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Teaching and Research – How the Duo are not Mutually Exclusive

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Abstract— Teaching and research in academia have long been viewed as two different fields with a fuzzy, if not crisp, boundary. Nonetheless, the past few years have witnessed encouraging acceptance of their nature of complementing each other, rather than mutually exclusive endeavors. This paper highlights the dynamic relationship between these two essential pillars of higher education and presents some case studies to support the hypothesis. It also discusses how students stand to gain from the integration of Research-informed teaching pedagogy and effective usage of modern simulation, modeling, and analytical computer-aided design tools. The paper also underscores the need for higher technical educational institutes to develop a sustainable ecosystem where educators find these roles supporting each other and seamlessly transition between the two. The various takeaways of the case studies presented here assuredly suggest the potential benefits of research-enabled pedagogical practices in enriching students learning and improving retention capabilities.

Keywords: Teaching, Research, Higher Education, Modern-tools Usage, Improved Learning

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1. Introduction

Higher education institutes are continuously showing their interest and taking different measures to ensure quality education and improved student learning. These measures commonly include revision of course curriculum and inducting new courses, inculcating outcome-based education, enhanced use of information and communication technologies (ICT) tools, a few to name. Additionally, second decade of the current century also witnessed a sudden interest towards research and related activities to enrich the institute offerings. This trend further picked up to fulfil the specific criterion mandated by accreditation and governing bodies in India. In either way, this is helping all the stakeholders and fostering diverse learning experience and exploring new career dimensions, among students.

However, it is worth to mention that historically teaching and research were considered as two independent endeavors having zero relationship (Hattie & Marsh, 1996). The authors (Hattie & Marsh, 1996) reviewed various teaching and research relationship models to support the claim but, also advocated universities to devise strategies which enables positive synergies between the two. Consequently, relations between teaching and research were further investigated by Jenkins (Jenkins, 2004). Boyer, in his book 'Scholarship Reconsidered' (Boyer, 1990) advocated the enhanced role of scholarship to bridge the gap between teaching and research. The authors (Boyer, 1990) further proposed four critical attributes—discovery, integration, application or engagement, and teaching for scholarly teaching, popularly known as Boyer's theory of teaching and learning.

Amidst the ongoing discussions for establishing a potential relationship between teaching and research, if any, focus now looks shifted towards research-informed teaching (Pan et al., 2012). In addition, in one study authors (Brew & Boud, 1995) suggested more emphasis on the ways of knowledge generation and its effective delivery. And underlined important relationship between different aspects of teaching which leads to learning and the learning which occurs through research. In the backdrop of diverse demography of learners, adaptive teaching and its effects on learning outcomes was also discussed by authors in (Feser et al., 2019). These innovations and their appropriate adoption in teaching and learning are presently more critical in technical education in India. Facing the challenges on two key fronts like low employability quotient of engineering graduates and new demands from emerging Industry 5.0, technical education in India is also experiencing a paradigm shift in teaching learning processes. Furthermore, to keep pace with technological dynamism and fostering entrepreneurship culture among engineering graduates, research-informed or evidence-based teaching can efficiently facilitate quality teaching through transformation of learning process with the help of technology driven teaching pedagogies (TDTP).

This paper presents integration of modern Technology Computer-Aided Design (TCAD) tools in different phases of instructions in semiconductor device and physics course. Here, MathWorks's MATLAB—a numeric computational tool is used to efficiently compute numerical values of a parameter related by multiple parameters in a complex relationship.

Additionally, Silvaco's Atlas—a two-dimensional (2D) device simulation TCAD tool is used to demonstrate the already calculated parameters using MATLAB. Furthermore, this tool also provides various insights of physical parameters related to the device under study. The underlying topics are illustrated here to underline the possible use of suitable TCAD tools in effective demonstration of the theoretical concepts related to the topic. It also helps in multistep verification of end results and further facilitates subsequent analysis of the results.
These demonstrations are expected to put device theory in practice and help learners to visualize the concepts and theory of the underlying topic. Research enabled learnings are integrated into teaching and employed in successful demonstration of following case studies.

2. Demonstration of Successful Integration

A. Intrinsic Carrier Concentration in Silicon Semiconductor

At room temperature, 300 K (27°C), the value of intrinsic carrier concentration ni in Silicon (Si) is approximately 10^{10} cm^{-3} and can be obtained using following relation.

$$n_i^2 = N_C N_V \, e^{(E_V - E_C)/k.T} \tag{1}$$

To get the n_i value, parameters in the right-hand side like effective density of states in conduction band (N_C) and in valence band (N_V) at room temperature are calculate as follows. The term ($E_C - E_V$) is energy bandgap of Si.

$$N_C(T) = 2((2\pi m_e^* kT)/h^2)^{3/2} \tag{2}$$

$$N_V(T) = 2((2\pi m_h^* kT)/h^2)^{3/2} \tag{3}$$

And effective mass for electrons and holes are given by following relations.

$$m_e^* = 1.18 m_e e18 \tag{4}$$

$$m_h^* = 1.18 m_h 6.24e18 \tag{5}$$

Where, m_e and m_h are effective mass for electrons and holes, respectively. k is the Boltzmann constant, h is Plank's value constant, and T is equal to room temperature value. The value of n_i is calculated in bottom-up approach manner as represented in Figure 1.

