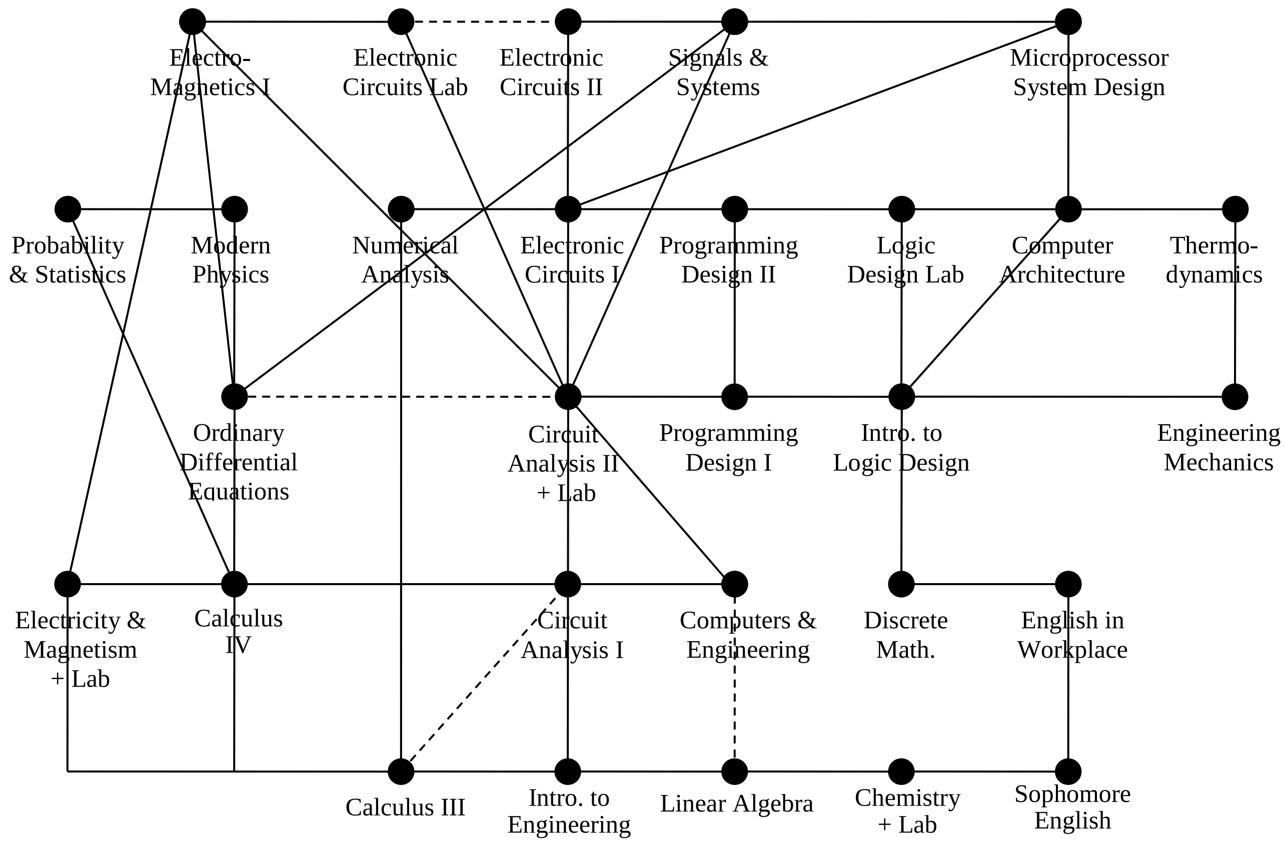

Figure 5 - Partial view of the suggested electrical engineering program at NDU.

1. Assessed engineering knowledge is measurable, as manifested by the grade assigned to the corresponding assessment. Accordingly, this knowledge could still be modeled by a signal.

