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BURSA ULUDAG UNIVERSITY

INSTITUTE OF EDUCATIONAL SCIENCES

MATHEMATICS AND SCIENCE EDUCATION

DEPARTMENT OF SCIENCE EDUCATION

DETERMINING PHOTONICS EDUCATION FRAMEWORK FOR SCIENCE EDUCATION: A DELPHI STUDY

MASTER'S THESIS

Hümeyra Azize YALÇIN

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Danışman

Prof. Dr. Salih ÇEPNİ

BURSA - 2022

BİLİMSEL ETİĞE UYGUNLUK

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Hümeyra Azize YALÇIN

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"Determining Photonics Education Framework For Science Education: A Delphi Study" adlı Yüksek Lisans tezi, Bursa Uludağ Üniversitesi Eğitim Bilimleri Enstitüsü tez yazım kurallarına uygun olarak hazırlanmıştır.

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Determining Photonics Education Framework for Science Education: A Delphi Study

Yukarıda başlığı gösterilen tez çalışmamın a) Kapak sayfası, b) Giriş, c) Ana bölümler ve d) Sonuç kısımlarından oluşan toplam ………… sayfalık kısmına ilişkin, ……/……/…….. tarihinde şahsım tarafından .... (Turnitin)* adlı intihal tespit programından aşağıda belirtilen filtrelemeler uygulanarak alınmış olan özgünlük raporuna göre, tezimin benzerlik oranı % …..'tür.

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EĞİTİM BİLİMLERİ ENSTİTÜSÜ MÜDÜRLÜĞÜNE,

Matematik ve Fen Bilimleri Eğitimi Ana Bilim Dalı'nda 801851024 numara ile kayıtlı Hümeyra Azize YALÇIN'ın hazırladığı "Determining Photonics Education Framework for Science Education: A Delphi Study" konulu Yüksek Lisans çalışması ile ilgili tez savunma sınavı, ../../20… günü 0..:..-0..:.. saatleri arasında yapılmış, sorulan sorulara alınan cevaplar sonunda adayın tezinin (**başarılı/başarısız)** olduğuna (**oybirliği/oy çokluğu)** ile karar verilmiştir.

Sınav Komisyonu Başkanı
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Tez	Fen Bilimleri Eğitimine Yönelik Fotonik Eğitimi Çerçevesinin Belirlenmesi: Bir Delphi Çalışması
Tez Danışmanları	Prof. Dr. Salih ÇEPNİ, Doç. Dr. Umut AYDEMİR

FEN BİLİMLERİ EĞİTİMİNE YÖNELİK FOTONİK EĞİTİMİ ÇERÇEVESİNİN BELİRLENMESİ: BİR DELPHİ ÇALIŞMASI

Fotonik sağladığı yeşil çözümler ile sürdürülebilir bir gelecek sunmada birinci yüzyılın önemli bilim ve teknoloji alanıdır. Fotoniğin ve fotonik teknolojilerinin günlük hayatımızdaki yeri arttıkça bu alanda yetişmiş işgücüne ve bu alanda bilgi ve becerilerle donanmış, fayda ve zararlarını değerlendirebilen, gerektiğinde sosyopolitik konulara katılım gösterebilen vatandaşlara ihtiyaç artacaktır. Bahsedilen bu ihtiyacı karşılama eğitim önemli bir role sahiptir. Bu nedenle bu tezin amacı en kısa ifadesi ile fotonik eğitiminin nasıl olması gerektiğini araştırmaktır. Fotonik eğitimin en etkili şekilde sınıf ortamlarında nasıl verilebileceğini araştırmak amacıyla (1) fotonikle ilgili konu ve içerikler, (2) fotonik ve fotonik teknolojileriyle ilgili beceriler ve tutumlar (3) etkili öğretim süreçlerinin- öğretim yöntemi ve değerlendirme tekniklerinin– bu alandaki uzmanlarla tartışılmıştır. Araştırmada Delphi tekniği kullanılarak alanda uzman olarak belirlenen kişiler ile görüşmeler yapılmış ardından anket ile uzmanların fikir birliğine varmasına imkan sağlanmıştır. Alan uzmanları 3 alt gruptan oluşmaktadır: eğitimciler, fotonik alanında bilim insanları, fotonik sektör çalışanları. Araştırma sonuçları alan uzmanlarının fotonik eğitiminde fotoniğin bilim boyutunu vurgulamak için bilimin doğası ve bilim tarihinden faydalanmayı, teknoloji boyutu içinse günlük hayat örnekleri üzerinden konuların verilmesinin faydalı olacağını savunduklarını göstermektedir. Ayrıca laboratuvar dersleri, proje ve probleme dayalı metotlar ile öğrencilerde sorgulama, bilimsel ve analitik düşünme, problem çözme ve optik fotonik deney düzeneği tasarlayabilme gibi becerilerin kazandırılmasını önermişlerdir. Değerlendirmelerin de bu süreçlere eşlik edecek şekilde süreç, performans, proje ya da ürün odaklı, yöntemler ile ve bağlam ve deney temelli sorular yoluyla olması gerektiğini düşünmektedirler. Araştırmanın sonucunda bulgular özetlenerek bir *Fotonik Eğitim Çerçevesi* geliştirilmiştir. Ayrıca fotonik okuryazarlığına yönelik ihtiyacın saptanması ve çalışmaya ek değer kazandırılması adına *Fotonik Okuryazarlığı için Fotonik Eğitimi Çerçevesi* de fen okuryazarlığına ilişkin çalışmalar, literatür ve bu çalışmanın bulguları bir araya getirilerek oluşturulmuş ve sunulmuştur.

Anahtar Sözcükler: *Fen Eğitimi, Fotonik, Fotonik Eğitimi, Fotonik Okuryazarlığı, Fotonik Eğitim Çerçevesi,*

ABSTRACT

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DETERMINING PHOTONICS EDUCATION FRAMEWORK FOR SCIENCE EDUCATION: A DELPHI STUDY

Photonics is an important science and technology field of the twenty- first century in providing a sustainable future with the green solutions. As the place of photonics and photonic technologies in our daily lives increases, the need for a workforce trained in this field and citizens equipped with knowledge and skills in this field, who can evaluate its benefits and harms, and who can participate in socio-political issues when necessary, will increase. Education plays an important role in meeting this need. For this reason, the aim of this thesis is to investigate how photonics education should be. In order to investigate how photonics education can be delivered most effectively in classroom environments, (1) the subjects and contents related to photonics, (2) skills and attitudes related to photonics and photonic technologies, and (3) effective teaching processes-teaching methods and assessment techniques- were discussed with experts in this field. In the research, interviews were conducted with people who were determined as experts in the field by using the Delphi technique, and then the experts were allowed to reach a consensus with the questionnaire. Field experts consist of 3 sub-groups: educators, scientists in the field of photonics, workers in the photonics sector. The results of the research show that field experts advocate using the nature of science and the history of science in order to emphasize the science dimension of photonics in photonics education, and it would be beneficial to give the topics over daily life examples for the technology dimension. In addition, they suggested that students gain skills such as questioning, scientific and analytical thinking, problem solving and designing photonics experimental setups through laboratory courses, project-based and problem-based methods. They think that evaluations should be process, performance, project or product oriented, and suggests contextual-based and experiment-based questions to accompany these processes. As a result of the research, a *Photonics Education Framework* was developed by summarizing the findings. In addition, in order to determine the need for photonic literacy and to add additional value to the study, the *Photonics Education Framework for Photonics Literacy* was created and presented by bringing together studies on science literacy, reviewed literature and the findings of this study.

Keywords: *Photonics, Photonics Education, Photonics Education Framework, Photonics Literacy, Science Education*

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Hümeyra Azize YALÇIN

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LIST OF ABBREVIATIONS

ICT	: Information and Communications Technologies
MoE	: Ministry of Education
PE	: Photonics Education
STEM	: Science Technology Engineering Mathematics
OP	: Optics and Photonics

CHAPTER ONE

INTRODUCTION

In this section, based on the relevant literature the problem situation is explained and accordingly the purpose and the importance of the research, the research questions, assumptions, limitations in this study and definitions of the key words are given.

1.1. Problem Statement

We are living in an age of technology and communication. In 21st century, Photonics is one of the important science and technology area that accelerated. So much so that believed "the 21st century will depend as much on photonics as the 20th century depended on electronics and 19th century depended on steam power" (International Year of Light 2015, n.d).

Photonics and photonics technologies increase their place and importance in our lives day by day. Our awareness and efforts to understand these technologies that exist and will gain more place in our life, are open to discussion (Florensa, Marti, Kumar, & Carrasco, 2013). For this reason, it is important to develop teaching processes targeting first, to increase awareness and scientific literacy towards photonic and photonic technologies (Viera-González, Martínez-Contreras, Ponce-Hernández, & Sánchez-Guerrero, 2019), then develop scientific knowledge and skills that will provide workforce in these fields (Aydın et al., 2019; Bieber, Marchese, & Engelberg, 2005; Nof et al., 2013).

In the near future, the demand for qualified personnel in the Photonics and related areas will be increased (Bieber et.al, 2005; Verlage et al., 2019; Vogt, 2019). As a result from this necessity, there some efforts to promote photonics related careers (Dulmes & Kellerhals, 2017; Panayiotou, 2019; Poulin-Girard et al., 2018; Sala et al., 2016; Posner et al.,2016, Vogt, 2019). Gilchrist, & Alexander (2019) believe that to evoke the interest in optics careers on wide range of students, promoting optics contents and engagement with professionals from related fields and optics hands-on experiences are influential. Therefore, more pedagogical initiatives are needed in this area.

As technology progresses, there will be a need for scientifically literate people who understand, interpret, and integrate these technologies in their daily lives. For example, in the early days of the discovery of electricity, the teaching of that new technology to young minds may have called to be an oppressive idea. Nevertheless, today electricity is a content existing in the primary education curriculum as it is an indispensable part of our daily life (The Minister of Education [MoE], 2018a). A similar situation will be valid for photonics. Just as happened the early times of electricity, the teaching of such an interdisciplinary science field such as photonics at primary and secondary level may seem incomprehensible or extraordinary, nowadays. However, we believe that, as photonic technologies replace electrical technologies and become an indispensable part of our daily life, teaching these subjects will become more significant and eventually photonics subjects will be included in the curriculum in order to increase scientific literacy in this area.

In today's education systems, although curricula include photonics-related subjects like light and its nature, there is a gap that points out the need for content that explicitly enables the awareness, knowledge, and skills of the term "photonics". Besides, there is a lack of teaching resources and professional development opportunities prepared for teachers and faculty members to be used in Photonics education (Massa, Dischino, & Donnelly, 2008). It is important to eliminate these deficiencies and to plan teaching materials and processes. Cornu believes that "the integration of new technologies requires newly designed integrated environments" (1995, p.9). Our main goal in this study is to be the among of those who pioneered to discussed how to design educational environment for an effective photonics education integration.

1.2. Statement of Purpose

The purpose of this study is to develop a Theoretical Framework of Photonics Education in order to increase the awareness of Photonics, contribute to the dissemination of Photonics education, and shed light on the education process. In this study, in order to investigate how photonic education can be given in the most effective way, (1) the contents, (2) learning outcomes, skills and attitudes related to photonics and photonics technologies, and (3) effective teaching processes - teaching techniques and evaluation of teaching – for students to engage in photonics education, are discussed with the experts in this area.

1.3. Research Questions

In this study, in order to investigate how photonic education can be given in the most effective way, answers to the following questions will be searched:

1. Theoretically, how should be the conceptual framework of a photonics education module at primary and secondary level?
2. According to the experts' opinions, how should photonics education be?
    a) What are the essential concepts in Photonics that should be taught in science education?
    b) What are the learning outcomes in terms of skills and attitudes that should be included in photonics education?
    c) What are the suitable teaching methods and strategies that would be used in photonics education?

d) What are the suitable evaluation methods and strategies that would be used in photonics education?
e) What are the suitable informal education environments that would be used in photonics education?

