Online learning games and simulations for photonic integrated circuit (PIC) sensor design and operation

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ABSTRACT

In this paper, we describe *Illuminator*, a digital, online game that offers students the opportunity to learn about the design and operation of sensors that employ integrated photonics. The game is level-based, providing students foundational concepts, and then building on that knowledge to offer progressively more difficult challenges. Though the game could theoretically stand alone, students are intended to play the game in the context of an online course, which was designed in concert with the game so that the game levels support the course material. *Illuminator* and its paired course are situated within an overall program designed to teach students about various application areas of integrated photonics via other courses, games, and simulations. *Illuminator* focuses primarily on absorption sensing, though also touches on index sensing.

Keywords: learning games, sensors, absorption sensing, simulations, methane

1. INTRODUCTION

Advanced manufacturing in optics and photonics enables an ambitious revitalization of industrial capacity for a 21st-century high-tech economy. In addition to creating a new technology infrastructure, there is a need to develop scalable digital learning tools built around interactive simulation environments. These digital training tools can increase engagement and learning outcomes for a global audience of optics and photonics students. MIT's Virtual Manufacturing Lab is training the modern advanced manufacturing workforce using: (i) online learning modules and courses, (ii) desktop VR tool-training simulations and photonics visualization tools, and (iii) application-focused educational games, increasing engagement for technician and engineering audiences.

Illuminator is a single player game designed to help students learn about sensor design, with a primary focus on absorption sensing. This paper goes into detail about one game, *Illuminator*, out of several that we created.

Photonic integrated circuits (PICs) are commonly used for chemical and biological sensing. A common technique is to monitor changes in the complex effective refractive index ($n^* = n + ik$) [1] of the confined electromagnetic wave travelling through the waveguide, also called a mode. The changes in n* occur due to interaction of the waveguide mode's evanescent tail (the part of the light that decays exponentially as one moves away from the waveguide), with the target chemical or biological species to be detected, as depicted in Figure 1.

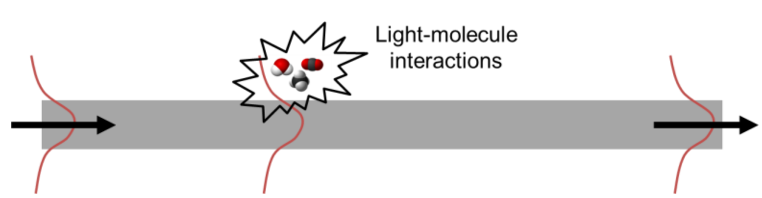

Figure 1. Electromagnetic wave travelling through a waveguide. The evanescent tail of the guided mode interacts with the molecules to be detected, modifying the mode's complex (effective) index of refraction.

When monitoring the real part (n), the method is called refractive index sensing (refractometry), and when the complex part (k) is monitored the technique is called absorption sensing. Both have distinct advantages and disadvantages. For example, refractive index sensing needs a sorbent layer or a functionalized coating to make the sensor specific. However, it is wavelength agnostic, hence convenient as it can be performed at wavelengths where sources and detectors

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are low cost and easily available. Absorption sensing is highly specific since absorption occurs only at select wavelengths depending on the frequency of molecular vibration. This typically occurs in the mid- and long-wave infrared wavelength range where light sources and photodetectors are expensive. In this game, students have an opportunity to explore both techniques and learn about trade-offs in sensitivity, specificity, wavelength choices, fabrication and component cost, and availability. Off-chip light sources and/or detectors are often used in sensor systems, so efficient coupling from off-chip to on-chip and vice versa, is critical [2]. Students are taught to select tapered couplers to enhance coupling.