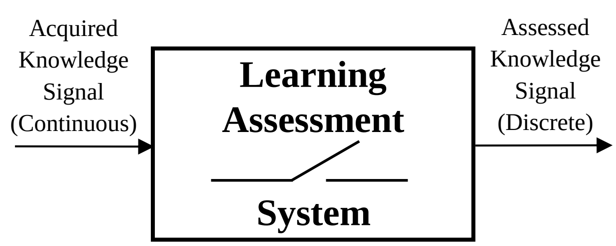

Figure 6 – The Learning Assessment Process modeled as a sampling system.

2. However, the assessed engineering knowledge can be considered as an image of the acquired student’s knowledge only in a particular period of time, namely the duration of assessment. As a matter of fact, the knowledge captured during a one-or-two hour assessment may be considered as minimal compared to the knowledge acquired during the 1680 hours of a 10-week quarter or the 2520 hours of a 15-week semester. Whereas acquired engineering

knowledge is dynamically and continuously evolving, consciously or subconsciously, during these long hours, assessed engineering knowledge is captured only for the relatively minimal duration of assessment. It could thus be asserted that assessed engineering knowledge is a set of samples of the acquired engineering knowledge, taken at the times of assessment (sampling). Accordingly, this assessed knowledge could be modeled by a discrete-time, rather than a continuous-time signal [11]. As a direct consequence, the learning assessment process could be modeled by a (hybrid) sampling system (Figure 6), which samples a continuous-time acquired knowledge input, and produces a discrete-time assessed knowledge output, typically illustrated in Figure 7.

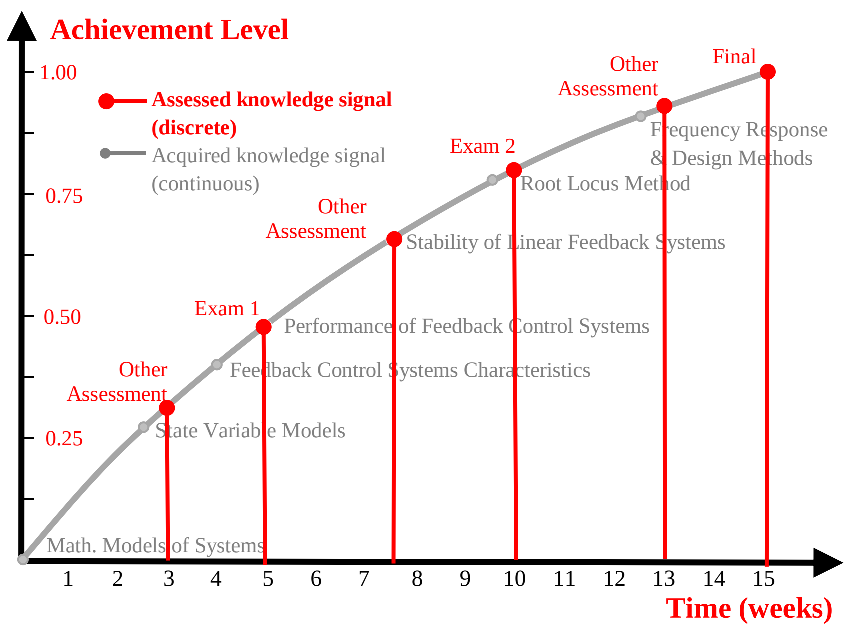

Figure 7 – Possible discrete signal model for the assessed knowledge associated with the Feedback Control Systems course.

IV – Point versus Path Assessment – Limitations of Individual Assessments

At this stage, it is perhaps clearer that one of the main reasons for conducting several assessments in engineering schools, i.e. taking several samples of the acquired knowledge signal, is to attempt to reconstruct that signal. In other words, several points in time (i.e. single assessments) are used in order to attempt to recover the path (continuous knowledge signal). The need to take numerous samples is due to the fact that single assessments have typically numerous limitations compared with path assessments. Following are some of these limitations:

1. **Depth and Breadth Limitations**

   In preparing a one-or-two hour exam covering information given over several weeks, the engineering instructor typically makes some hard choices relating to the levels of depth and breadth of each tested topic. Because of the exam time limitation, not everything given in class could be tested in the exam, and not always to the same degree of depth. Consequently, an individual assessment cannot simply capture the acquired knowledge level of the student to a high degree of rigor and accuracy!