1.4. Significance of the Study

Reviewing literature showing that most of the studies on teaching photonics, are mainly fulfilled by Scientists from Science and Engineering departments, Staff of Science Centers, or organizations actively studying in Optics and Photonics fields (Yalçın, Çepni, & Aydemir, 2021). These studies include outreach activities to take students attention on photonics, and related career options (Dulmes & Kellerhals, 2017; Panayiotou, 2019; Posner et al.,2016; Poulin-Girard et al,, 2018; Sala et al., 2016; Vogt, 2019). Also, there are some studies on activity and material development for teaching photonics. Although authors give information about the developed and/or implemented activities, most of the reviewed studies need to be fulfilled with their outcomes or influences on the students in many dimensions. Therefore, within a collaborative environment consist of scientists from education departments and scientists of photonics, more substantial and permanent studies, like curriculum development and policy-making steps in the early stages, are required for the widespread impact on this area. This study, by bringing all these stakeholders together aims to develop educational framework for photonics education that could be useful for whomever to includes photonics to their teaching environment. Also, this study is believed to contribute to the literature with epistemological and pedagogical dimensions of Photonics Education.

1.5. Assumptions and Limitations of the Study

In this study, it is assumed that the participants of the study sincerely reflected their views during the interviews and survey.

The potential limitations in this study are:

1. The research sample was limited within the 23 participants from Turkey.
2. It was aimed to examine the rationales behind the ideas of the participants, but due to the disconnection and interruptions in the interviews, it was abandoned after a point.
3. While the two-rounded Delphi provided an adequate process of reaching consensus on four of the five research questions on how photonics can be taught, it might not provide sufficient detail and justification on the first research question that examine the topics that can be taught.

1.6. Definitions of the Key Terms

Nature of Science: Characteristics of scientific knowledge as derived from the manner in which it is produced, that is, scientific inquiry (Lederman, Schwartz, & Abd-El-Khalick, 2015, p. 694).

Photonics: Field of science and technology based on the combination of optics and electronics endeavor to generate, manipulate, and detect photons (Rogers, 2008).

STEM: Approach that aims to help students understand the concepts of mathematics and science and associate them with daily life events, increase science literacy, develop twenty-first century competencies, and prepare for the workforce (Bybee,2010; Çepni & Ormancı, 2018).

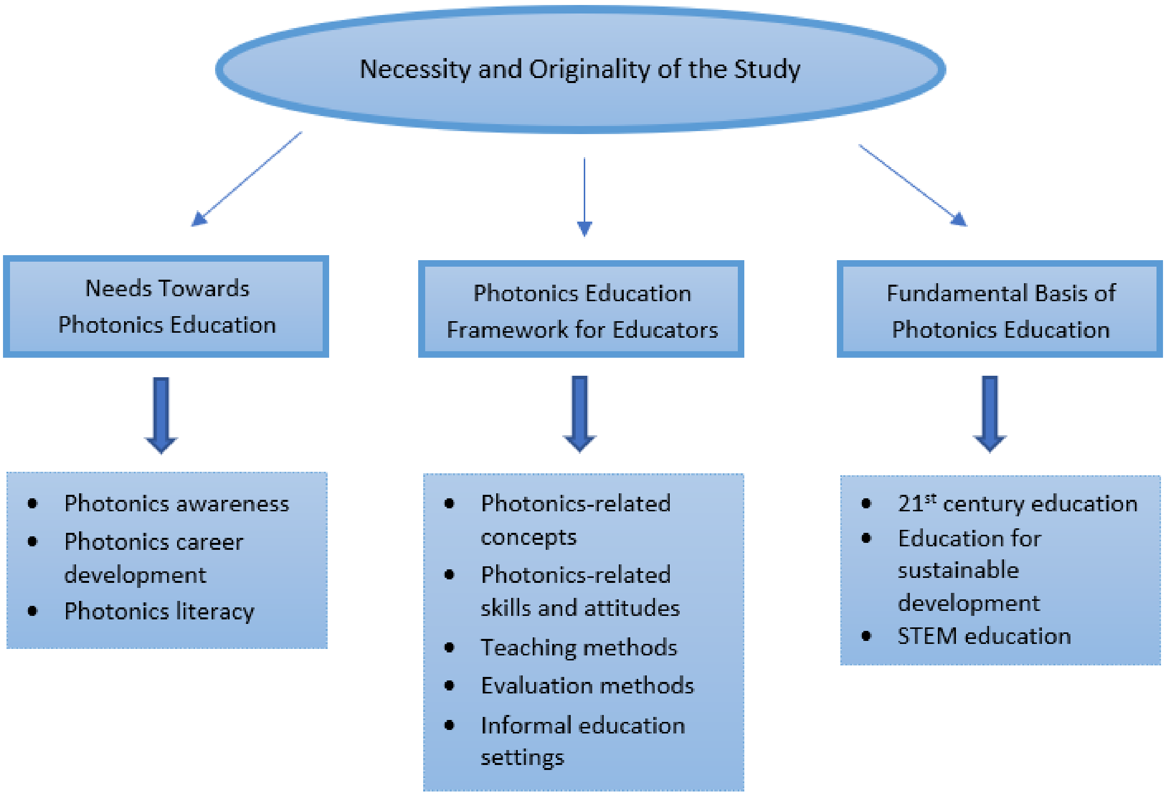
CHAPTER TWO

CONCEPTUAL FRAMEWORK

In this section literature review is given according to conceptual framework of this study. The conceptual framework of the study is constructed by considering the necessity and originality of the study, as seen in Figure 1 based on study of Çepni, 2021. The needs and importance of photonics education will be discussed in this section according to the literature. The photonics education framework is expected to be formed as a result of this study; thus, the sub-contents also be discussed according to the literature in this section.

Figure 1

The conceptual framework of the literature on necessity and originality of the study



2.1. Photonics and Photonics Technologies

2.1.1. Photonics

The word photonics is a combination of the photon and electronics. As can be understood from the origin of the word, photonics is a field of science and technology based on the combination of optics and electronics (Rogers, 2008). All kinds of photon and electronic interaction, light production from electric current and/or electrical current generation from photons form the basis of this field (Pearsall, 2003). In other words, photonics is the field of engineering and science studies that endeavor to generate, manipulate, and detect photons.

Studies in this area cover the semiconductor technology that underlies laser technology, optical fibers developed with lasers and sensors using optical sources such as photodetectors (Köksal & Köseoğlu, 2016). Photonics is related with many scientific fields such as optics, electrical-electronics, atomic structure, semiconductors, quantum physics; and it is a highly interdisciplinary field that enables advances in physics, biology, chemistry and technology. According to the National Photonics Initiative, which is an organization in US, advanced manufacturing, communications and information technology, defense and national security, energy, and health and medicine are the five important photonics-related fields (Sala, 2014).

2.1.2. Photonics Technologies

Photonics is everywhere! Some of the examples of photonic technologies in everyday life include; DVD players, remote TV control; fiber optic communication systems widespread in telecommunications; biomedical and nanomedical technologies in healthcare fields and also, methods and tools especially used in eye health and surgery; laser cutting and processing tools in the manufacturing industry; infrared cameras and remote sensing systems used in the military, defense and security industry; holography, laser and light shows used in the entertainment area; photovoltaic technology offering clean solar energy (Köksal, & Köseoğlu, 2016; Nof et.al., 2013; Pearsall, 2003; Varol, & Yağımlı, 2008). In addition, we can see the reflection of photonic technologies in electronics with LED screens, such as smartphones that we all use every day, and televisions we watch also in autonomous cars / vehicles with lasers in the working principle. Today, fiber optic cables are responsible for transferring over 90 percent of all data worldwide (Wessler & Tober, 2011).

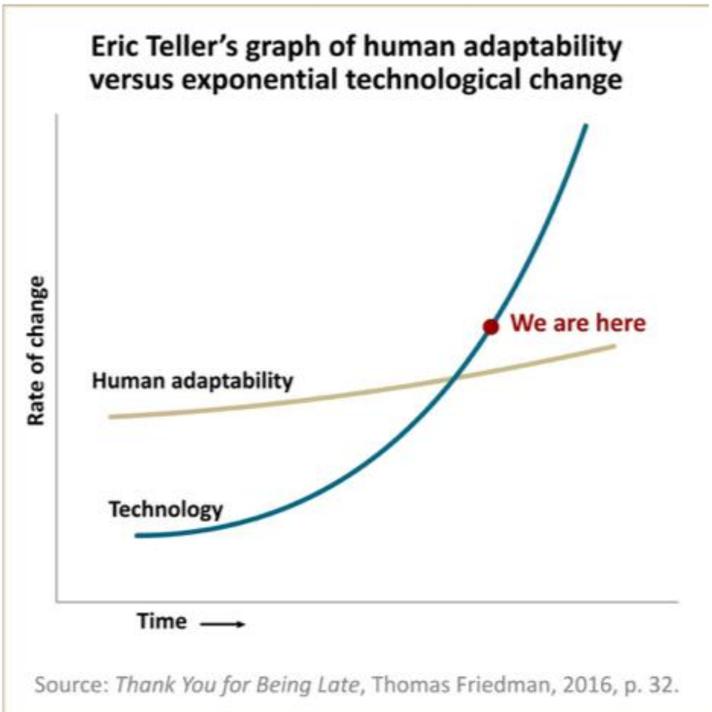
2.2. Needs Towards Photonics Education

We are living in a world of rapid scientific and technological advances. However, the adaptation process of the technological advances in society follows in slower rate as showed in Figure 2 retrieved from Hoffman (2020). Photonics technologies are one of the emerging example of this. According to De Carvalho, Martins, Fabris, Muller, & Fabris "the newer generations have experienced over-whelming technological advances, being ordinarily surrounded by numerous devices based on photonics" (2019, p.1). In this age, everyone in society is in some way or another acquainted with or affected by photonics. It is impossible to imagine a day without photonics devices. Although in our daily language we are unfamiliar the word "photonics", we are using its technological advances constantly. Most of us using these technologies without understanding the science and technology behind it (Florensa et al., 2013). Therefore, in order to increase the human adaptability of these photonics technologies' advances, photonics awareness should be raised in the society (Florensa et al., 2013;

Phoojaruenchanachai, & Sumriddetchkajorn, 2009), firstly. Secondly, science literacy on photonics (Pompea, & Hawkins, 2002), which will be used as photonics literacy in this study, will gain importance in society to promote adaptation process.

Figure 2

Eric Teller's graph of human adaptability versus technological change



In optics and photonics areas, worldwide shortage of trained and well-skilled personal is exist (Vogt,2019) and the demand will be increased in near future (Bieber et.al, 2005). Therefore, workforce for the photonics industry will be another important need in societies. It is important to inform young people, about the future career options, especially the ones who have intrinsic motivation and interest on STEM (Science, Technology, Engineering and Matemathics) fields (Gilchrist, & Alexander 2019).

In this section, there potential needs of society towards photonics education in the near future will be discussed. Grounded on the literature review, assumed that technological developments on photonics have been evoking three essential needs in society presented in Figure 3:

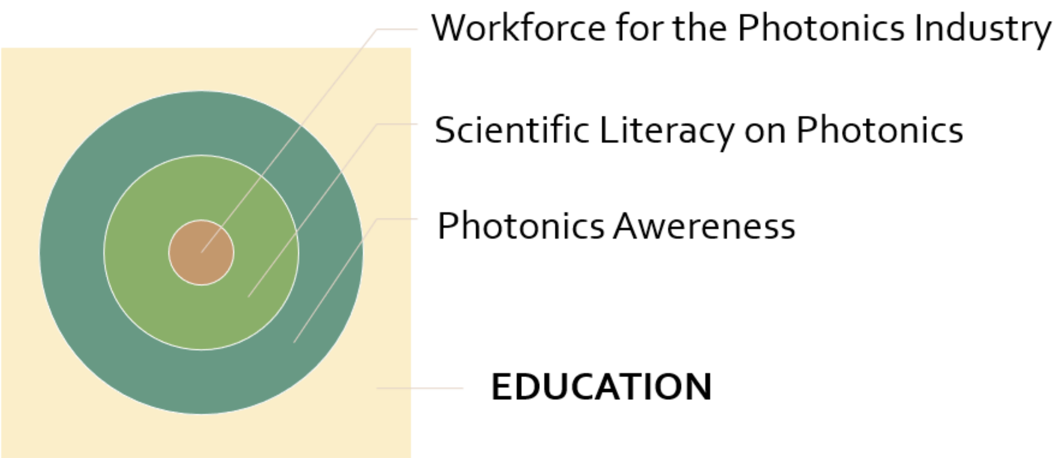
(1) awareness of photonics, (Florensa, Marti, Kumar, Carrasco, 2013; Phoojaruenchanachai, & Sumriddetchkajorn, 2009),

(2) workforce for the photonics industry (Dulmes & Kellerhals, 2017; Panayiotou, 2019; Poulin-Girard et al., 2018)

(3) scientific literacy on photonics (Pompea, & Hawkins, 2002).