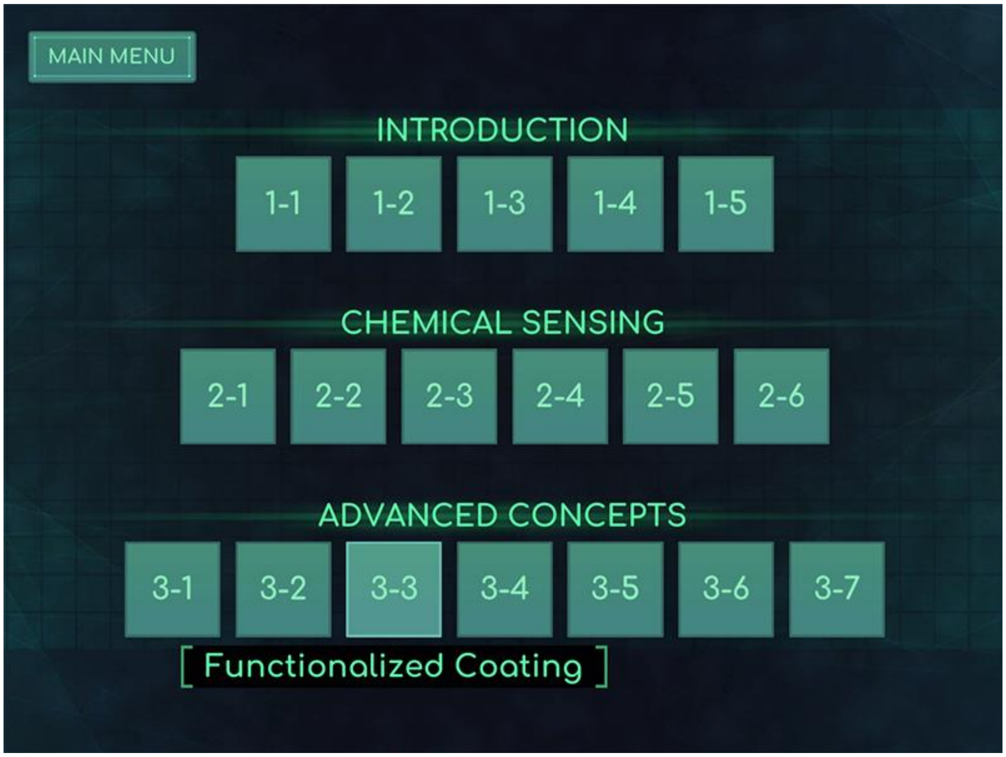

Figure 2. All the levels available in *Illuminator*, with the player hovering over level 3-3, showing the level title.

2. LEARNING GOALS

Illuminator is an original game design, created in active consultation with an MIT subject matter expert who co-created an online course focusing on PIC sensors. Therefore, the learning goals of the game, listed below, are chosen to closely align with the learning goals of the online course. Increase engagement with the matching online course material

- Increase familiarity with using integrated photonics in sensors
- Increase familiarity with specific integrated photonics components (e.g. ring resonator, spiral waveguide, etc.)
- Understand the SWAP-C tradeoffs for various components

3. LEVEL DETAILS

Describing every level (see Figure 2) in *Illuminator* is beyond the scope of this paper, but we will highlight two levels here and identify key features of those levels. The early levels in the game help the player learn the user interface and core elements of the game.

Figure 3 (next page) shows an early level of the game, where the player is quite limited in their selection of components, in the lower left of the screen. On later levels, the player can choose from many more options, including waveguide coupling structures, ring resonators, photodetectors, etc [3].

Figure 3. The player places a spiral waveguide component onto the PIC to complete the circuit.

Figure 4. The player has tested the circuit with methane present. They hover over a spiral waveguide, which shows details about light loss due to interface loss (none), material loss (-1.2 dB), and absorption loss (-5 dB).

In Figure 4, we see what it looks like after a player has built a circuit and begun testing it. The player can test with and without the presence of methane, or any other target chemical included on a given level. Most levels use methane, for consistency. Figure 4 shows what happens when the player hovers their mouse pointer over any part of the circuit – they get additional information about that piece of the circuit, and all the light loss that is occurring there.

In Figure 5, we see a zoomed-out view of the circuit, showing the context of the laser light [4] coming in, and the photodetectors at the end of the circuit. A significant portion of the game focuses on proper wavelength selection. In this level, the player is required to select the wavelength of light that will yield proper sensing results [5,6]. They are able to see the absorption spectrum data for methane in Figure 6 (next page). If they properly read the graph and understand what the graph means, then they will properly pick the 3240 nm wavelength of light, and the game will show the light being absorbed when exposed via a spiral waveguide or ring resonator. On the other hand, if the player does not pick the proper wavelength, the light will not be absorbed, and the player will not complete the level. At that point, the game offers context-sensitive hints, so the player can try again and fix their mistake. Furthermore, because the game offers a reasonably accurate model of light passing through the circuit, players can experiment in many ways, learning by playing and exploring.

Figure 5. The player chooses which wavelength of light to use for their laser.

Figure 6. The player sees the absorption spectrum data for methane, allowing them to pick the proper wavelength of light.

4. DEVELOPMENT TEAM

Illuminator was designed and developed by an internal team at MIT in collaboration with an external team at Fire Hose Games. The internal team included one game designer/project manager, one programmer for digital prototyping, and one primary subject matter expert. The team also consulted with additional subject matter experts as needed. The external team included one programmer, one artist, and one audio designer.

5. CONCLUSIONS AND FUTURE WORK

Illuminator will be tested in Fall 2022 in combination with the online course for which it was designed. Small scale tests were performed with a target audience of graduate students and students from a community college. Students played an early version of the game and their feedback was part of the iterative design process. We observed expected gameplay behaviors, such as building the circuit, testing it, and solving the challenge of a given level. Perhaps the most exciting observation was that many students spent considerably more time than we expected simply "playing" with the circuit simulation. The game offers players many options for building their circuit, and students seemed to enjoy that freedom and the creative expression it allowed [7].

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