2. **Coverage Limitations**

   For the same reasons mentioned above, instructors find themselves sometimes unable to include all covered topics in the exam. Similarly, the student may have another set of priorities that does not match the priority scale of the instructor. This coverage-related mismatch may well lead the instructor to build a certain image of the student knowledge that is different from the true image, when evaluating his or her assessment.

3. **Circumstantial Limitations**

   These limitations are related to the special circumstances of both instructor and student on the day of the assessment. Personal, family, social, and work circumstances all play important roles in both the instructor's preparation of a single assessment and the student's performance on that assessment. Due to these real-life circumstances, it is sometimes observed that it is possible for the same student, with the same level of preparation, to take the same assessment on two different occasions, and get two different sets of results!

Accordingly, to evaluate the student performance fairly, it is obviously more accurate to reconstruct the complete continuous acquired knowledge signal from the assessed (discrete) knowledge signal, instead of relying on discrete sets of single assessments. A subsequent comparison between the reconstructed knowledge signal and the desired knowledge signal produces an "error signal" which can justifiably be considered as the basis for a proper, more accurate evaluation of knowledge acquisition (Figure 8).

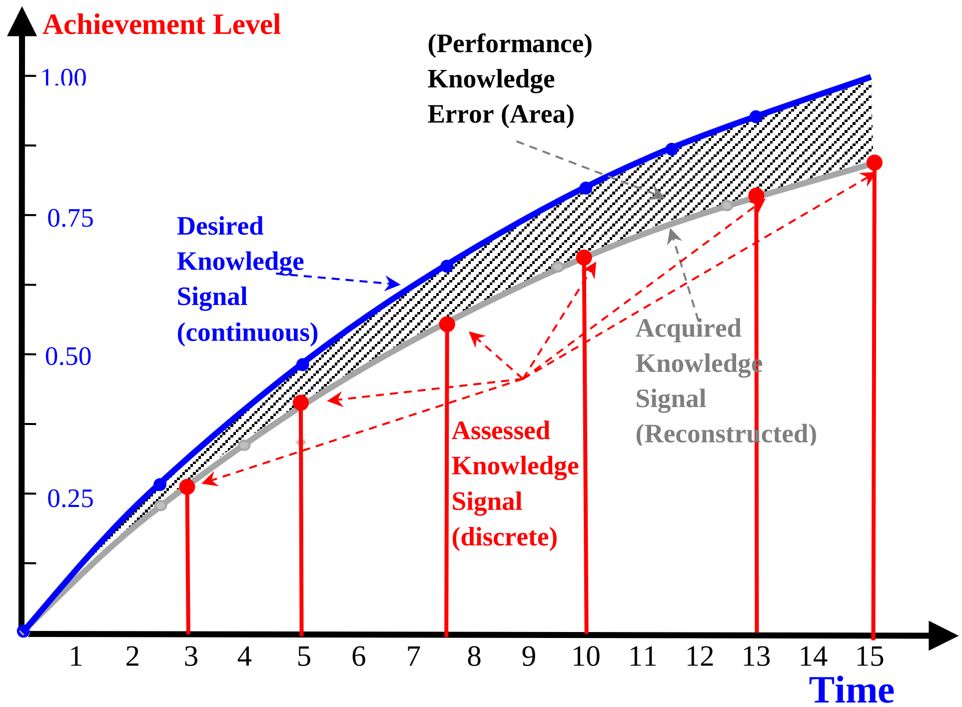

Figure 8 – Possible depiction of the knowledge error as the (continuous) difference between the desired knowledge signal and the (reconstructed) acquired knowledge signal.