Figure 3

Three potential needs of society towards photonics education



Education will be the key component here: Through the well-prepared educational programs and initiatives we can meet these needs. Accordingly, photonics education at every level, starting from the younger ages is a necessity.

2.2.1. Photonics Awareness:

Today, some people have either have little idea about the place and uses of light in the daily lives or think photonics technologies like lasers are inaccessible and incomprehensible in our daily routines (Florensa et al., 2013). The fact that Optics and Photonics are not adequately promoted as a field on their own and that they do not take part in the core education system with their own name cause the society not to realize how optics and photonics affect our lives and not have the motivation to learn in this field (Phoojaruenchanachai, & Sumriddetchkajorn, 2009).

Declaring the 2015 as the International Year of Light (IYL) and light-based technologies, The United Nations promote publicizing optics and photonics (International Year of Light 2015, n.d). During the IYL 2015, in many countries, so many great activities initiated to rise an awareness on field of photonics. According to Curticapean (2015), activities on IYL grabbed public interest, in a wide range of participants from different ages and locations, on achievements and the new frontiers of optics and photonics and enabled new educational aspects of teaching and training of optics and photonics.

One of the large audiences IYL outreach activities is a show garden exhibit named 'Reflecting Photonics' constructed in UK (Posner et al., 2016). The collaborative researcher team in this study aimed to engage approximately 80,000 visitors to promote the field of photonics. Researchers observed positive attitudes towards the exhibit, positive attitude changes towards physics and public engagement in photonics.

Another good example of collaborative study on rising awareness on photonics is the European project “GoPhoton!”, an initiative of ECOP (European Centres of Outreach in Photonics) that done between the years 2014 to 2016 (Sanmarti-Vila, García-Matos, Beduini, & Carrasco, 2016). This study targeted to the general public, young minds as well as current and future entrepreneurs. With a collaboration based on the development and sharing of photonics activities, over 200 different events were organized by the partners in the project with the participation of nearly half a million people and estimated two million impact area. The researchers believe that traditional way of communicating science such as traditional talks and guided tours are insufficient to fascinate students, entrepreneurs, educators, general public etc. thus, institutions need to find innovative new ways that compatible with 21st century. This research reveals that the innovative activities such as “big, highly visible events, photonics apps, exhibitions, toolkits, shows, congresses and science- talks, open-days, and art-activities like polarization and light painting” created in this collaborative environment greatly contribute to the promotion and awareness of photonics.

2.2.2 Photonics Careers:

In 21st century new technological and scientific developments bring new career opportunities along with. In optics and photonics areas, worldwide shortage of trained and well-skilled personal is exist (Vogt, 2019) and the demand will be increased in near future (Bieber et al., 2005; Johnstone, Culshaw, Walsh, Moodie, & Mauchline, 2000; McCarthy & Moore (2006); Thériault & Galibois 2019; Verlage et al., 2019). McCarthy & Moore (2006, p. 742) state the importance of education as “in an era when technology companies are bemoaning the lack of suitable scientists, it is noteworthy that these same companies fail to see the link between the student of today and the scientist of tomorrow”.Thériault & Galibois (2019) argue that to correspond the trained personnel demand at all levels from technicians to PhD candidates, collaborations between the industry and educational institutions to identify number of graduates and of their skillsets and are vital. Through the education, in order to sustain the future needs, it is crucial to inform students about optics and photonics career opportunities. Photonics is a field where students do not know career diversity exists, or even the field itself (Bieber et al.,, 2005). Informal education and outreach activities on optics and photonics seem to have positive impact on students’ interest on optics, photonics and STEM careers (Bieber et al., 2005; Gilchrist, & Alexander 2019).

Bieber et al. (2005), in their study, examined an after-school program at a college which aims to introduce career options on optics and photonics, and promote interest in technology careers especially to minorities in the technology fields, namely blacks, Hispanics, and women. In this program, in three main areas which are fiber optics, traditional optics and lasers, activities planned to promote conceptional understanding and skills deemed essential by the photonics industry. The students that involved in the study, mostly stated they might consider the career options in the future. The researchers suggested a similar program for younger students, before final year of high school.

McCarthy & Moore (2006) present a structured template to promote optics and optical engineering to young students named Maximum Impact Flow (MIF). According to the researchers, MIF optics education involves four steps which are: (1) *identification* or awareness of the optics elements within the students' daily life, (2) *fostering* materials and approaches that will provide dialogue between teacher and student, (3) *development* of web and technology aid, (4) *cross-fertilization*, spreading to the interdisciplinary field. Researchers believe that this educational stream is vital for creating next generation of scientists and engineers while preserving the sustainable development goals as seeking current and future needs.

2.2.3. Scientific Literacy on Photonics: "Photonics Literacy":

Hodson (2003) argued that although scientific literacy is on the center of the science education, there is no consensus has been reached on its definition. He also proposed a framework for scientific literacy which defined the four major elements of science education:

> (1) *learning science*: acquiring and developing conceptual and theoretical knowledge, (2) *learning about science*: developing an understanding of the nature and methods of science, appreciation of its history and development, awareness of the complex interactions among science, technology, society and environment, and sensitivity to the personal, social and ethical implications of particular technologies; (3) *doing science:* engaging in and developing expertise in scientific inquiry and problem-solving, and developing confidence in tackling a wide range of "real world" tasks and problems; (4) *engaging in sociopolitical action*: acquiring (through guided participation) the capacity and commitment to take appropriate, responsible and effective action on science/ technology-related matters of social, economic, environmental and moral-ethical concern (Hodson, 2011).

As Hodson's framework describes science education for scientific literacy today goes beyond the body of knowledge, and concerns more practical and action-oriented educational paradigms towards socio-scientific, environmental, and sustainability issues (McFarlane, 2013). Jenkins

(1999) also emphasized the importance of being scientifically literate so that all citizens could make decisions on individual or political issues concerning science and technology. Therefore, as future citizens, students have a great responsibility of decision-making on science and technologies that are of interest to society, while teachers have a duty to create educational environments and processes that prepare students for decision makings (Mansour, 2009).

From this point of view, when the studies on Photonics education examined, there are some initiatives for developing scientific literacy on Photonics. Firstly, as *learning science* dimension of the framework proposed by Hodson conceptual and theoretical knowledge is aimed to acquired and developed in many studies on Photonics education (as detailed in Table 1 under Photonics concepts heading). Secondly as *learning about science*, in their study, Li, Wang, Yang, & Si, (2017) aimed to discuss advantages and disadvantages of light-based technologies with a humanistic approach by integrating them with human, nature and health issues and the history of science. Thirdly, as *doing science* there are studies on photonics education aimed to gain students to scientific inquiry and problem-solving (Chang, Chen, Kuo, & Shen ;2011; Gilchrist & Alexander 2017; Viera-González et al., 2019) through real-life problems (Donnelly & Donnelly; 2019; Massa et al. 2008). As far as can be reached, there is no study found on action in the literature searched on *engaging in sociopolitical action*.

2.3. Photonics Education

The reflections of the advances in science, engineering and technology on daily life have sparked the discussions about the fact that few employees have a strong background and people have deficiencies in their basic knowledge in STEM fields (National Research Council, 2012). In this circumstance, in the United States, New K-12 Science Education Standards are charged as Next Generation Science Standards (NGSS) in 2012 to inspire students on science, technology and engineering, to make them appreciate in their daily lives, make informed decisions and to courage to enter careers of their choice. Teaching photonics is compatible with new NGSS in different grade levels and there are possible adaptations in photonics teaching environment to align with NGSS (Donnelly, Magnani & Robinson, 2016).

In Europe, there are several optics and photonics-based international projects are achieving over the last decade. In these projects, such as Photonics21, importance of the educational dimension is emphasized for the dissemination of photonics (Sanmarti-Vila et al., 2016). Outreach activities are favorably employed for this purpose in these projects (Yalçın et al., 2021).

In Asia also, studies reveal the fact that to sustain industrial demand, industry-university collaborations (Chang et al., 2011), to heighten public awareness and to inspire new generations of science and technology in photonics (Phoojaruenchanachai, & Sumriddetchkajorn, 2009) and initiatives of teaching Optics and Photonics with new teaching methods are considerable (Lyu, 2017).

Conferences on Photonics Education namely ETOP (Conference on Education and Training in Optics and Photonics) and Optics Education and Outreach, are organized by organizations like OPTICA (formerly OSA) and SPIE (formerly the Society of Photographic Instrumentation Engineers, later the Society of Photo-Optical Instrumentation Engineers) to support and make the efforts visible in the education of this emerging field. Another organization UNESCO conveyed a program namely Active Learning in Optics and Photonics (ALOP) to help teachers to attract their students by enabling inquiry-based, student-centered learning environments (Niemela, 2016).

Photonics has been recognized as an emerging technology field in world. In Turkey, Photonics is a priority research area, and this thesis is an application of this priority research area on education.

All around the world in addition to those are mentioned, there are so many different utility works and efforts on Photonics Education. The literature of Photonics Education mainly built on the conferences and the analysis of these conferences' papers show that more substantial and permanent studies on educational side to consider pedagogical and epistemological perspective, like curriculum development and policy-making steps in the early stages, are required for the widespread impact on this area (Yalçın et al., 2021). Also, in order to arouse students' interest in photonics, the help of educators is imperative (McCarthy & Moore, 2006). Rapid developments in science and engineering have created deficiencies in educational materials and standards, forcing educators to make efforts to develop new classroom environments and educational programs (Jones et al., 2013). On the other hand, de la Barra & Wilson (2010) states that General Physics and Optics -Photonics are less often introduces at elementary school level because of the teachers' background deficiency and low self-confidence in these areas. Besides, there is a lack of teaching resources and professional development opportunities prepared for teachers and faculty members to be used in Photonics education et al., 2008). Thus, it is important to know current situation and to discuss the needs of today and tomorrow.

2.3.1. Photonics Concepts:

Optics and photonics are usually shown in certain units in the secondary and high school curriculum, but more space is left for outreach activities to detail and arouse curiosity in this area this area, which is closely related to the experiences of students in daily life such as *light*, *color, waves, reflection, communication, and the internet* (Hamdy et al., 2019). Wong, Posner, & Ravagli (2017) stated that some secondary school curricula cover *basic geometric optics* concepts such *as reflection and refraction*, but very few of them go into detail about fiber optics and its relationship with global telecommunications and stated that students rarely encounter these topics until they come to university. This seems a general phenomenon for different countries and their curricula. For example, in Turkey secondary school science curriculum involves optics concepts such as *propagation of light, reflection, refraction, colors, mirrors and lenses* throughout 5th,6th and 7th grades also involves *electricity and circuit* (MoE, 2018a). In addition, the secondary school science curriculum includes some objectives expects students "to exemplify innovative applications of solar energy in daily life and technology", "to discuss their ideas about how solar energy can be used in the future", "to design a model based on the conversion of electrical energy into heat, light or motion energy" and "to design a unique lighting tool" (MoE, 2018a). These objectives refer to provide a basic understanding and introduction to photonics, although the Turkish science curriculum never mentions Photonics as a term. While some science curricula have more objectives on optics, curricula in other countries allocate less or limited time. For instance, Chu, Treagust, & Chandrasegaran (2009) state the Korean science curriculum contain optics only in 8th grade middle school and leaves little time to identify and resolve students' misconceptions about light and waves. According to Hamdy et al. (2019), California (in US) Next Generation Science Standards includes light and waves in only one unit on for grades 6-8 and another for grades 9-12. In Thailand, researchers state that neglecting the students as future employees led students rarely interrelated with optics and photonics at primary and secondary schools (Phoojaruenchanachai & Sumriddetchkajorn, 2009).

