# Artificially Intelligent Method (AIM) for STEM-based Electrical Engineering Education and Pedagogy Case Study: Microelectronics

**Dr. Faycal Saffih, University of Waterloo**

Dr. Fayçal Saffih (IEEE, 2000) received B.Sc. (Best Honors) in Solid-State Physics from University of Sétif-1, Algeria, in 1996, M.Sc. degree in Bio-Physics from University of Malaya, Malaysia, in 1998, and Ph.D. degree in Electrical and Computer Engineering from the University of Waterloo, Canada, in 2005. In 2006, he joined the Communication Research Laboratory, McMaster University, Hamilton, ON, where he developed a versatile FPGA-based prototype for biomedical smart imaging application known as the wireless endoscopic capsule. Dr. Faycal Saffih joined Voxtel Inc., OR, USA, as Senior Analog Active Pixel Sensor engineer, designing imagers based on SOI-CMOS technology for high-energy physics particles detection, and electrons microscopy imaging. From 2009 until 2012, he joined KAUST as Research Fellow where incepted his invention on Smart Nano-photonic devices dedicated for imaging and solar energy harvesting. Dr. Saffih recently (March 2017) got certified from Renewables Academy (RENAC: www.renac.de), Germany, for developing Renewable Energy projects. Driven by his interest on Intelligence-Harvesting and (Physical- and Bio-) Mimicry, Dr. Saffih has published various papers in Imaging and suggesting AI application in pedagogy and education starting with his paper at 142nd ASEE International Conference, Columbus, OH, USA, on June 2017. To disseminate his research and teaching activities and findings, Dr. Saffih has launched his channel that can be accessed here: https://www.youtube.com/user/fsaffih

# Artificially-Intelligent Method (AIM) for STEM based Electrical Engineering Education and Pedagogy. Case study: Microelectronics


## ABSTRACT:

The teaching of microelectronic requires a multidisciplinary approach. This includes solid-state physics, microelectronics fabrication, electronic circuit analysis, Mathematics, and a good exposure on its applications. This is exactly what Science-Technology-Engineering-Math (STEM) curriculum is campaigning for to boost education and its impacts. These teaching dimensions, and intellectual faculties, are related to the nature of the subject itself which is just a one side of the "teaching coin" of the proposed Artificially-Intelligent Method (AIM) approach. The other side of this coin, which is common to all teaching disciplines, involves a good understanding of "learning psychology" of the students in addition to their socio-cultural conditions and realities. In the present paper, both facets of the AIM teaching coin are presented and more specifically how to use the associative nature of the student's memory to enhance their revision and "in-class understanding moment" recall performance which in turns enhance their knowledge acquisition of the subject.



## KEYWORDS:

**Artificially-Intelligent teaching, Multidimensional blended teaching/learning, intelligent teaching/learning, STEM curriculum/teaching, smart learning**


## INTRODUCTION

Education is one of the most, if not the most, vital process for preparing young future generations to take over to move mankind forward to a better future development as well as facing the growing challenges that grow with increasing population and its impact on this planet. However, education is also a complex system that involves many observables and hidden factors both of which are assessable and non-assessable starting with the psychology[1] of the student and finishing with his/her grade assessments analysis. Optimizing this complex system to achieve its goals of educating, engaging and put-on-track the students for their future endeavors, is obviously not an easy task and it is, by its nature, very dynamic due to the fast changes affecting modern societies with emerging technologies and their impact on their users. Therefore, education is, and will continue to be, a continuous (non-stop) and cyclical task, involving revisiting the foundations of education and its tools.

From this big picture of education, the focus of this paper will be on the segment of "course delivery" and engaging students to make it as efficient as possible to assure the "knowledge transfer" aspect of the education process. In addition, considering the complexity nature of engineering disciplines themselves, teaching such subjects needs an integral approach. In this holistic view, and for engaging students in engineering topics, other disciplines need to be called and used to convey the course, namely mathematics and other sciences backed by technological realities and advancements. This is a very similar approach to the science-technology-engineering-

[1] Thus, is the focus on the pedagogy of learning in this paper through the "*learning moment*" recording/recalling

mathematics STEM curriculum program [1] launched by the U.S. Department of Education since 2009 and which is expected to have a positive impact on U.S. economy providing much needed skillful workers[2]. The U.S. Department of Education define excellently STEM mission by following. "The United States has developed as a global leader, in large part, through the genius and hard work of its scientists, engineers, and innovators. In a world that's becoming increasingly complex, where success is driven not only by *what* you know, but by what you *can do* with what you know, it's more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information. These are the types of skills that students learn by studying science, technology, engineering, and math—subjects collectively known as STEM" [3]. This integral approach of combining various disciplines in teaching engineering courses is coined as "blended learning" as it blends various fields in teaching an engineering course and as referenced in [1] at young ages and up to high school level and beyond!