V – Nyquist-Shannon's Theorem and Aliasing Errors

The reconstruction of a continuous signal from discrete samples is a problem addressed by Harry Nyquist (1889 – 1976), and Claude Shannon (1916 – 2001). In their work, a special kind of sampling is adopted, called ideal sampling, whereby the continuous signal, say $f(t)$, is multiplied by an infinite series (train) of so-called unit impulse functions, to produce the discrete/sampled version, $f_S(t)$, of the continuous signal:

$$f_s(t) = f(t) \sum_{n=-\infty}^{\infty} \delta(t - nT_s)$$

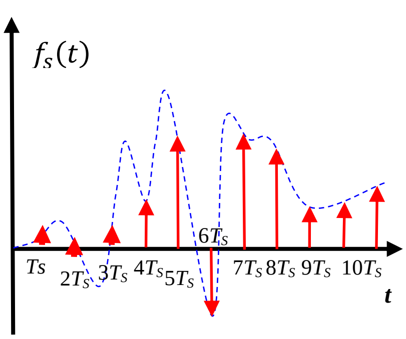

Figure 9 – Ideal sampling of a continuous signal $f(t)$ (dashed) with a sampling period T_S.

where the train of unit impulse functions has a sampling period equal to T_S. By definition, each impulse function is an extremely high (infinite) amplitude continuous signal occurring over an extremely small period of time, and having the characteristic property that its integral over all times (called weight) is equal to one. Typically, this impulse function is graphically represented by an arrow pointing vertically, and located at the sampling instant (Figure 9).

We note that the frequency spectrum, $F(\omega)$, of a continuous signal, $f(t)$, is a representation, in terms of frequency, of the magnitudes and phases of the sinusoidal signals necessary to reconstruct that continuous signal. In this context, one of the main findings of Nyquist and Shannon is that the frequency spectrum of a discrete signal obtained by ideally sampling a continuous signal is composed of infinite replicas of the frequency spectrum of the corresponding continuous signal, repeated every sampling frequency ω_S (Figure 10):

$$F_s(\omega) = \frac{1}{T_s} \sum_{k=-\infty}^{+\infty} F(\omega - k\omega_s)$$

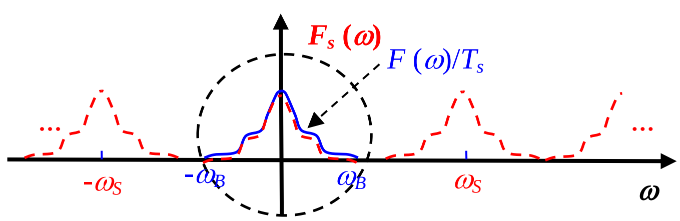

Figure 10 – Scaled frequency spectrum of a continuous signal (solid line) and the frequency spectrum, $F_s(\omega)$, of its sampled version.

Under these conditions, it should be clear that in order to reconstruct/retrieve the continuous signal from the corresponding discrete/sampled signal, the sampling frequency, ω_S, needs to be at least twice as large as the largest frequency, ω_B, of the (frequency spectrum of the) continuous signal. Otherwise, overlap may occur between the various components (replicas) of the discrete signal frequency spectrum, which affects the accuracy of the reconstructed signal. This finding is called Nyquist-Shannon's theorem and the error linked to the inaccuracy of the signal reconstruction is called aliasing error [11], [14].

At this stage, it is important to mention a few words about the actual significance of aliasing errors. One common occurrence of aliasing errors could be perceived when looking at the turning wheels of a speeding car in a movie picture. At times, we may see that the car is moving forward, for example, while the direction of rotation of its wheels suggest a motion in the opposite direction! This perception error is commonly attributed to the fact that the frequency of the movie camera shots is not sufficient compared to the rotation frequency of the wheels [11]. As far as the learning assessment system is concerned, this error may well cause a serious difference between our perception and the reality of the student learning achievement level!

VI – Weighting the Impulse Function – Exams versus Other Assessment Schemes

To be able to make use of Nyquist-Shannon's theorem, we need to ask one important question: how "ideal" is our sampling/assessment process? To respond to this question, we need to adopt a practical approximation of the unit impulse function. As mentioned in the previous section, ideal sampling is obtained by multiplying a continuous signal by a unit impulse train, composed of an infinite periodic series of unit impulse functions. As mentioned previously, the ideal unit impulse function is a continuous signal of infinite amplitude and infinitesimally small time duration, one of its characteristic properties is given as follows:

$$\int_{-\infty}^{+\infty} \delta(t)\, dt = 1$$

where the value of the integral is called the weight (or strength) of the impulse function. This function, $\delta(t)$, is graphically represented by an upward arrow located at the sampling instant of time, with its weight placed next to it, and could be approximated by a practical pulse, $g(t)$, of width ε and amplitude $1/\varepsilon$ as $\varepsilon \to 0$ (Figure 11).