Examining the outreach activities to may be more beneficial for better understanding of photonics concepts, rather than the curricula. Hasegawa & Tokumitsu, 2016, in their study of outreach activities in Japan, performed experimental classes on the topics which are "*fundamental properties of light (reflection and refraction, spectrum of white light), optical communication"* for 5th grades and; "*sunset color and blue sky, air and water pressure, electric power generation and their storage in capacitors, static electricity*" for 6th grade classes.

Cords, Fischer, Euler, & Prasad (2012) designed intra-curricular kit named Photonics Explorer kit for within the Photonics Explorer programme in Europe, to support teaching of optics and light-related topics in physics across various European secondary school curricula with hand-on inquiry-based activities. In this study, researchers introduce *lasers for diffraction and interference; LEDs for light signals and color mixing, electric circuits*. The worksheets in the study, aimed to promote students understanding of physical concepts and their applications in their daily life.

Table 1

Photonics concepts in studies according to their levels

Photonics concepts	Level	Authors
Lenses	Middle and high school	Gilchrist et al,2017
Reflection	Middle school	Nelson et.al, 2019
	High school	Ali, & Ashraf, 2017; Posner et al, 2016
Refraction	Middle and high school	Posner et al., 2016
	High school	Ali, & Ashraf,2017
Diffraction	Elementary School	Resnick & Monroy-Ramírez, 2017; Sánchez-López et al.,2016
	Middle school	Nelson et al., 2019
	Secondary school	Ali, & Ashraf, 2017; Sánchez-López et al.,2016
Dispersion	Elementary School	Resnick & Monroy-Ramírez, 2017
Polarization	High School	Gauthier et al, 2018; Lobato et al,2015; Suzuki et al., 2019
Colors	Elementary School	Nakadate, et al., 2019; Resnick & Monroy-Ramírez, 2017
	Middle School	Hamdy et al.,2019; Nelson et.al, 2019
	Secondary school	Cords et al.,2012
Electromagnetic spectrum	High School	Barra & Wilson, 2010; Gauthier et al, 2018; Posner et al., 2016
LEDs	Elementary school	Andre, & Jones, 2019; Dreyer et al.,2016; Hasegawa, & Tokumitsu, 2016; Nakadate, et al., 2019
	Middle school	Gilchrist & Alexander, 2017; Nakadate, et al., 2019
	Secondary school	Bunch, & Joenathan, 2018; Cords et al.,2012; Hasegawa, & Tokumitsu, 2016; Nakadate, et al., 2019
Lasers	Middle school	Stirling et al,2018 Sala et.al,2016
	High school	Ali, & Ashraf, 2017; Bieber et al., 2005; Dulmes, & Kellerhals, 2017; Massa et al., 2019; Ross et al., 2017; Stirling et al., 2018
Imaging	Elementary school	Andre, & Jones, 2019
	Middle and high school	Gauthier et al, 2018; Gilchrist et al,2017
	High School	Suzuki et al., 2019
Solar Power	Middle and high school	Gilchrist et al.,2017; Sala et al.,2016
Telecommunication with light	Middle and high school	Gauthier et al, 2018; Posner et al, 2016; Stirling et al,2018
Fiber optics	Middle and high school	Posner et al, 2016; Stirling et al,2018; Wong, 2017
Energy	Elementary school	Dreyer et al.,2016
	Middle and high school	Posner et al, 2016

Some photonics related concepts acquired to students in the studies which are generally on outreach activities are given in the Table 1. As seen in the Table 1, many concepts related to Photonics introduce to students at different levels. When introducing light to school students, there are several limitations caused by presenting quantum physics and mathematical formalism (Henriksen, 2018; Mešić, Hajder, Neumann, & Erceg, 2016). Discussions of philosophical and epistemological aspects of light including aspects of the nature of science and history of science are suggested rather than acquisition of concepts through mathematical descriptions (Henriksen, 2018).

2.3.2. Skills and Attitudes for Photonics:

In science teaching, besides "what contents we teach", "what students acquire" is also crucial. In addition to students' knowledge, teachers should ensure that they acquire some skills and attitudes toward this scientific knowledge. Rutherford states that (1964, p.80)

> "*When it comes to the teaching of science it is perfectly clear where we, as science teachers, stand: we are unalterably opposed to the rote memorization of the mere facts and minutiae of science. By contrast, we stand foursquare for the teaching of the scientific method, critical thinking, the scientific attitude, the problem-solving approach, the discovery method, and of special interest here, the inquiry method.".*

There are some skills in the studies that desire students to develop about optics and photonics context in the literature. In their study, Donnelly & Massa (2015) states that to meet industrial demand for well-qualified employees in optics and photonics, the educational process should ensure that students- future employees- to develop *critical thinking* and *problem-solving skills*. Chang et al., (2011) designed project-based learning activities on photonics to help students to grasp the operating principles of LEDs and develop LED *design skills* as well as support students to improve student *inquiry, reflective thinking, teamwork, creativity*, and *problem-solving skills*.

Viera-González et al. (2019) revealed that volunteers in their outreach project, who are college students, have developed *team-working, leadership, problem-solving, effective communication, event organization, teaching, and mechanical skills* while conducting activities for kids, teenagers, and the public.

Serna et al. (2019) summarized the required skills in photonics workforce based on interviews and discussions with industry, and research. According to the findings in their study the necessary basic skills for technician and/or lab engineers in photonics can be outlined as *communication skills, lab organizational skills, safety organizations in setup, hands-on work* *experience, data organizing, interpretation and reporting using Microsoft Office tools, and Photonics/optics-based content expertise*.

In “The Solar Cell and Photonics Teaching and Research Module” for high school students and teachers, Gilchrist & Alexander (2017) aimed to improve students’ *arithmetic, technical skills, communication, collaboration, critical thinking, creativity and work ethics* which align with *21st century skills* for the global workforce and college. Similarly, engineering education is desired to include essential skills for 21st-century citizens which are system thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations (Katehi, Pearson, & Feder, 2009).

Metacognition is another skill we come across in photonics studies (Chang et al., 2011; Massa et al.,2019), although it has not been adequately explored. Massa et al. (2019) states that the student-directed education environments in which students exhibit a *systematic research process skills* such as defining the problem, reflecting on their prior and required knowledge, identifying the constraints, and making informed decisions to overcome the problems helps students develop metacognitive skills.

In addition to conceptual knowledge of optical fiber communication, in their experimental teaching Lan, Liu, Zhou, & Peng (2017) emphasized to develop students’ *scientific methods and thinking,* promote *scientific spirit and moral character,* improve *innovative spirit and learning ability.*

Gilchrist & Alexander (2017) in their study mentioned before, aimed to measure students’ *attitudes toward STEM* and found out that the rural students show significantly higher score on attitude towards science and engineering compared to students who participated in urban areas.

In literature, there are limited studies that explore the effects of photonics formal or outreach education process on students’ skill development. Based on the studies we reached some cognitive skills such as *problem-solving skills, reflective thinking, creativity, critical thinking, inquiry,* some team skills like *teamworking, collaboration and communication, leadership* also, *systematic research, mechanical, and technical skills.*

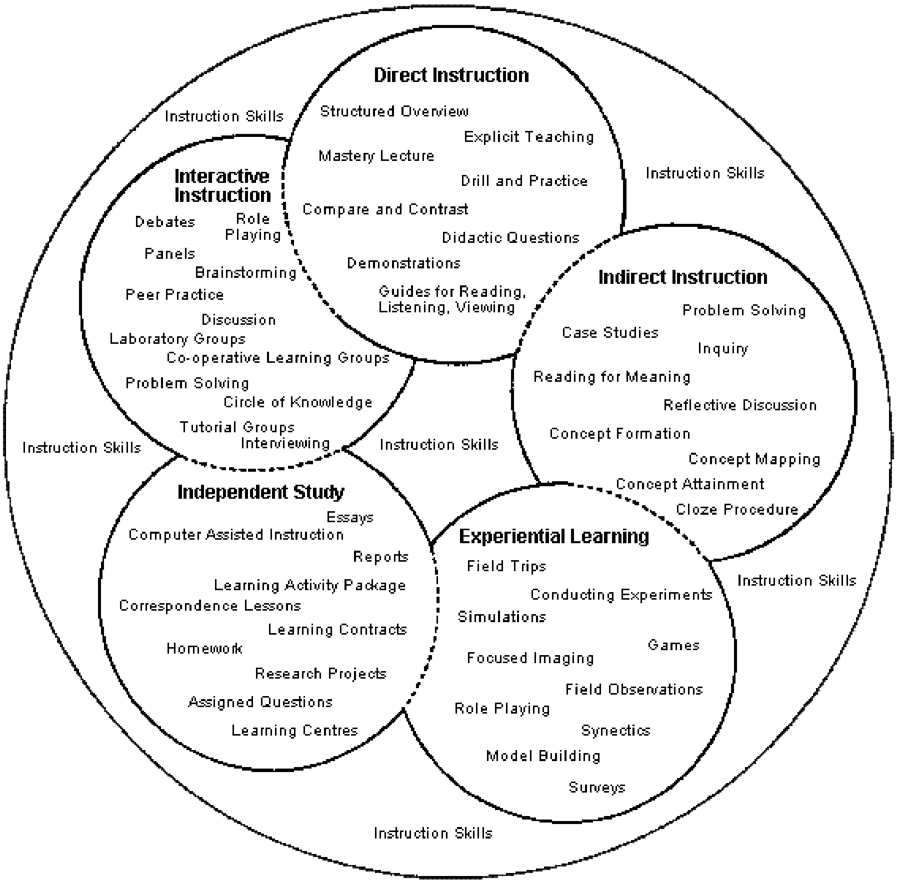
2.3.3. Teaching Methods Used in Photonics Education:

Constructing a teaching environment with an appropriate teaching method requires teachers to consider various variables such as, learning objectives and prerequisite skills, learners’ motivation and learning styles, students’ individual ability, culture and social context, availability of technology, subject matter, or content itself, and also teachers’ own abilities and preferences (Bonner,1999; Borich,2017; Clark, & Starr, 1996).

There are different categorization of teaching strategies and methods as well as various definitions. According to Orlich, Harder, Callahan, Trevisan, & Brown (2012, p.4) “(…) the term method, it implies some orderly way of doing something. The term strategy implies thoughtful planning to do something.”. As a different definition, while “strategies determine the approach a teacher may take to achieve learning objectives” classified as direct, indirect, interactive, experiential, or independent, instructional method “is used by teachers to create learning environments and to specify the nature of activity in which the teacher and learner will be involved during the lesson.” (Saskatchewan Education, 1991, p.13). In Figure 4 sample of various methods organized under the five instructional strategies according to the definition and categorization of Saskatchewan Education (1991). Considering this classification, teachers may prefer to use *case studies, problem solving, inquiry or concept mapping* methods under the indirect instruction strategy; *lecturing or demonstrations* as direct instruction; *field trips, games, simulations, conducting experiments* methods for experiential learning; *research projects, learning centres, homework* for independent study; *discussions, co-operative learning* for interactive instruction.

Figure 4

Instructional Strategies and methods (Saskatchewan Education, 1991, p.20)



In today's classrooms there are several methods that researchers strongly recommended for effective science education in relation to the concepts. According to Chiappetta, Koballa, & Collette "Teaching science must be consistent with the nature of science in order for course content and methods to reflect how scientific knowledge is constructed and established." (1998, p.102). With this approach, they claimed that inquiry in classrooms enables students develop certain reasoning skills, scientific attitudes and sense of intellectual power of science, instead of teaching science as a body of knowledge that can engage students little and may result in rote memorization. Accordingly, inquiry-based learning is used to promote Optics and Photonics contents by engaging students in photonics education studies worldwide (Ali, & Ashraf, 2017; Donnelly, Donnelly, & Park, 2018; Fleck, & Hachet, 2015; Magnani, & Donnelly, 2015; Niemela, 2016; Prasad, Debaes, Fischer, & Thienpont, 2013). As an example, to enhance scientific literacy in Europe long term and to exemplify inquiry-based learning activities for teachers Cords et al., (2012) design Photonics Explorer kit, an intra-curricular kit for hands-on activities based on *inquiry-based learning*. As a result of this study, researchers stated that the approach engage students with the sense of freedom and creativity on their work and encourage and support teachers to use inquiry-based learning. In addition, the education kits were designed to promote group-working as small groups of 2–3 besides materials the class of about 25–30 students can work together.