This part of the demonstration is done using MATLAB (MATLAB, 2018); however, any other suitable tool can also be used. It is also understood that here all values can be also calculated manually using pen and paper. Nonetheless, these TCAD tools provides extra degree of freedom and facilitates learners for exploring more challenging and complex problems. Once script for the underlying problem is written, analyzing effects of independent variables on end results are quite easy. It is also worth noting that language syntax of these tools is quite simple for a beginner also. After calculation result in terms of n_i value is shown in Figure 1 (right), and is equal to 9.95×10^{15} m^{-3} or 9.95×10^{9} cm^{-3}, which is almost same as $n_i = 1.0 \times 10^{10}$ cm^{-3} widely reported and used in (Halkias, 1973; Nashelsky, 2021; Neamen, 2006; Streetman & Kumar Banerjee, 2006).

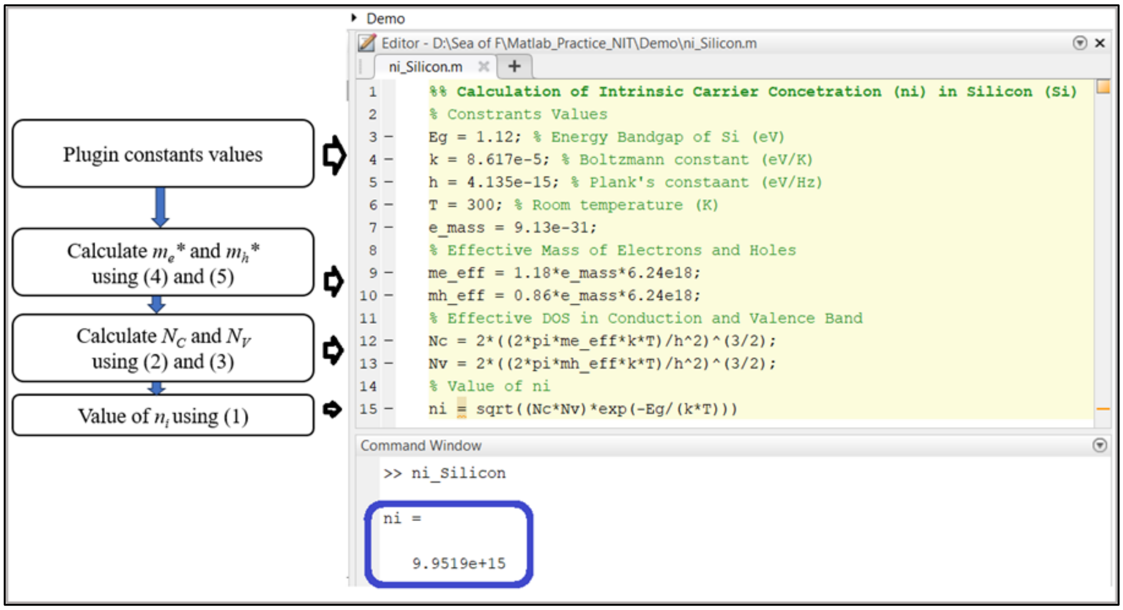

Figure 1: Calculation of ni following the steps (left) and result using MATLAB (right).

All the rest intermediate values of all the parameters are also readily available in MATLAB workspace for any further analysis. Any type of further processing like plotting and other mathematical analysis of the results help learners enhanced learning experiences.

B. Intrinsic Carrier Concentration and Energy Bandgap in Silicon

Second stage of demonstrations are done using another 2-D physics-based device simulator—SILVACO Atlas (Silvaco, 2019), other similar tools are also available. This TCAD tool provide electronic device process simulation and variety of studies like electrostatic, thermal analysis, and reliability-related, to name a few. Here, the demonstration of value of intrinsic carrier concentration (n_i) and energy bandgap (E_g) in Si are presented. These two parameters in Silicon semiconductor are presented under default material properties in Atlas as well as user-defined parameters of Silicon semiconductor calculated in previous section.

Figure 2 shows the simulation deck in which structure area has been defined first, followed by material type and solutions in thermal equilibrium. It should be noted that default Silicon properties like E_g, N_C, N_V (circled in blue box) resulted in electron as well as hole concertation *i.e.*, $n_i = 1.45 \times 10^{10}$ cm^{-3} which is not same as calculated in previous section. This is attributed to default values of E_g, N_C, N_V parameters of Silicon in Atlas material database, and are different from values of these parameters calculated earlier. The corresponding plot of n_i values is also shown along the x-axis in the Silicon material under study.