In the present paper, an artificially-intelligent blended learning method is proposed, applied and analyzed for future recommendation and development. Firstly, the application subject namely the course used to implement and carry the suggested approach is presented. In the following section, the suggested pedagogical approach's plan is laid out and justified to serve the set goals. Finally, and after implementing the proposed holistic pedagogical approach, a quantitative and qualitative assessment of the suggested blended teaching method is discussed followed by a conclusive section along with recommended future work, part of which is currently undertaken. It is worth mentioning that the suggested pedagogical methodology was the core of the author's project on Smart Learning course transformation project (CTP) presented to Center for Excellence in Teaching and Learning (CETL) at UAE University in the spring semester of 2017 [4]. The presentation was welcomed by the attending faculty members of the College of Engineering[5].

## AREA OF APPLICATION

The area of the suggested intelligent teaching/learning method is microelectronics which is outcome fruit of the great advancements of solid-state physics since the mid-1950's with the emergence of Silicon transistors[6][7], 10 years only after adopting this field under the this name by the American Physical Society [6]. This shows the science-origin of microelectronics and therefore the need of solid-state physics in explaining and analyzing its microelectronics phenomena and outcomes. In fact, solid-state physics is always the first chapter in teaching microelectronics!

It is worth-mentioning that solid-state physics itself could not reach its amazing advancements without theoretical physics that itself is strongly founded on mathematics, which consequently has a great importance as useful tool in microelectronic circuits and devices' I/V characteristic analysis. Therefore, and without any stretching microelectronic education represent one of the best (if not the best) applications of STEM curriculum and its "field-based blended" learning. Previous attempts to blend mathematics with microelectronics was suggested [8] which represent the first step attempted toward endorsing the full STEM curriculum.

In addition, another type of blended learning is added to mix to make up the suggested AIM approach namely the digital type. This electronic type of delivering the course is a "media-based

blended learning" by integrating an audio-visual source of learning for delivering the course content this time through an on-line channel. This type of learning is similar (if used separately) to eLearning pedagogy, however, in contrast to its definition[2], in our case it is used in conjunction (and as a backup) to the off-line (in-class) learning.

## PLAN OF APPLICATION OF AIM TEACHING METHOD

The new blending technique added to the suggested intelligent teaching approach is explained in the application part of the proposed teaching/learning method. This blending technique is based on recording a class that the teacher, who is the author of the present paper, offered for a course titled "Fundamentals of Microelectronics" during fall and spring semester of 2016 and 2017 respectively at the UAE University, and post it on a YouTube channel [9], [10]. The course outcomes are summarized in the following:

1. Explore basics of semiconductor materials and electrical characteristics
2. Investigate and analyze diode characteristics and diode based circuits
3. Investigate and analyze MOSFET structure, electrical characteristics, DC biasing and the use of MOSFET as switch and amplifier
4. Investigate and analyze BJT structure, electrical characteristics, DC biasing and the use of BJT as switch and amplifier
5. Utilize simulation tools to analyze bias point, DC sweep and perform transient analysis.

In this course, the students will be exposed rapidly to solid-state physics of semiconductors before applying that knowledge into the basic microelectronic devices namely the PN junction diode. The student will then learn and appreciate importance of modeling in studying PN junction diodes and their circuits involving Math and electrical engineering. The same structure of subject learning is translated towards MOSFET and BJT transistors study. For all these devices, a good exposure in Technological application with both recoded laboratory experiments and videos of interest from YouTube channel are shown in class.

It worth noting that AIM suggested pedagogy and its supporting channel is not Web2.0[3] as it might seem to be because the channel is meant for a social media platform. The course channel is merely a public storage medium where students, not only of the local level but also at the international stage, can have access to review the course content. Therefore, the student not only will be attending the class for in-class off-line learning but will find that very "*learning moment*" recorded! This is what we coin as "learning-moment" recording which will help the "recalling" process of the student later on when revision is undertaken. This "associative memory" [11] between the "leaning moment" and the "knowledge" being taught at that "particular moment" is very important in enhancing and easing the recall, understanding and further information processing of the knowledge being learnt at that moment in class. This feedback loop is one of the major pillars of artificially embedding intelligence in the learning process as suggested by the

[2] learning conducted via electronic media, typically on the Internet.

[3] Web 2.0 describes World Wide Web websites that emphasize user-generated content such as social media

research-driven teaching philosophy discussed in [12] and inspired by Bidirectional Associative Memories (BAM) originally proposed by Kosko [13].