Gilchrist & Alexander (2019), in their study found the positive effect of Imhotep Academy, in which developed integrated lesson plans and activities used a pedagogical approach of *inquiry* and *problem-based learning* and *5E* aligned with the Next Generation Science Standards on student achievement, engagement in STEM, promotion of optics careers and reaching underserved students.

Massa, Donnelly, & Mullett (2019) claim that *Problem-Based Learning (PBL)* is a key approach teaching optics and photonics to correspond the creative and cooperative problem-solvers that industry demand. They developed, introduced, and implemented PBL scenarios on photonics concepts in order to help supplying the lack of material in this area and to provide guidance to teachers.

Project-based learning is another method, we reached in the literature, which is preferred to use in teaching photonics (Chang, et al., 2011; Chang, Wu, Kuo, & You, 2012; Clark et al, 2020; Dehipawala et al., 2018). Chang, et al., (2011) believe that project-based learning may be useful for junior students in university to grasp the operating principles of LEDs and develop LED design skills as well as support students to improve student inquiry, reflective thinking, teamwork, creativity, and problem-solving skills. Zhu, Liu, Liu, Zheng, &

Zhang, (2019) found out the guidance of instructor, collaboration with peers, communication with other stakeholders and complexity level of projects are effective in stimulating students' epistemological thinking by limiting or broadening their own thinking and solving the problem within constrains in problem-based learning for engineering education.

Hasegawa, & Tokumitsu, 2016 in their study, enable university students to meet with local Japanese elementary students to perform out-of-curriculum activities with experimental design on optics and photonics. They state that *experimental activities* are beneficial for student to stimulate interest on optics and photonics and to obtain scientific knowledge. Hamdy et al., (2019) found that students in their study mostly enjoyed open-ended and experimental challenges that force them to formulate hypothesis, to analyze the situation for possible options, and to communicate other students to find out working solutions which are basically point out the scientific research process. They also stated that *discussions* in a Socratic manner facilitate student engagement and involvement instead of lecturing. Likewise, according to Bieber et al. (2005) interactive *discussions* and *hands-on activities* are considered pleasant way to connect with students by teachers and appreciated and enjoyable experiences by students. Phoojaruenchanachai & Sumriddetchkajorn, (2009) state that *low-cost educational kits* and *demonstrations* on optics and photonics are needed to support scientific and critical thinking process of students.

Lan, Liu, Zhou, & Peng, (2017) suggest instead of demonstrations and lectures, teachers may prefer cooperative experiments, which enable students contact with each other's while developing their knowledge by researching probes and solving problems.

As a conclusion, there are several student-oriented teaching methods used in photonics education found in literature, which are inquiry-based learning, problem-based learning, project-based learning, 5E, laboratory work or experimentation, cooperative-learning and hands-on activities. Furthermore, demonstrations and in-class discussions have been used as direct instructional methods.

2.3.4. Evaluation Methods Used in Photonics Education:

Evaluation should be aligned with the teaching process in education (Biggs, 2003). Therefore, evaluation in teaching photonics should be aligned with the teaching process. Some of the examples of evaluation methods in the studies of Photonics education will be given in this section.

Donnelly & Massa (2015) stated that content assessments and concept mapping effective for the evaluation of student content knowledge acquiring within the problem-based learning process. In addition, to evaluate students' problem-solving ability they used formative (in process) and summative (final) assessments, with the aid of an interactive web-based tool called "Whiteboards" and reflective journal called the "Final Challenge Report". Similarly, Bieber et al., (2005) employed formative and summative evaluations for assessing students' learnings in the active learning lessons.

Serna et al. (2019) have developed a modular laboratory curriculum in graduate and undergraduate level to teach the fundamentals of basic integrated photonics devices and designed exercise to evaluate students' learnings within the laboratory experiments which aimed to assess (1) lateral out-of-the-box thinking, (2) deductive reasoning, (3) the application of prior comprehension, (4) blended learning outcomes, (5) the ability to use tools in a photonics testing laboratory, (6) data analysis skills. In the application of this curriculum students was graded according to their demonstrations, data analysis and interpretation and answering the questions.

Lan et al. (2017) in their study, to assess learnings in the optical fiber communication context, employed a three-stage evaluation, namely, the experiment preview, the experimental operation, and the experimental results, respectively made up 10%, 30% and 60% of the overall rating. Niemela (2016) also found multiple assessment valuable and used a special test at the beginning and end of the workshop in order to assess the conceptual understanding of participants by comparison.

As the teaching processes in photonics education mainly derived from outreach activities, the evaluation of the learnings is mainly restricted in the literature. The studies on this field, mainly assess students' engagement and attitude changes towards photonics and STEM and based on non-formal evaluations such as observations and responses to the questions of the researchers (Posner et al., 2016). Another reason of this restriction may be relevant with the researchers' background on science and engineering fields that result in limited experienced on evaluating students learning objectives in cognitive, affective, and psychomotor domains. For instance, Posner et al., (2016) discussed their study team's limited backgrounds in social science methods lead difficulties in evaluating students' learning outcomes on their project. Pompea & Carsten-Conner (2015) suggest that planning the evaluation ways to measure success in the beginning of a project could be more efficient to overcome limitations of the assessment process.

2.3.5. Informal Settings in Photonics Education:

Informal learning environments such as museums, exhibits, science centers and web-based events are believed to contribute to science literacy in optics and photonics (Pompea, & Hawkins, 2002). To engage K-12 students and public in photonics, outreach activities in informal locations such as fairs, science centers, or open houses conducted by industry professionals, scientist, faculty members, and graduate students are widespread (McKee, Magnani, & Posner, 2019). Outreach activities for photonics education can be cited as a significant contribution in informal photonics education settings, where students be able to participate in activities where they had the opportunity to get to know the area and to meet and interact the scientist and developers of this area (Gilchrist & Alexander, 2017; Hasegawa, & Tokumitsu, 2016). According to Posner et al. (2017) student-led outreach environments contribute the field by aiding to overcome the inequalities between students to reach the potential skilled young in STEM education. About 62% of the studies on photonics education in elementary and high school levels presented on ETOP and Optics Education and Outreach Conferences years between 2015 and 2019 have been focused on outreach activities (Yalçın et al., 2021). As the literature on optics and photonics mainly consists of these conferences, it would not be wrong to say that informal outreach activities constitute the majority of the studies in this field and have great contribution the dissemination of photonics to larger audiences.

2.4. The Fundamental Basis of Teaching Photonics

The fundamental basis of teaching Photonics roots in the photonics three major importance which are being enabling technology of the 21st century, providing green or sustainable technological solutions and promote STEM education and developments.

2.4.1. 21st Century Technology:

Photonics has been acknowledged as one of the Key Enabling Technologies (KETs) of the 21st century in Europe (European Commission, 2020). There are several reasons why Photonics is one of the core technologies in todays and future world. Firstly, photonics is an applied science area motivated by the fact that it supports the development and progress of various fields of science on social and economic dimensions (Peccianti, 2021). He exemplifies this explanation from the history of science by stating that the invention of the optical microscope enabled developments in many areas including medicine and biology. Accordingly, the challenges of the 21st century will be decisive in developing new photonic technologies (Photonics Leadership Group, 2020).

Secondly, the photonics offers 21st century solutions with green and sustainable ways (Kalyani, & Charan,2014; Wessler & Tober, 2011). Due to the climate crisis that the world is in and increasing day by day, it is not enough to produce solutions to the problems of the 21st century, these solutions must be sustainable (Kılkış, Krajačić, Duić, Montorsi, Wang, & Rosen, 2019; Lorey,2002). As will be detailed later, photonics offers innovative and clean solutions for a more sustainable world.

Educational goals of 21st century include students who are citizens of the future as well as scientists and aim to enable them all to gain the skills of problem solving, calculating risks, making decisions, following the developments in science and technology, and realizing the value of science in daily life (Hurd, 2000). Integrating photonic technologies that are easy to encounter in daily life into lessons can be one of the effective ways to help students gain problem-solving skills, which is one of the educational goals of the 21st century (Oktavia, & Halim, 2018). A pioneer example of the transfer of photonics to the twenty-first century educational environment is the study of Donnelly & Massa (2015) which is used the problem-based teaching method, in which students develop their critical thinking and problem-solving skills through real challenges obtained from the photonics industry.

2.4.2. Education for Sustainable Development:

The sustainable development (SD) developed as a key concept for dealing with the environmental issues by considering the social and economic dimensions to supply natural resources for future generations (United Nations Conference on Environment and Development (UNCED), 1992). Brundtland Commission defines SD for the first time in “Our Common Future” as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p.43). Photonics will have an important position in sustainability by minimizing our environmental impacts (Hakola et al., 2020; Kalyani, & Charan,2014; Lee, 2021; Wessler & Tober, 2011; Quan, 2012). Throughout the industrial design, production techniques and products photonics offering benefits to called as "green" by enabling to generate or conserve energy, reduce greenhouse gas emissions, offer environmentally sustainable production and enhance public health (Kalyani, & Charan,2014; Wessler & Tober, 2011). The contributions of Photonics to sustainable development are summarized by Wessler & Tober (2011, p.356) and Kalyani & Charan, (2012, p.9) given in the Figure 5 and Figure 6 respectively, are demonstrated that Photonics offers potential sustainable benefits in various applications.

With the declaration of 2015 as the International Year of Light, the importance of photonics and photonic technologies in sustainable development was emphasized, international policy makers and stakeholders were informed about the potential of light technologies in solving the problems that may be encountered in the future (Sala, 2015). Also, according to Sala (2015), many outreach and educational activities are planned to promote Photonics' position in sustainable development to the students and public.

Figure 5

Photonics Contribution to Sustainable Economy

Photonics contribution to a Sustainable Economy

Sustainable Energy Generation

- Photovoltaic solar energy

Reduced Energy Consumption

- Solid-State Lighting (SSL)
- Communication Technologies

Enabled Eco-friendly Design & Production

- Light-weight product design using advanced laser processing
- Material savings by precise laser cutting
- Control of production processes by sensors
- Laser processing for clean manufacturing

Reduced Risk Potential

- Sensor networks for higher safety & security
- Environmental monitoring by sensors

(Wessler, & Tober, 2011, p.356)

Figure 6

Photonics Contribution to Sustainability

Technology	Underlying Technology	Application	Impact
Photovoltaics	xSi, pSi, aSi, CdTe,	Power generation	Renewable energy, reduced carbon emissions, reduced pollution
Solid State Lighting	LEDs, OLEDs	Illumination, Displays	Reduced energy consumption, reduced mercury pollution
UV Disinfection	UV LEDs	Water purification	Improved drinking water quality, reduced mercury pollution
Optical Sensors	Fiber optics, Bragg gratings, Detectors	Energy extraction, Gas sensing, environ mental monitoring.	Reduced energy consumption, Reduced pollution, Reduced greenhouse gas emission
Low Power Displays	OLEDs, LEDs, MEMs, Electrophoretics, LCDs	Info. and Entertainment Display	Reduced energy consumption

(Kalyani & Charan, 2012, p.9)

Education plays a central role to support sustainable development by preserving and disseminating knowledge in photonic technologies (Sebak, Haj Bakry, Alshebeili, Fathallah, & Alajlan, 2014). However, photonics education for sustainability should go beyond this, and should enable students to acquire a set of skills and attitudes that contribute to being informed citizens in society. For instance, transferring quantum computing and technological developments to science classes encourages students to gain perspectives to they can find out sustainable and creative technological solutions to future problems with creative thinking (Rasa, Palmgren, & Laherto, 2022).