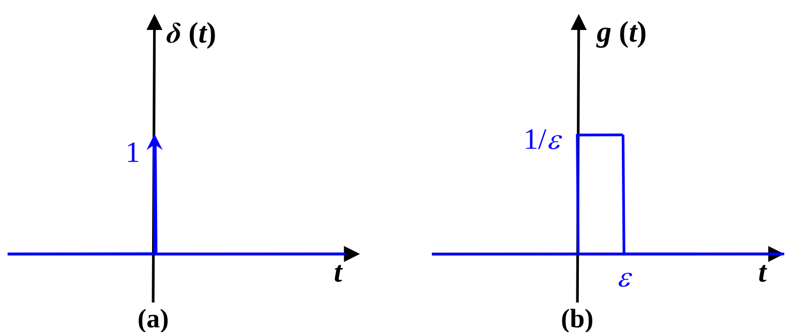

Figure 11 – (a) Graphical representation of a unit impulse function and (b) a practical approximation of a unit impulse function.

In our case, it is possible to adopt the conventional one-or-two hour exam as the basis for a practical unit impulse function. In the case of a quarter-based or a semester-based engineering curriculum, the time duration of the practical pulse will be in the order of $\varepsilon = \frac{1}{168} \cong 6 \times 10^{-3}$ week, and its magnitude in the order of 168, which is very large compared to the prescribed maximum achievement level in a semester (assumed to be of unit magnitude).

Using the same rationale, we could deduce that, while a conventional quiz may be low on weight (product of time by amplitude), a homework assignment could also serve as the basis for a practical pulse approximating the unit impulse function, in the absence of dishonest behavior, because each engineering homework assignment often necessitates a minimum of two hours to complete. However, in those cases where cheating and plagiarism is widespread, one seriously needs to question if the Nyquist-Shannon's condition on assessment/sampling frequency is being met!

For other assessment schemes, such as projects and presentations, one may assign a weighting factor for each of them, that depends on a number of factors that contribute to its approximation of a unit impulse function (including level of difficulty, time duration, accessibility to resources, etc.), in comparison with a conventional one-or-two hour exam, as is done in [15].

VII – Facts and Figures – A Data Snapshot from the International Scene

In 2013, a short engineering education survey was distributed to 233 engineering educators affiliated with the engineering faculties of four leading universities in Lebanon (the Middle East). The survey included a number of questions on issues ranging from the number of supplementary assessment schemes (homework assignments, quizzes, and projects) given to students per semester to the estimated number of lecture-hours needed to cover a typical course chapter [15].

Table 1 summarizes some of the results obtained in that survey, and refers to the percentage of respondents who used fully graded assessment schemes, as opposed to partially graded, TA-assisted, or simply inspected assessment schemes.

Table 1 - Percentage of Respondents Using Various Modes of Assessment Schemes.

Assessment Mode	Full	Partial	TA	Inspection	Other	N/A
Homework Assignments	24.5%	4.1%	18.4%	34.7%	18.4%	
Quizzes	61.2%	4.1%	4.1%	8.2%	2.0%	20.4%
Projects	65.3%	8.2%	4.1%	0.0%	2.0%	20.4%

On the other hand, Figure 12 shows another set of results of the survey, whereby a weighted average of Combined Supplementary Assessments (i.e. homework assignments, quizzes, and projects –

other than the main three exams) was calculated for several modes of assessment schemes (i.e. fully or partially graded, inspected, or grading-assisted by a TA). The weights adopted for the calculations were: 1 for a homework assignment, 0.33 for a quiz, and 3 for a project.