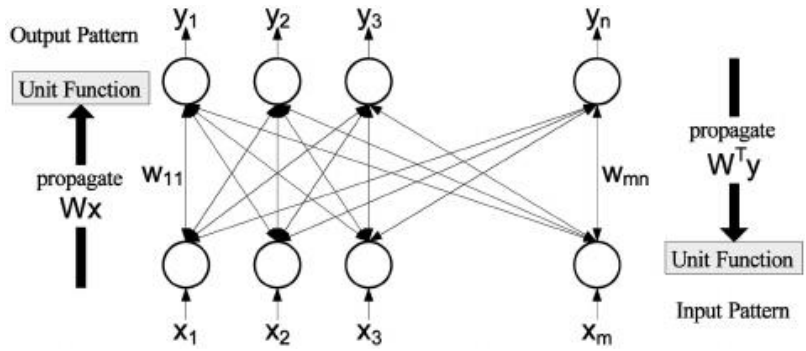



*Figure 1. Bidirectional Associative Memory artificial neural network[13].*

Figure 1 shows a general view of the artificial neural network of a BAM in which there are two layers of neurons; the X layer and Y layer each of which is an input and output for the network interconnected by feedback loops with specific synaptic strengths (which are where the memories are stored). The main objective of this intelligent memory is to associate a memory presented on X layer to that presented on the Y layer and store it into the feedback synaptic strength connections relating the two neural layers. This operation happens in the learning phase. In the processing phase, once the learning has been culminated, the user can present a distorted information of a stored memory to the X layer, for example, and the BAM artificial neural network will pass the neural information back and forth between the two neural layers updating their values through the influence of the interconnection of the synaptic strengths. This dynamic will settle eventually by not only the closed information to the initial input but also with the associated information of the input as stored in the learning phase! This heuristic solution (memory recall) is however not always achievable as other energy minima can trap the neural dynamics, into what is called spurious states that do not correspond to a stored memory, i.e. the artificial neural network like the biological is not perfect in every memory recall attempt.

The novelty suggested herein is to take above-mentioned memory recalling and apply it on the brain neurons of the students themselves to enhance their revision efficiency as explained below.

The blending (i.e. association) of in-class (off-line) and off-class (on-line) does nothing but enhancing the memory recall process which is very important to the student to recall the concepts taught in class. Therefore, in analogy to the BAM associative memory, the neurons' layers X and Y represent the in-class student's **experience** neuronal activity (including attention, sound, discussions…etc.), video-recorded for off-class review, and the student's **understanding** neuronal activity when grasping knowledge during class. This association of neuronal experiences becomes very valuable when the student reviews that class by watching it online, which will recall, hopefully, not only the *learning moment* but also that moment's associated understanding, which is the goal of the revision itself! This artificial neural network inspired pedagogy is exactly the reason behind naming the suggested pedagogy AIM as it was inspired by BAM intelligent memory and its recalling dynamics.

The STEM-based blended teaching/learning was implemented in the course by embedding mathematical analysis whenever a certain physical phenomenon is not well understood intuitively. This was applied for example in the case of the dependence of the PN junction barrier voltage $V_o$ on the temperature $T$. The equation of $V_o$ is:

$$V_o = \left(V_T = {}^{KT}/_{q}\right) \times ln\left({}^{N_A N_D}/_{n_i^2}\right) \ldots. (1)$$

The first term of $V_o$ is increasing with temperature while the second term is decreasing with temperature and a simple mathematical analytical demonstration reveals the winner in this "competing" process when the temperature increases as shown in [14]. This step is then blended with an experimental engineering demonstration in the laboratory whereby the students could see the effect right in from of their eyes with a pre-recorded video [15] to show the mathematical prediction proven with and experimental measurement. This blending of the **E**ngineering experiment with the **S**cientific theory and with **M**athematical analysis to understand an important **T**echnological device such as a diode [16], [17]) (which is the most fundamental device of microelectronics) is a strong demonstrator of STEM blended learning in AIM pedagogy.

In summary, in the suggested artificially-intelligent method (AIM) blended learning, two blended teaching/learning techniques have been used to lay the foundation of microelectronics in the minds of students, one during the class lecture itself using STEM approach (in-class) while other based on artificial intelligence recalling process supporting "memory recall" for the off-class revision as shown by the red arrows in the diagram of Figure 2 and explained previously.