Lawale & Bory-Adams stated that "dealing with risk and uncertainty, problem solving, critical thinking, 'values' clarification, collaborative and social learning, collaboration and dialogue, 'out-of-the box-thinking' to induce innovation are some of the tenets of education for sustainability" (2010, p. 549). These skills are among the skills that are aimed to be acquired by students in photonics education studies which mentioned in previous sections.

2.4.3. STEM field:

STEM (Science-Technology-Engineering-Mathematics) is an approach that aims to help students understand the concepts of mathematics and science and associate them with daily life events, increase science literacy, develop twenty-first century competencies, and prepare for the STEM workforce (Bybee,2010; Çepni & Ormancı, 2018). In the field of Photonics education, in order to train a world-class science and engineering workforce, awareness-raising studies are carried out regarding STEM careers (Gilchrist, Young, Bowles, Brady, & Grable, 2017; Hall-Wallace, Regens, & Pompea, 2001; Sanmartí-Vila, Tognetti, Beduini, & Carrasco, 2020).

The power of STEM is in the interdisciplinary structure in which its components are included (Vasquez, Sneider, & Comer, 2013). When you get involved in the quantum world, STEM's cross-disciplinary structure becomes a necessity (How, 2022). Therefore, Photonics is a STEM field by its nature which all the components of STEM highly interrelated each other and can be useful context in education.

2.5. Results of Studies Driven from the Conceptual Framework of the Photonics Education

In order to increase the awareness and engagement of photonics, it is generally endeavored to introduce photonics in informal education environments with outreach studies. However, there is no definite findings and consensus on how to elaborate on photonics and light in the curricula. In this regard, there are criticisms that policymakers in the field of education do not attach sufficient importance to photonics (Phoojaruenchanachai & Sumriddetchkajorn, 2009). The main purpose of outreach studies introducing photonics, which is a 21st century technology and offers green solutions for the future (Kalyani, & Charan,2014; Wessler & Tober, 2011) to guide students to STEM careers in these fields (Bieber et al 2005; Gilchrist, & Alexander 2019). However, when approached from an educational point of view, the importance of creating scientific literacy about photonics has become apparent (Pompea, & Hawkins, 2002). Photonic literacy enables, citizens' recognition of photonics as an effective field of science and technology in coping with the problems they encounter in their daily lives and in discussing the problems of the twenty-first century with moral values, as well as awareness of photonics and the development of knowledge that will be useful in photonics career can be developed. It should be discussed that which subjects will be taught and how their learning will be evaluated in photonics education that will provide photonic literacy to students.

CHAPTER THREE

METHODOLOGY

In this section, the research design, participants, data collection process and tools, data analysis of the study are given.

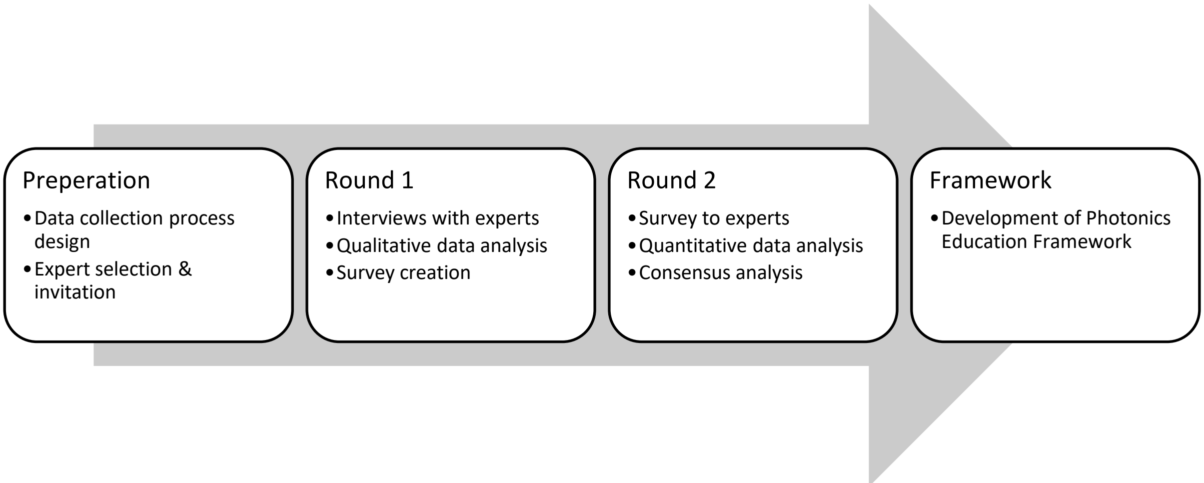
3.1. Research Design

In this study, Delphi Method was used to investigate how photonic education should be. In the Delphi method, experts of a subject, who are anonymous to each other, develop answers to the questions posed to them and a consensus is aimed based on these opinions (Delbecq, Van de Ven, & Gustafson, 1986; Hasson, Keeney & McKenna, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Delphi method is considered beneficial to use generally for the topics we do not know much about, to develop programs, instructions or standards (Green, 2014), studies involving stakeholders from different areas of interest (Delbecq, et al., 1986; Hasson, et al., 2000). The reason for choosing the Delphi method in this study is that Photonics is a rather ambiguous subject because it is not included in educational sciences yet, and because of its interdisciplinary nature, there are many stakeholders on the subject. In the theoretical framework to be developed, university faculty members working in the departments related to photonics, employees of institutions that develop photonic technologies in the private sector, and university faculty members from science and physics education departments are regarded as experts on the subject.

Different applications of the Delphi process appear in the literature: while classic Delphi process have four round, recent studies demonstrate two or three rounds are sufficient as long as knowing where to stop (Hasson et al., 2000). The research process in this study is given in the Figure 7.

Figure 7

Delphi Process



In this research, the Delphi study has been planned to be carried out in 2 rounds. In the first round, experts were asked to answer of open-ended questions via online interviews. Afterwards, after analyzing the responses from the experts, a Likert-type scale was created by converting them into short statements. In the second round, experts were asked to evaluate Likert-type statements according to their agreement levels. Similar to the consensus definition used by Krijtenburg-Lewerissa, Pol, Brinkman, & Van Joolingen (2019) in their study, expressions mean, and variance statistics considered for agreement upon experts opinions

3.2. Participants of the Study

In Delphi studies, the experts are generally determined by non-probability sampling techniques, either purposive sampling or criterion sampling, since the participants are selected to consult according to their knowledge on the researched subject (Hasson et al, 2000). In this study, criterion sampling technique of purposeful sampling, (Patton, 2002) was used in the selection of the experts to participate study in order to establish richer data from predetermined participant groups. The criteria of the selection of participants are derived from the sub-group of the experts. The sample in the study compose of 3 subgroups as mentioned: (1) *photonics* group; university faculty members who have photonics or photonics-related studies, (2) *industry* group; employees of institutions developing photonic technologies in the private sector, and (3) *education* group; university faculty members from science and physics education departments. Participants of the study did not have information about the other participants, as in the nature of the Delphi studies (Osborne et al., 2003).

Study maintained with a total of 23 experts, 6-8 experts in each subgroup. According to Green (2014) in order to provide validity of the results, the heterogeneity of the participants must be maintained. Heterogeneity of the participant is tried to be established with the diverse groups of experts. The demographics of the participants are giving in the Table 2, below. The codes in the table ensuring the anonymity of the experts, are used throughout the thesis. The first letter of the codes indicates the sub-groups of the experts which are: E for education, I for industry, and P for photonics.

Full participation indicates that the expert participated both first and second round, while first round indicates that the expert only been interviewed. There were three experts who did not participate in the survey as seen in from the Table 2. In addition, the profession areas, the institution they are working, and the years of experience are given in the Table 2.

Table 2

Experts/Participants of the Study

Sub-group	Code	Profession	Institution	Experience	Participation
Photonics	**P1**	Molecular photonics materials and devices	İzmir Institute of Technology	26 years and above	Full participation
	P2	Optoelectronics	Koc University	11-25 years	Full participation
	P3	Optical/Photonics, Electromagnetic	Erciyes University	26 years and above	Full participation
	P4	Nanooptics	METU and GÜNAM	11-25 years	Full participation
	P5	Biomedical Engineering	İzmir Biomedicine and Genome Center	6-10 years	Full participation
	P6	Photonic Sensor	Kırşehir Ahi Evran University	11-25 years	Full participation
	P7	Photonics	Atatürk University	11-25 years	Full participation
	P8	Photonics	Bursa Uludag University (Retired)	26 years and above	First round
	P9	Physics	Eskişehir Technical University	11-25 years	Full participation
Industry	**I1**	Photonics Technologies	private sector	11-25 years	First round
	I2	Solar energy	private sector	11-25 years	Full participation
	I3	Optical Design and Analysis Engineering	private sector	6-10 years	Full participation
	I4	Optical Design and Analysis Engineering	private sector	6-10 years	Full participation
	I5	Optoelectronic	private sector	1-5 years	First round
	I6	Optoelectronic, Semiconductor Fabrication	National Nanotechnology Research Center	6-10 years	Full participation
	I7	Laser Design Engineering	private sector	6-10 years	Full participation
	I8	Optical Engineering	private sector	6-10 years	Full participation
Education	**E1**	Atomic and molecular physics	Atatürk University	26 years and above	Full participation
	E2	Physics Education, Solid State Physics	Gazi University	26 years and above	Full participation
	E3	Chemistry Education	Boğaziçi University	11-25 years	Full participation
	E4	Physics Education	Balıkesir University	11-25 years	Full participation
	E5	Science education	Ege University	11-25 years	Full participation
	E6	Physics and Science Education	Bursa Uludag University	26 years and above	Full participation

3.3. Data Collection Process

In the first round of the study, online interviews were held with the experts. According to the Delbecq et al. (1986) the limited social-emotional rewards and verbal clarification might restrict the experts' decision-making process. In order to avoid that and increase the rate of return the first round of the Delphi process decided to carry out with interviews instead of written responses. Through the online meetings approximately took one hour per expert, 5 open ended questions are asked. Only one participant (P9) did not be interviewed instead, conveyed answers via e-mail through the open-ended questionnaire form. The interview form and the questionnaire form used in the first round are given in the appendices as Appendix-A, and Appendix-B respectively. The five questions are determined by researchers according to the pedagogical needs in the photonics education and literature. All the five questions are asked to the experts in the same sequence. All the participants informed about the Delphi Process before the interviews and confirmed to attend next round.

In the second round of Delphi process, the survey prepared based on the experts' opinions in the first round send to all participants. Twenty of the twenty-three experts are completed the survey on Google Docs. In this process, participants evaluate the Likert scale items considering the needs and future of the photonics education.

3.4. Data Collection Tool

In the first round of Delphi, 5 open-ended questions were prepared to ask to experts. "The Photonics Education Survey" is prepared by the researchers for the data collection. Then based on the survey, interview form was prepared and used in the interviews. The interview form and the questionnaire form used in the first round are given in the appendices as Appendix-A, and Appendix-B respectively. As the participants have diverse backgrounds, in order to increase clarity, alternative questions for each question were prepared and had been asked.

In the second round of the Delphi, data collected via survey with Likert scale questions. The survey was created and responded in Google Docs. The questions and the items are composed of the analyzed and coded answers of the experts from the first round of Delphi. Therefore, in this round, participants had chance to evaluate other ideas and re-evaluate their own ideas had been shared in the first round. The survey items are giving in the Apprendix-C below.

3.5. Data Analysis

Data analysis in this research carried out in the rounds separately: for the first-round data analysis content analysis, for the second-round data statistical analysis had been done. In the first round, data collected through structured interviews with experts. The opinions of the experts transcribed after the interviews. The transcriptions were exposed to content analysis for the discovery of the opinions, question by question. Content analysis is the process of minimizing and consolidating textual data in a sensible way while preserving its essential coherence and meaning (Miles & Huberman 1994; Patton, 2002). While managing the opinions, the general ideas were tried to be preserved. In order to determine whether the sub-groups have significantly diverged or dominant ideas, the subgroups analyzed within themselves, and the codes were defined accordingly. In the analysis of the collected data, coding can be done according to (a) predetermined concepts, (b) the concepts derived from the data, or (c) it can be done within a general framework, which is a combination of two methods (Çepni, 2018). In this study, general framework of the concepts according to the questions were existed however some concepts are derived from experts' descriptions while some directly consisted with predetermined concepts. After the codes and themes identified, the frequencies are determined and the survey form for the second round was constructed. The researchers are determined the items based on the full agreement.