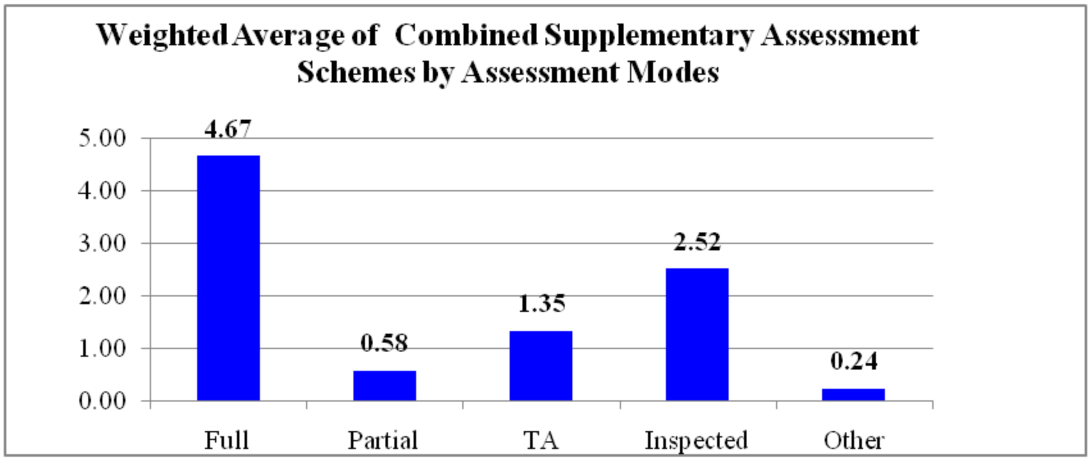

Figure 12 - Weighted Average of Combined Supplementary Assessment Schemes.

Out of that study, two numbers are particularly relevant to the present work. The first one is the estimated average number of lecture-hours needed to complete an average engineering chapter (the duration of which being interpreted as a cycle/period of the acquired engineering knowledge signal), which turned out to be 5.7 lecture-hours per average chapter. Given that 3 (three) engineering lecture-hours are typically offered per week, the 5.7 lecture-hours correspond to 1.9 weeks per chapter. The second number of particular interest to the present work is the weighted average of fully-graded or TA-assisted secondary assessments offered by each instructor per semester, which turned out to be 6.02 equivalent supplementary assessments per instructor per semester.

VIII – Results and Interpretations

Coming back to the present study, if we accept that the assessed knowledge signal is obtained by (ideally) sampling the (continuous) acquired learning signal, we could readily apply Nyquist-Shannon's theorem. In other words, to accurately reconstruct the acquired knowledge signal from the sampled knowledge signal, at least two samples/assessments should be taken/conducted in the smallest period of the continuous signal. Towards that end, any known frequency of the acquired knowledge signal could be used to define a necessary minimum bound on the sampling frequency. In this regard, one obvious frequency is the frequency at which we start a new chapter in an engineering course. As alluded to in the previous section, this frequency corresponds, on average, to 1.9 weeks per chapter which translates to $\frac{1}{1.9} = 0.53$ chapter (or cycle) per week [15].

Accordingly, assuming ideal sampling, and an average period of the acquired engineering knowledge of about 2 weeks, it is possible to state that a necessary condition for sampling the acquired knowledge signal, for the purpose of avoiding aliasing errors, is to adopt a sampling/assessment frequency of 2 assessments/samples every two weeks, which amounts to 15 assessments per semester.

This result points to the insufficiency of the 9.02 equivalent assessments per semester (three main assessments added to the 6.02 supplementary assessments) to avoid aliasing errors. Perhaps more important is the lack of scrutiny for the estimated/claimed number of assessments administered in engineering schools in many developing countries. In the US, however, the potential problem pointed to by the present work may not be as severe as it is in developing countries, namely because homework and other assessment schemes are typically frequently administered and properly (fully) evaluated (through the services of graduate Teaching Assistants sufficiently populating engineering schools, in general); nevertheless, this work may draw the attention to the significance of approximating each homework assignment by a knowledge impulse function, and consequently, to the significance of considering each homework assignment as important as a regular exam!