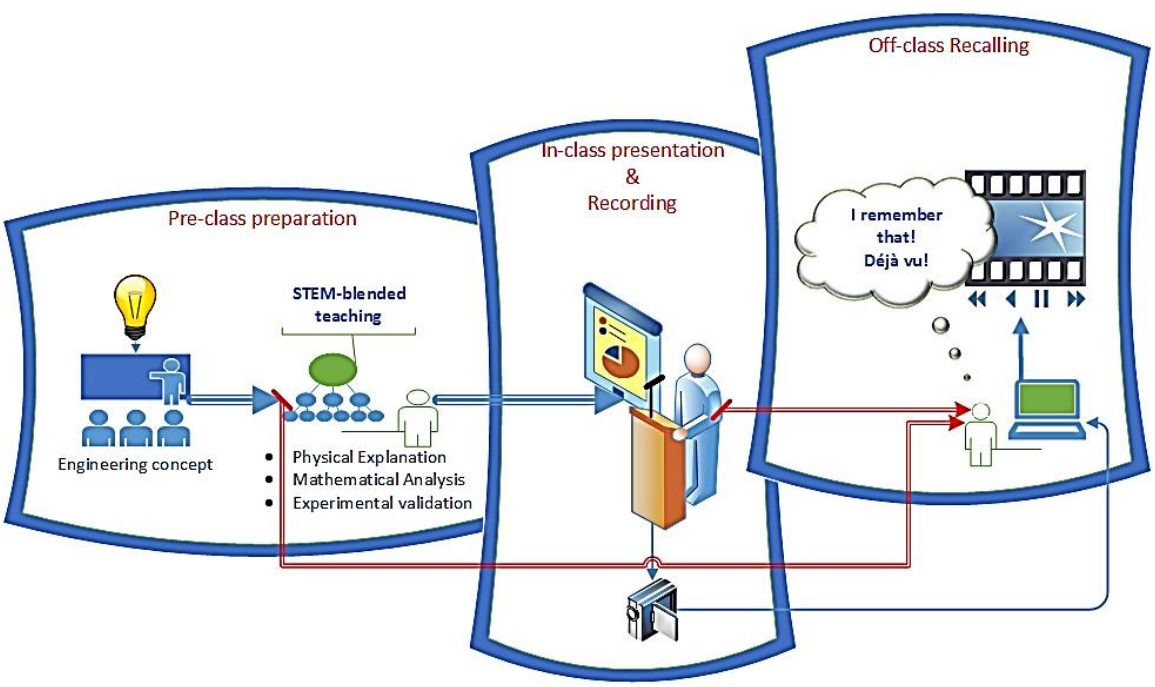



*Figure 2. Multidimensional Blended Learning of the suggested AIM approach*

Furthermore, the designed approach has been used by the students to take it to another level for off-class revision. In this level, the student will go back to the recorded class (in the course channel [9]) and revisit that "particular moment" where he/she did not understand the delivered concept and ask about it. The teacher (the author) goes to the recorded material to get the indicated moment and the question to explained the ambiguity to the requester. This off-class online QA interaction between the teacher (instructor) and the student is well portrayed in Figure 3 and posted in [18].