Varieties in the Delphi designs derived from participant numbers, aim of the research and resources leads to diversities in the agreement level definitions and disallow the formation of a universally used consensus statement (Hasson et al., 2000). In this study, similar to the consensus definition used by Krijtenburg-Lewerissa et al. (2019) "analysis mean ≥ 3.5 and variance ≤ 1" indicates a consensus regarding the importance the statement and considered as agreed statements as given in Table 3.

Table 3

Consensus Analysis

Mean	Variance	Description	Color
Mean ≥ 3.5	Variance ≤ 1	A consensus regarding the importance of a concept / method / setting	
Mean < 3.5	Variance ≤ 1	A consensus regarding the unimportance of a concept	
	Variance > 1	No consensus is obtained concerning the importance of a concept	

After the consensus analysis in the second round of Delphi, for some items on which consensus was not obtained, the mean ranks between the groups were compared and it was evaluated whether there was a statistically significant difference among the groups of experts.

For this reason, the non-parametric Kruskal Wallis H- test was used, which compared the mean ranks by converting the values into ordinal (Çepni, 2018).

CHAPTER FOUR
FINDINGS & RESULTS

In this section, the findings of the study are presented, according to the Delphi process.

4.1. Photonics Concepts

In this section, concepts to acquire students in photonics education are presented based on the expert opinions from Delphi process.

4.1.1. Photonics Concepts: The First Round Delphi Findings:

In the first round of the Delphi process, interviews with experts were made and they were asked to answer 5 open-ended questions. As the first question of the questionnaire used in the interviews, experts were asked "What are the essential concepts in photonics that should be taught in science education?". Also, in order to increase clarity and easy response an alternative question was asked which is "Which of the knowledge on photonics do you think students should acquire in elementary, secondary, and college levels?". The answers of experts after the content analysis are giving in the Table 4. The answers of the experts were analyzed within the sub-groups which are Education, Photonics, and Industry and given in the Table 4 based on this analysis. The codes in the table are contents obtained from the interviews and themes are the levels of the contents stated by the experts while sub-themes were defined by researchers based on the Turkish Science and Physics Curricula.

Table 4

Photonics concepts from first round Delphi

Theme	Sub-theme	Codes	f(Edu) n=6	f(Phot) n=9	f(Ind) n=8	TOTAL n=23
Middle School Level	The Nature of Light	Light and features of light	3	2	4	9
		Wave property of light	1	3		4
		Particle property of light	1	1		2
		Wave and particle property of light		1		1
		Speed of light	1			1
	Interaction of Light with Matter	Diffraction		2	1	3
		Reflection		2		2
		Lenses		1	1	2
		Mirrors		2		2
		Colors - RGB			1	1
		The relationship between temperature and color			1	1
	Transmission of Electricity	Electrical Resistance				1
		Electrical Current			1	1
	Electrical Circuits	Circuits: Parallel and series coupling		1		1
		Electrical Current				1

Theme	Sub-theme	Codes	f(Edu) n=6	f(Phot) n=9	f(Ind) n=8	TOTAL n=23
		Lighting: Kelvin, Lumens concepts			1	1
	Energy Conversions and Environmental Science	Photosynthesis		1		1
		Sun and vitamin D, (association with biophotonics)		1		1
	Matter and Industry	Electron			1	1
		Periodic table and elements				1
		Semiconductivity		1		1
	Conversion of Electrical Energy	Energy and energy conservation; Energy production and consumption		1		1
	Extra-Curricular	Photon	1		2	3
		Lasers and their application areas		1	1	2
		Fiberoptics			2	2
		Optical devices (Camera, microscope, telescope)		1		1
		Light sources: Light bulb, LED, laser		1		1
		Semiconductor devices (laser, LED, detector)			1	1
	Examples of daily life in secondary school	Examples of daily life should be given.	3	2	4	9
		Why the sky is blue?		1	1	2
		What color light should be used in which room?			1	1
		Differences between LED and lamp			1	1
		Artificial lighting for plants			1	1
		Uploading information to the light: fiberoptics, music CDs		1		1
		Polarized glasses		1		1
		3D cinema		1		1
		Photography			1	1
High School Level	Optics	Reflection, Snell's Law and Refraction	1	2	1	4
		Optics Theories		1		1
		Light-matter interaction		1		1
	Wave Mechanics	Waves	1	1		2
		Electromagnetic spectrum		1		1
		Young's experiment		1		1
	Atomic Physics and Radioactivity	Structure of the atom	1	1		2
		Electron and Energy Levels	1	1		2
		Energy	1	1		2
		Generation of light	1		1	2
		Radiation	1			1
		Electrochemistry		1		1

Theme	Sub-theme	Codes	f(Edu) n=6	f(Phot) n=9	f(Ind) n=8	TOTAL n=23
	Modern Physics	Planck and Planck constant	1	1		2
		Photoelectric Effect		2		2
		The wave and particle nature of the light		1		1
		Momentum of light		1		1
	Applications of modern physics in technology	Laser		1	1	2
		LED		1	1	2
		Fiberoptics			1	1
	Electricity and magnetism	Conductivity and conductors			1	1
		Electrical circuits			1	1
	Physical Science	Thermodynamics		1		1
	Extra-Curricular	Simple P-N junctions		1	1	2
		Spectrum, Spectroscopy	1	1		2
		Photonics and its application areas		1		1
	Mathematics	Geometry		1		1
		Mathematical modeling		1		1
		Statistics		1		1
	High school daily life examples	Fiberoptics	2	1		3
		Imaging technologies	1	1		2
		Telescope construction				1
		Cameras and lenses		1		1
University Level	Lessons	Quantum Mechanics	1	5	1	7
		Basic Optics		3		3
		Solid state Physics		2	1	3
		Basic Electrical and Electronics courses	1		1	2
		Geometric Optics		1	1	2
		Modern Physics		1	1	2
		Semiconductor Physics		1	1	2
		Basic Sciences & Engineering Courses		1		1
		Photonic Circuit Elements		1		1
		Circuit Lessons		1		1
		Calculus		1		1
		Differential Equations			1	1
	Concepts	Electromagnetic Theory	1	4	1	6
		Interaction of light and matter		1		1
		Signal Processing		1		1
		Photoelectric Effect	1			1
		Heisenberg Uncertainty Principle	1			1
		Compton Scattering	1			1

Edu= Education, Phot= Photonics, Ind =Industry

As seen in the Table 4 light and features of light (f=9), mirrors (f=2), lenses (f=2), diffraction (f=3), fiberoptics (f=2), lasers and their application areas (f=2), photon (f=3) are some of the contents that experts suggested for teaching in middle school level. In high school level, reflection and refraction (f=4), Structure of the atom (f=2), electron and energy levels (f=2), LEDs (f=2) and laser (f=2) are some of the contents that experts suggested for teaching in high school level.

In the interviews it is observed that participants respond this question based on the context of the subjects. Therefore, some examples are preserved by themed under daily life examples.

Some of the explanations why experts suggest the concepts given in Table 4 are giving below:

> *Speaking at the high school level, the topics should generate curiosity. Laser and led difference can be given here. Narrating the scientific process of related inventions may increase interest. For example, the patent process of the laser. (I6)*

> *There is no need to change the subjects (in curricula). Photonics can be placed in physics, chemistry, biology. For example, in biology; The importance of vitamin D, the fact that photosynthesis is related to photonics, bio-photonics, photosensitive material, cancer treatment. In chemistry; periodic table, semi-metal and semiconductor connection, becoming conductive by doping, interaction with light... In physics, the optical part, when describing the mirror, the lens and then the photonics. (P1)*

The concepts that the experts suggested to teach in photonics education are coded and categorized in the Table 4. During this process researchers tried to avoid omitting the concepts and ideas. For this reason, the daily life examples are preserved and coded. In addition, in order some general ideas stating as the answers for the question are coded and bringing together in the Table 5.

As seen in the Table 5, researchers believe that cooperating the historical development of photonics and the important scientist in this process are essential in the photonics education. A quote supporting these ideas are giving below:

> *I think it would be more appropriate to briefly talk about the electromagnetic spectrum and leave it to the university. How did Maxwell derive it, where did he need it, how did the concept of electromagnetic wave originate, why did it not work in the black body, photoelectric phenomenon? How did quantum theory explain these events? It seems to me more appropriate at the university level that it should be dealt with in the context of history. It's like children can't understand too much. (E4)*

Table 5

General Ideas on Teaching Photonics in first round of delphi

Theme	Codes	f(Edu) n=6	f(Phot) n=9	f(Ind) n=8	TOTAL n=23
The Nature of Science Ideas	It should be given with the knowledge of historical development.	2	1	1	4
	Important scientists should be given in connection with the subjects.		2		2
	The cycle of science and technology influencing each other should be given.	1			1
General Ideas	The existing topics of optics and physics in the curriculum are sufficient, photonics topics should be added to these subjects.	1	1		2
	Both the particle and the wave property of the light must be given at the same time.	1			1
	Classical physics hinders students' learning. Modern physics can be taught directly to the new generation.		1		1

In addition, some ideas are preserved under the general ideas in Table 5. An example of a general idea on concepts of photonics education is given below:

> *Explaining modern physics after classical physics is not the right way. The new generation is capable of perceiving modern physics subjects much faster. Afterwards (when they come to university) we have difficulties when teaching modern physics. Modern physics can be directly taught to students in the early stages. ... Classical physics inhibits students' thinking. (P4)*

The contents obtained from first round of Delphi, were used in the survey of second round. When the survey is constructed, some of the contents were merged or separated based on all researchers' agreements.

4.1.2. Photonics Concepts: The Second Round Delphi Findings:

In the second round of the Delphi, the concepts obtained in expert interviews in the first round are included to survey as first question items. The first question of the survey is "Evaluate concepts that can be taught to students in the middle school (5th-8th grades), high school (9^{th}-12^{th} grade) and university levels in photonics education according to their necessity levels.". In this Likert-type evaluation, 1 indicates "dispensable", 5 indicates "indispensable". According to the degree of necessity of concepts evaluated by experts (n=20), mean and variance statistics has been calculated and analysis results have been shown in the Table 6.