IX – Summary and Concluding Remarks

In conclusion, this work in progress attempted to address the issue of engineering knowledge assessment from a Signals and Systems perspective. It sought the feedback of the engineering education community concerning the modeling of the assessment process as a hybrid system, where the input is the student acquired knowledge, modeled as a continuous signal, and the output is the assessed knowledge, modeled as a discrete signal. In this model, the nature and continuity of the input signal was mainly justified by the measurability of acquired knowledge and by the continuous activity of the human brain. On the other hand, the discrete nature of the output signal was justified by the relatively short assessment time periods. As such, the study concluded that this sampling system needs to satisfy the Nyquist-Shannon's sampling theorem, imposing a minimum value on the sampling frequency in order to avoid aliasing errors that may affect the accuracy of reconstructing the continuous acquired knowledge signal from the discrete output of the assessment system. In this context, it was argued that a flawed acquired knowledge signal reconstruction process can lead to a deficient evaluation of learning performance.

Partly based on previous work that estimates the average time it takes to cover one engineering chapter (i.e. one known cycle or period), the present work concluded that at least two regular assessments are necessary every about two weeks of engineering learning activities. This goal is not unrealistic and far reached, especially if we consider that a properly administered and well scrutinized formal homework, given in an ethical and trust-worthy environment, could well be considered as a valid assessment. Additionally, with the wide proliferation of educational technology in recent times, it is increasingly possible to design highly randomized, multifunctional, and properly timed on-line tests, specially designed to improve learning while minimizing dishonest behavior.

Consequently, in engineering schools where high ethical standards are being adhered to and where at least weekly formal homework assignments are given and properly scrutinized, in addition to the main major exams, the Nyquist-Shannon's theorem may well be considered to be satisfied. However, in those engineering schools where plagiarism is common, and where educators and instructors largely administer their homework assignments and projects in an informal fashion, without appropriate scrutiny, serious question marks need to be raised concerning the accuracy and effectiveness, if not the validity of the corresponding learning processes.

The feedback of the engineering education community was solicited with regard to the validity of the proposed assessment system model, its implications, and the feasibility of implementing changes to the assessment schemes commonly adopted in today's engineering schools. This feedback is especially important, because the present work is in line with some other significant research, based on cognitive psychology, advocating the administration of frequent low-stake assessments during the semester, instead of the 2 or 3 high-stake exams, as a way to fight plagiarism and improve learning at the same time [9], [16]. In this other research, it is argued that frequent retrieval, rehearsal and articulation of information (i.e. common activities practiced during assessments), can help improve learning and long-term retention [10].

IX – Future Work: Closing the Feedback Loop and Accounting for "Knowledge Noise"

The engineering learning assessment system modeled in this work, and the acquired and assessed knowledge signals, defined as the learning assessment system input and output, respectively, could well be complemented by other (sub) systems involved in the delivery, learning, and assessment processes, as depicted in Figure 13.

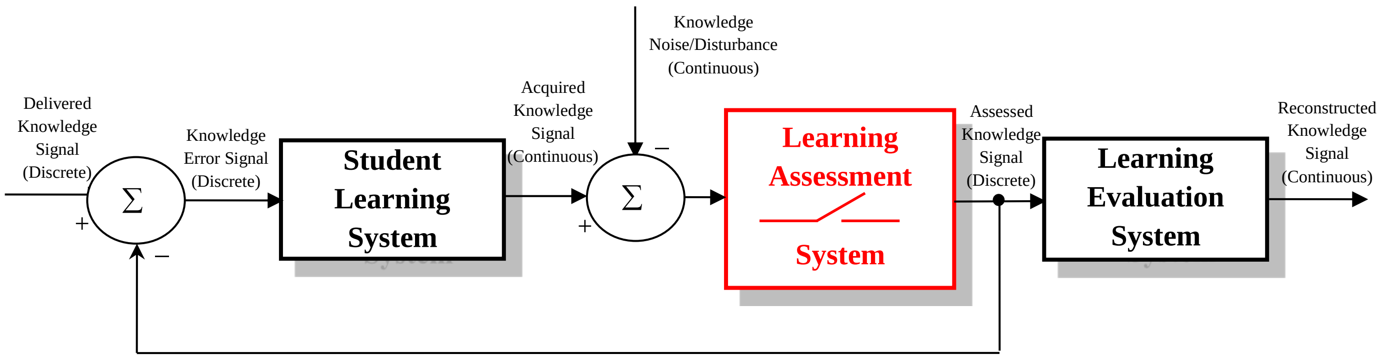

Figure 13 – The learning assessment system in a closed-loop configuration including knowledge noise.