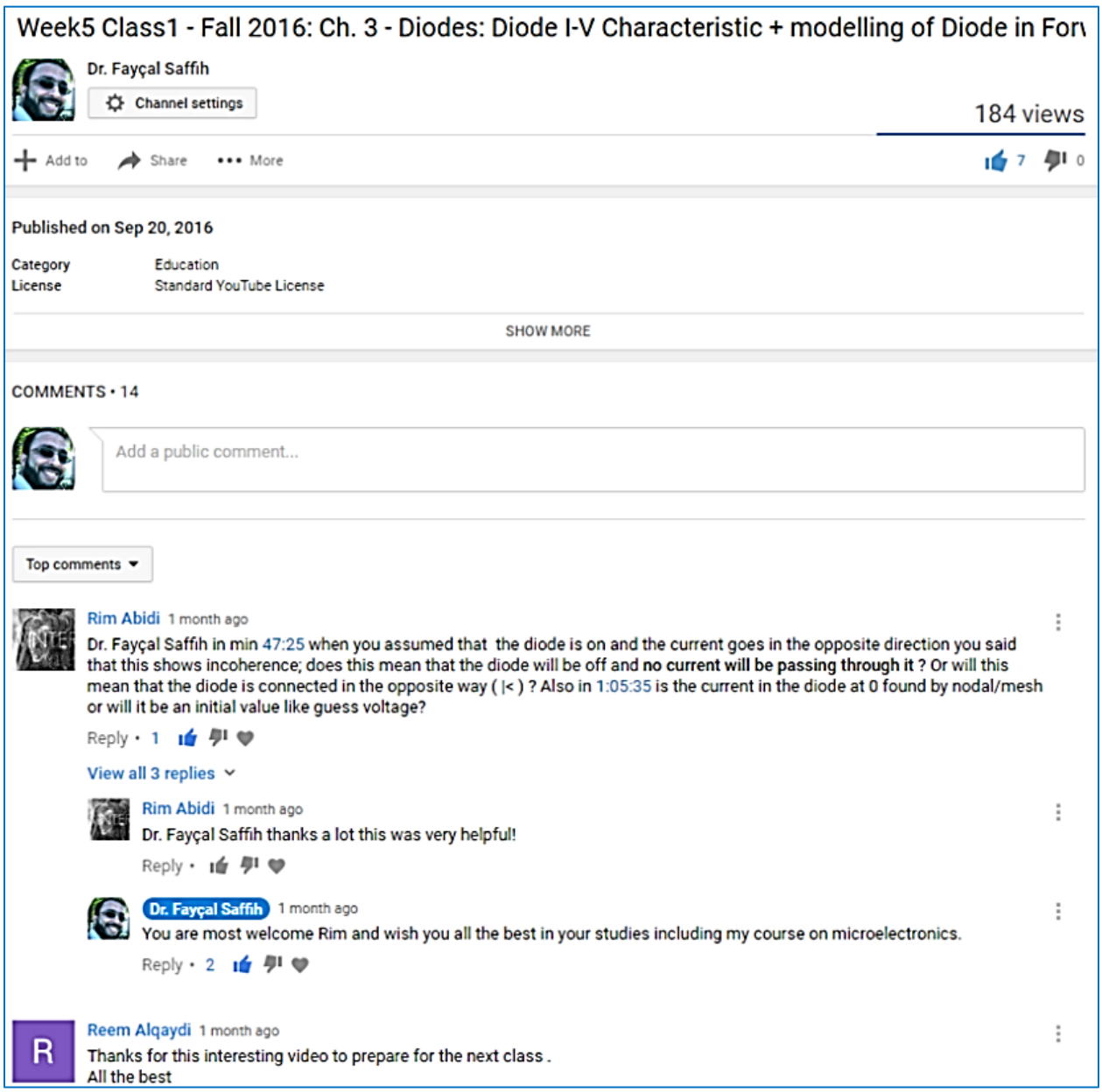



*Figure 3. Off-class online interaction using the suggested AIM approach [18].*

## AIM PEDAGOGY POSITION

AIM pedagogy is different from other popular blended learning pedagogies such as flipped and mixed mode classrooms. Figure 4 depicts flipped classroom as it flips between homework and classwork locations thanks to the readily available classroom online resources[19].

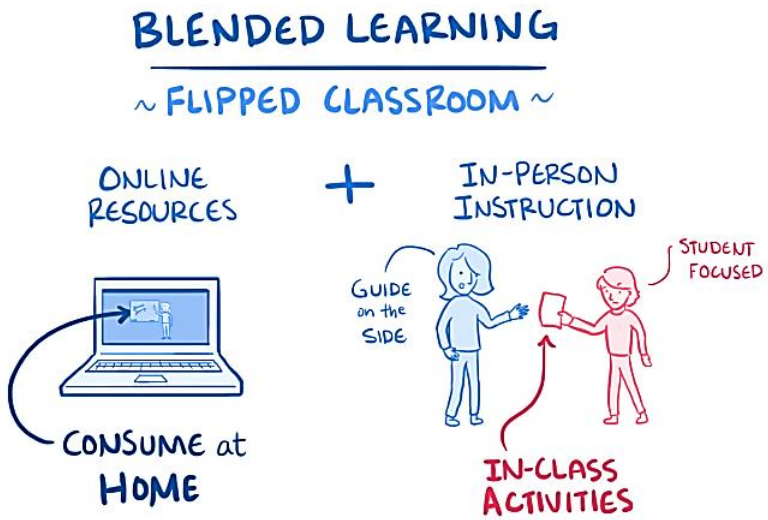



*Figure 4. Flipped classroom[19]*

Clearly AIM is not a flipped classroom concept as it does not do the flipping mechanism and keeps the classical course delivery scheme. Mixed mode classroom, on the side, is a Web based teaching pedagogy whereby traditional face-to-face learning is combined with learning at a distance through the Web in a structured fashion[20]. Our AIM pedagogy is also different from this concept as the learning is based on face-to-face and no Web based teaching is offered except the recoded experience of the learning experience.

In conclusion, the suggested AIM pedagogical method keeps the traditional face-to-face teaching as it keeps the class at a deterministic level of understanding while it gives students, some of whom might have difficulties catching up, the opportunity to review the learning material and the *learning moment*. This association between these two facets of classroom learning (knowledge grasping and *learning moment*) is very beneficial to students as their natural memorization works best by association which explains the call for the BAM intelligent memory analogy.

## QUANTITATIVE ASSESSMENT OF AIM TEACHING METHOD

The proposed AIM multidimensional teaching/learning method has been assessed during the whole fall semester of 2016 by carrying anonymous surveys and observing the viewing activity of the course channel. The survey has been carried out on two separate occasions; pre-midterm and pre-final exams. In addition, a formal survey carried by the hosting university has also been accomplished. Among other question, the following two questions, related to the proposed AIM blended learning, were asked:

1. Is blended learning: very useful, useful, average, not useful or very bad idea all together?

2. In terms of usage time, how do you study this course from the following resources: textbook, PDF slides and the course channel? The student then was given the choice between 5 options: never, rarely, sometimes, “most of the time” and only.

In the following figures, a histogram of the response of the students is depicted and discussed: Figure 5 represents the collected pre-midterm feedback while Figure 6 represents the collected feedback in the pre-final.