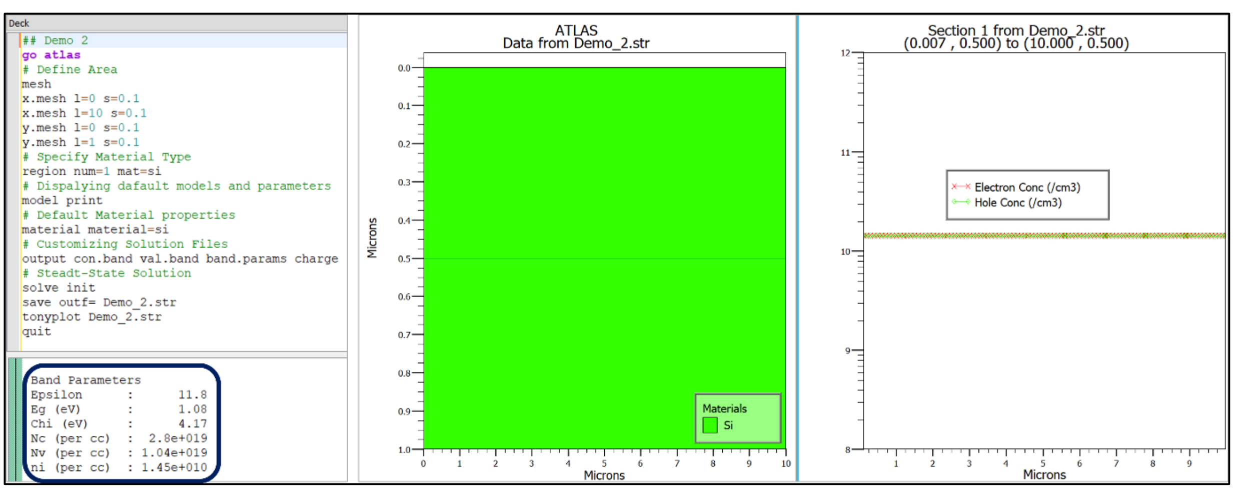

Figure 2: Atlas simulation deck (left), Silicon material structure simulated for steady-state solution (center), and plot of extracted ni values along x-axis in the Silicon material structure (right).

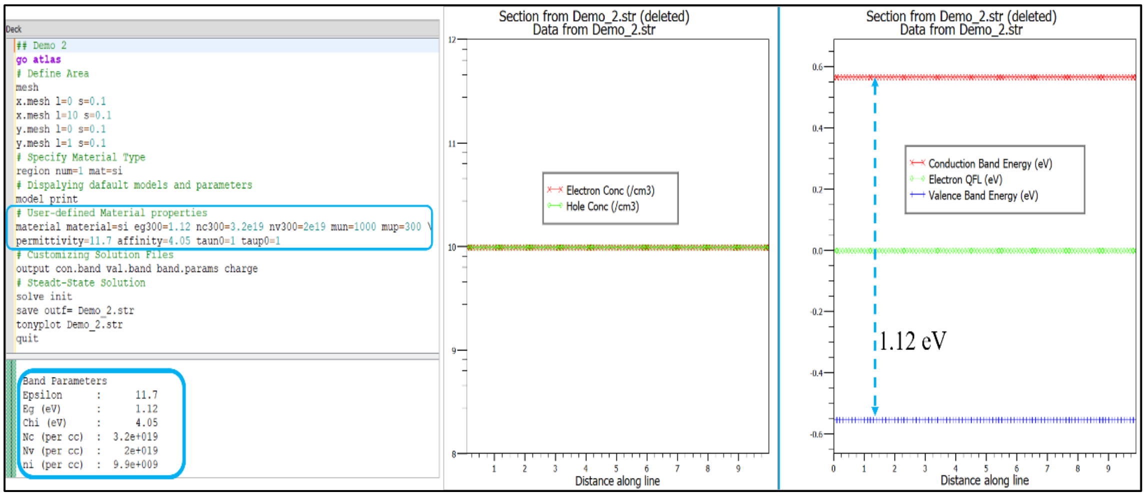

Figure 3: Simulation deck updated with already calculated Silicon key parameters (left), plot of ni along x-axis (center), and plot of conduction and valence band energy levels showing energy bandgap of 1.12 eV in Silicon semiconductor (right).

To remove this ambiguity in n_i values, some key default Silicon material properties are changed with the values already calculated earlier. Authors strongly highlight about this point and urge users to check and verify before processing the end results obtained from default simulator settings in any study. Figure 3 shows the results after updating simulation deck with key parameters of Silicon material changed as per the results obtained in previous section. Energy bandgap is also shown corresponding to the updated value of E_g *i.e.*, 1.12 eV. Now, the simulation deck results in $n_i \approx 1.0 \times 10^{10}$ cm^{-3} which is same as calculated earlier. Since n_i is also equal to electron and hole concentrations in steady state, all the three data show a single line in plot, Figure 3 (center).