In particular, the described model makes it possible to include a feedback loop that captures the assessed knowledge signal and compares it to the delivered knowledge signal to generate the knowledge error signal. This error signal is used by the engineering student to adjust his/her learning strategies and compensate for any eventual divergence.

Another interesting feature of the described model is the possibility to include noise or a disturbance signal to simulate distractions or misleading information. These and other interesting notions could well be addressed in the future.

References

[1] D. W. Johnson, R. T. Johnson, and K. A. Smith, *Active Learning: Cooperation in the College Classroom*, 2nd Edition, Interaction Book Co., Edina, MN, 1999.

[2] D. B. Kaufman, R. M. Felder, and H. Fuller, "Peer Ratings in Cooperative Learning Teams", *ASEE Annual Conference Proceedings*, 1999.

[3] S. Kadel and J. A. Keehner (eds.), "Collaborative Learning: A Sourcebook for Higher Education", vol. 2, *National Center on Postsecondary Teaching, Learning, and Assessment*, Pennsylvania State University, University Park, PA, 1992.

[4] D. R. Woods, *Problem – based Learning: Helping Your Students Gain the Most from PBL*, Woods Publishing, Waterdown, 1997.

[5] J. Bishop and M. A. Verleger, "The Flipped Classroom: A Survey of the Research", 120th ASEE Annual Conference and Exposition", Atlanta, June 2013.

[6] S. R. Haynes, L. Spence, and L. Lenze, “Scenario-based Assessment of Learning Experiences”, *39th IEEE Frontiers in Education Conference*, pp. 1 – 8, October 2009.

[7] R. M. Crespo, J. Najjar, M. Derntl, D. Leony, S. Neumann, P. Oberhuemer, M. Totschnig, B. Simon, I. Gutierres, and C. D. Kloos, “Aligning Assessment with Learning Outcomes, in Outcome-based Education”, *IEEE Education Engineering Conference (EDUCON)*, pp. 1239 – 1246, April 2010.

[8] G. Hassoun, “Towards Improving the Engineering Education Continuum”, *Proceedings of the International Conference on Technology, Communication and Education,* Mishref, Kuwait, 2008.

[9] B. Taylor, “Cheating Lessons, Part 3”, The Chronicle of Higher Education, August 19, 2013.

[10] J. D. Karpicke and H. L. Roediger III, “The Critical Importance of Retrieval for Learning”, Science, Vol. 319, February 15, 2008.

[11] C. L. Phillips, J. M. Parr, and E. A. Riskin, *Signals, Systems, and Transforms*, 4th Edition, Pearson Education, Upper Saddle River, 2008.

[12] National Institute of Neurological Disorders and Stroke, “Brain Basics: Understanding Sleep”, U.S. Department of Health and Human Services, NIH Publication No. 08-3440-c, also available at: http://www.ninds.nih.gov/education/brochures/Brain-Basics-Sleep-6-10-08-pdf-508.pdf (visited in January, 2016)

[13] David A. Sousa, *How the Brain Learns*, Third Edition, pp. 51, Corwin Press, 2006.

[14] Oppenheim and A. Willsky, *Signals and Systems*, 2nd Edition, Prentice Hall, 1996.

[15] G. Hassoun, “Aliasing Errors in Engineering Education”, *9th World Congress on Engineering Education,* Beirut, Lebanon, 2013.

[16] B. Taylor, “Cheating Lessons, Part 2”, The Chronicle of Higher Education, July 8, 2013.