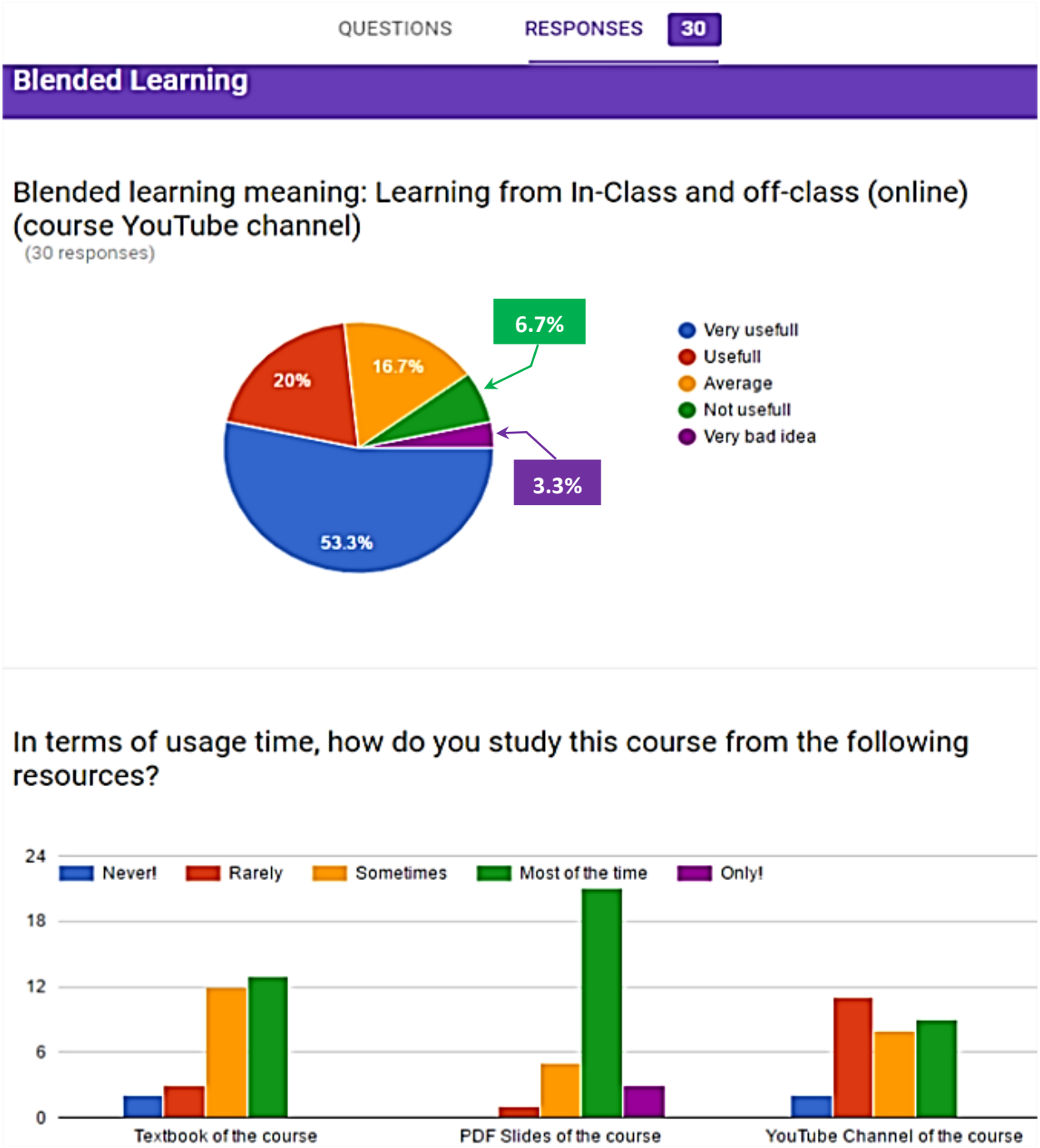



*Figure 5. Pre-midterm exam AIM method assessment feedback*

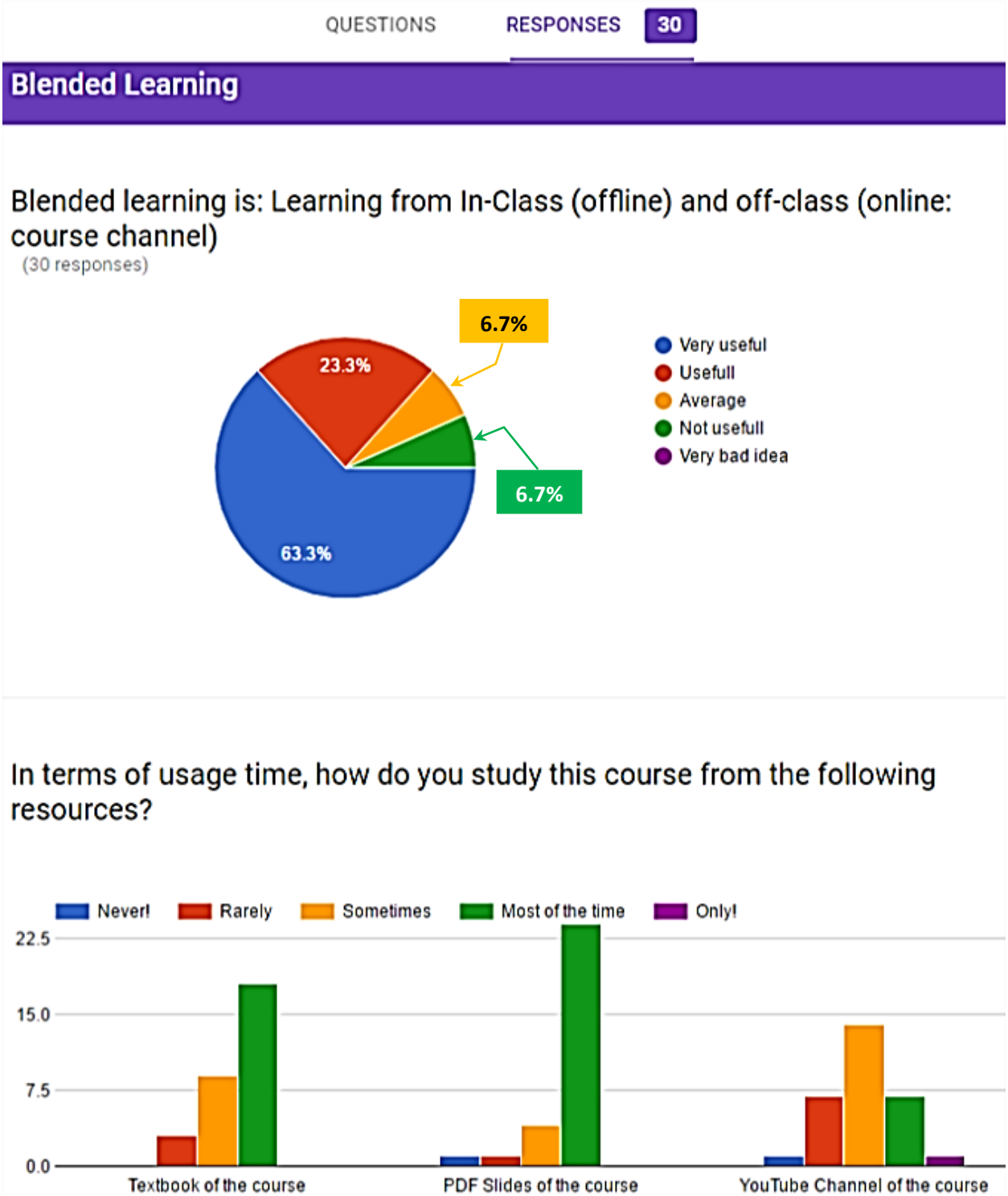


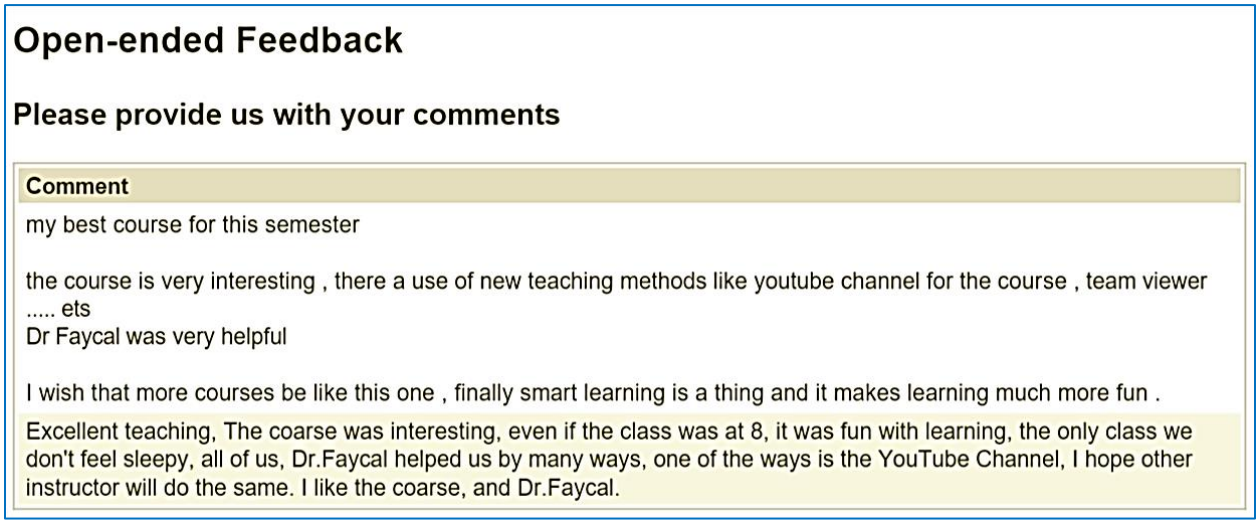

*Figure 6. Pre-final exam AIM method assessment feedback*

Regarding the first question, the students found the proposed AIM blended learning useful at 73% and 86.6% in pre-midterm and pre-final consecutively, which demonstrate the increasing usefulness of the technique as the students go deeper into the course.

As for the second question, and if the reader focus on the “most of the time” used way of revision, the reader will notice the same order of importance: PDF slides, then the textbook and finally the course channel. This comes as neither surprising nor in contradiction with the previous finding. This is because the student when revising uses the most condensed and concise form of the course material namely the presentation slides. If the student got stuck at this stage, the student turns to the second most dense form namely the textbook and if still not satisfied, the ultimate and final recourse is the channel. As the goal of the student is to refresh his/her memory of the course understanding, the student (like any physical system) routes through the least energy-time consuming path imitating how a mechanical system follows the Principle of Least Action in its dynamics [21].