Now, the simulation deck results in $n_i \approx 1.0 \times 10^{10}$ cm^{-3} which is same as calculated earlier. Since n_i is also equal to electron and hole concentrations in steady state, all the three data show a single line in plot, Figure 3 (center).

The two demonstrations presented above show how even primary-level integration of teaching and research provides engaged learning experience by shifting the paradigm from passive to active and participative learning. Additionally, adoption to these approaches encourage students in independent critical thinking, analyze the results in the given context, and pronounced understanding of underlying subject concepts. These practices show the potential to achieve higher-level cognitive skills over conventional teaching methods in an effective manner, Figure 4.

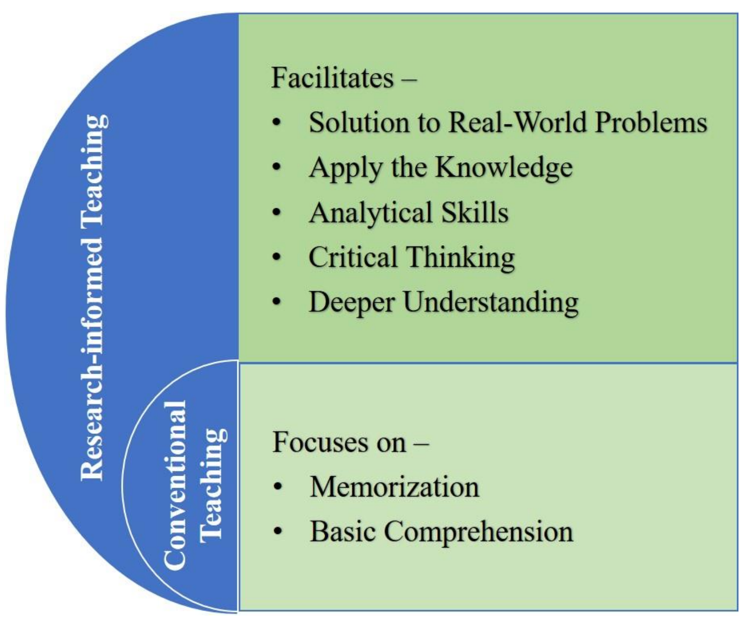

Figure 4: Potential benefits of research-enabled practices in teaching over conventional teaching in terms of cognitive skills

3. SOME COMMON CHALLENGES

Although the successful integration of research and teaching looks interesting and fruitful, some key challenges are also identified, and some are briefly discussed here.

1. Reluctance to Adopt – Out of all other possible challenges, reluctance among some teachers to adopt holistic research practices looks biggest barrier in the said context and show little to no interest in embracing research-informed innovative teaching methods. These resistances generally stem from familiarity with existing methodologies, lack of awareness of possible benefits, and lack collaborative of peer-learning environment, to name a few.
2. Resource and Time constraints – Although primary-level research-teaching integration may not require full-fledged resource-ready environment, letter stages of demonstrations and applications ask for fully-integrated hardware and software resources. Additionally, as research-based teaching requires more time in selection and planning, educators also find hard to meet expectations from other academic and non-academic responsibilities.
3. Technology and Infrastructure – As most of the higher technical institutions are mostly dependent on internal accruals for new-technology adoption and required infrastructure, in many cases out-date technologies and insufficient infrastructure facilities also hinder fostering research enabled learning environment.
4. Student Diversity and Discipline Differences – Research-enabled practices are bound to change in different disciplines, adopting these practices may vary from straightforward to quite tedious in some cases. Furthermore, diverse backgrounds, learning capabilities, and interest of students also need separate attention while implementing these policies.

4. CONCLUSION

In summary, these demonstrations show how research-enabled practices can help transform conventional teaching into quality teaching. Incorporating these practices into teaching help both educators as well as learners to develop critical thinking and analytical skills and facilitates the duo for possible application of knowledge and theoretical concepts into real-world problems. The demonstrations presented here show how integration of research and teaching can increase the students learning by increased retention as TCAD tools provide different interfaces which facilitate apply and verify and then explore it for possible solution of novel problems. It is also in-sync with concept of ‘learning by doing’—an effective teaching pedagogy to enhance the quality of education. Although, applications of the TCAD tools presented here is limited to primary levels only, authors believe that pronounced use of these tools in classroom teaching have the potential to help prepare the engineering graduates more industry ready. It also empowers the educators to bridge the gap between college education and industry practices. It is worth to mention that for other courses, any other appropriate TCAD tool can be used depending on the underlying topic.

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