However, this does not make AIM blended learning the least useful (remember that students are ordering their revision tools only herein!), to the contrary, this blended learning is deemed vital to them especially at the end of the course as shown by the increased “very useful” choice of AIM by the students from 73% (pre-midterm exam) to 87% (pre-final exam)!

Finally, it is worth mentioning the great impact the STEM-AIM multidimensional blended learning/teaching technique on the students from their snapshotted comments shown in Figure 7 below taken from their full University-based course evaluation that can be view form [22].



**Open-ended Feedback**

**Please provide us with your comments**

| Comment |
| --- |
| my best course for this semester<br><br>the course is very interesting , there a use of new teaching methods like youtube channel for the course , team viewer ..... ets<br>Dr Faycal was very helpful<br><br>I wish that more courses be like this one , finally smart learning is a thing and it makes learning much more fun . |
| Excellent teaching, The coarse was interesting, even if the class was at 8, it was fun with learning, the only class we don't feel sleepy, all of us, Dr.Faycal helped us by many ways, one of the ways is the YouTube Channel, I hope other instructor will do the same. I like the coarse, and Dr.Faycal. |

*Figure 7. Students comments after STEM-AIM introduction in Microelectronics class [22].*

To fully assess the impact of the proposed AIM pedagogy, further surveys and even clinical experiments might be necessary to single out its effect on the students’ performance. Grades which are the convolution of many factors surrounding the students learning experience, cannot be, however, used as a fair assessment tool. The above surveys, therefore, show the importance and usefulness of the AIM pedagogy to the students which seems to increase as the course material increases.

## CONCLUSION AND FUTURE SUGGESTIONS

The suggested AIM blended learning technique has been presented. It has been shown, that AIM was important on strengthening the understanding of the physical and technological realities and on engaging and enforcing the recalling process of the students learnt concept. Not only it provided the platform for recalling the learnt concept but also as a medium for interaction between the instructor and the students who found the suggested approach very supportive as the course grows in complexity and details.

Further analysis and studies need to be undertaken in this promising direction which is the next planned steps for future studies of this kind of smart learning pedagogies.

## REFERENCES:


[1] http://www.livescience.com/43296-what-is-stem-education.html

[2] http://stemconnector.org/publications/publications-resources/

[3] https:/www.ed.gov/stem

[4] http://bit.ly/CTP_presentation_by_Dr_FaycalS-Feb26_2017

[5] http://bit.ly/UAEU-COE_CTP-Welcome_Spring2017

[6] Martin, Joseph D. (2015). "What's in a Name Change? Solid State Physics, Condensed Matter Physics, and Materials Science". Physics in Perspective. 17 (1): 3–32

[7] Hoddeson, Lillian; et al. (1992). Out of the Crystal Maze: Chapters from The History of Solid State Physics. Oxford University Press.

[8] Colin Campbell, Fayçal Saffih, and Khaled Nigim, "*Improve Learning Efficiency with Integrated Math and Circuit Simulation Tools in Electrical and Computer Engineering Courses*". 2006 Annual Conference & Exposition of the American Society for Engineering Education (ASEE), Chicago, Illinois, June 2006.

[9] http://bit.ly/Fundamental_of_Microelectronics_by_Dr_Faycal-Saffih_Fall2016

[10] http://bit.ly/Fundamental_of_Microelectronics_by_Dr_Faycal-Saffih_Spring2017

[11] Fayçal Saffih, W. A. T. Wan Abdullah, Z. A. Ibrahim, A. Iftekhar, "*Parallel Learning-Processing for Artificial Neural Networks Implementation*" Scientific International, 10 (3), Kuala Lumpur, Malaysia, at ISO 98, 7-9 May, 1998.

[12] http://bit.ly/Dr_Faycal-Saffih_Research_Driven_Teaching_Philosophy

[13] B. Kosko, "Bidirectional associative memories," in IEEE Transactions on Systems, Man, and Cybernetics, vol. 18, no. 1, pp. 49-60, Jan/Feb 1988.

[14] http://bit.ly/Mathematical_Proof

[15] http://bit.ly/Experimental_Proof

[16] http://bit.ly/Special_Diodes_Class-Dr_FaycalS

[17] http://bit.ly/Special_Diodes_Lab-Dr_FaycalS

[18] http://bit.ly/off-class_online_AIM-Blended-Teaching

[19] https://www.osmosis.org/

[20] Jane E. Klobas, Stefano Renzi, "A Classification of Approaches to Web-Enhanced Learning", Encyclopedia of Information Science and Technology, 2nd ed., 2009.

[21] http://www.feynmanlectures.caltech.edu/II_19.html

[22] http://bit.ly/FM_Fall2016-Student_Evaluation