Table 6

Photonics Concepts: The Second Round Delphi Findings

Photonics Concepts	N	Mean	Variance
Middle School Level			
Colors - RGB	20	4,4000	0,253
Reflection	20	4,5000	0,263
Optical devices (Camera, microscope, telescope)	20	4,1500	0,450
Speed of light	20	4,3500	0,555
Photosynthesis	20	4,0500	0,576
Light and features of light	20	4,5000	0,579
Sun and vitamin D, (association with biophotonics)	20	4,0000	0,632
Mirrors	20	4,3500	0,661
Light sources: Light bulb, LED, laser	20	4,1000	0,726
Electrical Resistance	20	4,0500	0,892
Lenses	20	4,1500	0,976
Lasers and their application areas	20	3,3500	0,976
Artificial lighting for plants	20	3,6000	0,989
Electrical Current	20	**3,7500**	**1,039**
Circuits: Parallel and series coupling	20	**3,7500**	**1,145**
Electron	20	**3,7500**	**1,145**
Energy and energy conservation; Energy production and consumption	20	**4,1000**	**1,147**
3D cinema	20	**3,1000**	**1,147**
Fiberoptics	20	**3,3500**	**1,187**
Periodic table and elements	20	**3,6000**	**1,305**
Uploading information to the light: fiberoptics, music CDs	20	**3,0500**	**1,313**
Wave property of light	20	**3,5000**	**1,316**
The relationship between temperature and color	20	**3,7500**	**1,355**
Particle property of light	20	**3,2500**	**1,355**
Wave and particle property of light	20	**3,3500**	**1,397**
Polarized glasses and UV protection	20	**3,2500**	**1,461**
Photography	20	**3,1000**	**1,463**
Photon	20	**3,3500**	**1,503**
Electrical Current	20	**3,6000**	**1,516**
Lighting: Kelvin, Lumens concepts	20	**3,1000**	**1,674**
Semi-conductivity	20	**3,1000**	**1,674**
What color light should be used in which room?	20	**3,4000**	**1,726**
Differences between LED and lamp	20	**3,5000**	**1,737**
Why the sky is blue?	20	**3,6500**	**1,818**
Semiconductor devices (laser, LED, detector)	20	**3,3500**	**1,818**
Diffraction	20	**3,7500**	**1,987**

Photonics Concepts	N	Mean	Variance
High School Level			
Waves	20	4,6500	0,239
Reflection, Snell's Law and Refraction	20	4,6000	0,253
Electromagnetic spectrum	20	4,6000	0,253
LED	20	4,6000	0,253
LASER	20	4,6000	0,253
Photonics and its application areas	20	4,5500	0,261
Young's experiment	20	4,4500	0,261
Electron and Energy Levels	20	4,5000	0,263
Energy	20	4,6000	0,358
The wave and particle nature of the light	20	4,4000	0,358
Light-matter interaction	20	4,5500	0,366
Structure of the atom	20	4,5500	0,366
Conductivity and conductors	20	4,5500	0,366
Radiation	20	4,4500	0,366
Electrical circuits	20	4,4500	0,366
Generation of light	20	4,4500	0,471
Photoelectric Effect	20	4,2500	0,513
Geometry	20	4,3000	0,537
Telescope construction	20	4,0500	0,576
Theories of Optics	20	4,2500	0,724
Cameras and lenses	20	4,0000	0,737
Statistics	20	**3,4500**	**0,787**
Imaging technologies	20	3,8000	0,800
Fiberoptics	20	4,2500	0,829
Mathematical modeling	20	3,9000	0,832
Momentum of light	20	3,8500	0,871
Thermodynamics	20	3,7500	0,934
Electrochemistry	20	3,8500	0,976
Planck and Planck constant	20	3,8500	0,976
Simple P-N junctions	20	**3,7500**	**1,039**
Spectrum, Spectroscopy	20	**3,8000**	**1,221**
University Level			
Optics	20	4,7500	0,197
Interaction of light and matter	20	4,7500	0,197
Photonic Circuit Elements	20	4,7000	0,221
Electromagnetic Theory	20	4,7000	0,221
Basic Electrical and Electronics courses	20	4,6500	0,345
Geometric Optics	20	4,6500	0,345
Circuit Lessons	20	4,5000	0,368
Basic Sciences & Engineering Courses	20	4,6000	0,463
Differential Equations	20	4,6000	0,463

Photonics Concepts	N	Mean	Variance
Solid state Physics	20	4,3500	0,661
Modern Physics	20	4,6000	0,674
Quantum Mechanics	20	4,4500	0,682
Semiconductor Physics	20	4,4500	0,682
Calculus	20	4,4500	0,682
Photoelectric Effect	20	4,5500	0,682
Compton Scattering	20	4,3000	0,747
Heisenberg Uncertainty Principle	20	4,4500	0,787
Signal Processing	20	**4,1000**	**1,042**

Similar to the consensus definition used by Krijtenburg-Lewerissa et al. (2019), shown in Table 3, mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the importance of a concept, in this analysis mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the necessity of the concept, variance > 1 indicates that no consensus is obtained concerning the necessity of the concept, and mean < 3.5 and variance ≤ 1 indicates consensus regarding the unnecessity of a concept. Therefore, at middle school level while consensus regarding the necessity of concepts such as colors, mirrors, reflection, optical devices (camera, microscope, telescope), light and features of light obtained, consensus regarding the necessity of concepts such as electrical current, circuits, electron, diffraction, photon, semi-conductivity did not be obtained. Also, in elementary level, for the lasers and their application areas consensus regarding the unnecessity of a concept is obtained. This indicates that experts believe teaching lasers at this level is dispensable. Furthermore, no concensus is obtained regarding the importance of simple p-n junctions and spectrum, spectroscopy at high school level and signal processing at university level. However, there is a concensus on uniportance of statistics for photonics education at high school level.

Table 7

The Analysis of General Ideas on Teaching Photonics in Second Round of Delphi

Theme	Code	N	Mean	Variance
Nature of Science Ideas	The cycle of science and technology influencing each other should be given.	20	4,6000	,253
	It should be given with the knowledge of historical development.	20	4,4500	,261
	Important scientists should be given in connection with the subjects.	20	4,3000	,432
General Ideas	Both the particle and the wave property of the light must be given at the same time.	20	4,5000	,474

	The existing topics of optics and physics in the curriculum are sufficient, photonics topics should be added to these subjects.	20	**4,0500**	**1,103**
	Classical physics hinders students' learning. Modern physics can be taught directly to the new generation.	20	**2,8000**	**1,958**

The statistical analysis of general ideas on teaching Photonics is given in Table 7 based on the experts answers to Likert-scale in the second round of Delphi process.

As seen in Table 7 there is a concensus on cooperating nature of science ideas with photonics concepts. However, there is no concensus obtained on the ideas which "The existing topics of optics and physics in the curriculum are sufficient, photonics topics should be added to these subjects." and "Classical physics hinders students' learning. Modern physics can be taught directly to the new generation.". The statistical values in the item "Classical physics hinders students' learning. Modern physics can be taught directly to the new generation." indicates the lowest consensus values in this study.

4.1.3. Photonics Concepts: The Results of Delphi Study:

Delphi analysis show that 12 items (concepts) out of 36 -with daily life examples- are reached consensus regarding necessity of the concept at elementary level and 29 items out of 31 concepts at high school level reached consensus regarding necessity of the concept in Photonics Education. In the first round of Delphi, as all answers were desired to be preserved and presented to other experts in second round. Therefore, since the number of concepts were increased in the first round, the number of eliminated concepts in second round also been increased. The concepts which have more frequency in the first round, mainly reached consensus on its necessity in the second round, might indicate consistency in experts' answers. Furthermore, the Delphi analysis reveals that instead of giving all the information at once, the participants preferred to increase the topics by detailing them according to the levels of education.

4.2. Skills and Attitudes for Photonics

In this section, skills and attitudes to acquire students in photonics education are presented based on the expert opinions from Delphi process.

4.2.1. Photonics Skills and Attitudes: The First Round Delphi Findings:

As the second question of the questionnaire used in the interviews, experts are asked "What are the essential objectives regarding skills and attitudes in photonics that should be taught in science education?". Also, in order to increase clarity and easy response two alternative questions are asked which are “What skills and attitudes do you think the individuals in society and employees in photonics-related fields should have?” and “What skills and attitudes would you expect the individuals have acquired to understand and use photonic technologies?”. The answers of experts after the content analysis are giving in the Table 8. The answers of the experts were analyzed within the sub-groups and given in the table based on this analysis. Thus, the columns are organized by sub-groups of experts which are education, photonics, industry and the combination of their ideas are given under the heading "form".

Table 8

Photonics Skills and Attitudes: The First Round Delphi Findings

	EDUCATION (n=6)		**PHOTONICS (n=9)**		**INDUSTRY (n=8)**		**TOTAL (n=23)**	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**CODE**	**f**
Science Process Skills	Experimenting	2	Experimenting	2	Experimenting	1	Experimenting	5
	Analyzing data	1	Data Collection and Analyzing	2	Data Analysis	1	Data Collection and Analysis	4
	Observation	1	Observation	1			Observation	2
			Making inferences	1			Making inferences	1
					Experiment planning / Identifying variables	1	Experiment planning / Identifying variables	1
	Scathing a graph / Using Data and creating models	1					Drawing a graph / Using Data and creating models	1
Engineering Design Skills	Problem-solving skills	4	Problem-solving skills	1			Problem solving skills	5
	Engineering Design Skills (General)	1			Making literature review and conducting research	3	Literature Review and Research Skills	3
			Product, Project Development Skills	1	Project Development Skills	1	Product and Project Development Skills	2
Thinking skills			Inquiring	4	Inquiring	2	Inquiring	6
	Analytical thinking skills	1			Analytical thinking skills	2	Analytical thinking skills	3
	Critical and critical thinking skills	2					Critical thinking skills	2

	EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		TOTAL (n=23)	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**CODE**	**f**
			Scientific thinking skills	2			Scientific thinking skills	2
	Creative thinking skills/creativity	1					Creative thinking skills/creativity	1
			Mathematical thinking skills	1			Mathematical thinking skills	1
Technical skills	Psychomotor skills	2	Psychomotor skills	2	Motor skills	2	Psychomotor skills	6
	Ability to design the Optical Experiment	1	Basic optical design skills	1	Ability to Design Optical Experiment Setups	2	Optical Experiment Setups Designing Skills	5
	Device usage skills	3					Device usage skills	3
Other 21st century skills	21st Century skills (general)	3			21st century skills (general)	2	21st Century skills (general)	5
	ICT (Information Communication Technology) Skills	1	ICT skills and coding	1	Ability to use computers / software	4	ICT skills/ Computer usage / informatics / software skills	6
	Communication skills and collaboration	2			Cooperation and Teamwork	3	Communication skills and collaboration	6
					Communication skills	2		
					Time management	1	Time management	1
					Entrepreneurship and leadership	1	Entrepreneurship / leadership	1
Scientific Literacy	Interest and curiosity towards science	2	Scientific curiosity	1	Interest in the field, curiosity	2	Scientific curiosity / Interest in the field, curiosity	5
	Daily life usage and familiarity	1	Daily life usage	3	Daily life usage and familiarity	1	Daily life usage and familiarity	5
	Reasoning in the field of science and technology	1	Reasoning in the field of science and technology	1	Reasoning in the field of science and technology	1	Reasoning in the field of science and technology	3
			Understanding the nature of science	2			Understanding the nature of science	2

As seen in Table 8 skills and attitudes table, similar opinions obtained from the expert sub-groups. The skills mentioned in this section, are categorized as *science process skills,* *engineering design skills, thinking skills, technical skills, 21st century skills,* and attitudes found related to *science literacy* and given as themes in the table.

An example statement of expert P1 on problem solving skills (f=5) are given below:

> *This is not only for photonics but in general... We need to raise individuals who can solve problems. This requires the ability to see and prevent the problem before it occurs and to synthesize different information. (P1)*

Inquiring, categorized under the theme thinking skills, is exemplified with a quotation below:

> *Questioning the accuracy of the information…. S/he (student) should be able to question what s/he hears before he believes it. …(Also) to arouse curiosity about photonics... Examples from daily life can be used for this. (I5)*

A sector employee (I4) mentioned about 21st century skills (f=5) especially collaboration and cooperation (f=6) and research skills (f=3) as an important skills employee in this field must have as stated below:

> *Bringing 21st century skills into the lesson: for example, the ability to work in harmony in a team, self-learning through research skills, not giving up when faced with a challenge, caring about the opinions of others. In engineering, for example, it is very important to exchange ideas with others. (I4)*

Ability to design optical experiment setups (f=5) is another most suggested skills coded as technical skills, exemplified by P5 given below:

> *Ability to use optical setups... For example, imaging will be done by optical setups. Ability to know and use optical apparatuses is required here. (P5)*

The opinions of P8 on coded as understanding the nature of science (f=2) and reasoning (f=3) in the field of science and technology under the theme scientific literacy are giving below:

> *It is necessary to make them realize that nature is not the way we want it to be, but the way it is. Nature does not have to conform to our experience. (Student) should be able to accept when he encounters concepts other than his/her usual experience. (Student) should know the history of science. These technologies have long process, they were not made overnight. (P8)*

After the codes in the Table 8, united and simplified for the survey form, 25 skills and attitudes selected as survey items. These skills and attitudes were evaluated in the second round of Delphi by experts.

4.2.2. Photonics Skills and Attitudes: The Second Round Delphi Findings

In the survey used in the second round of Delphi, experts were asked to evaluate the skills and attitudes acquired for an effective Photonics Education. The question the survey was

“Evaluate the skills and attitudes can be acquired to students with Photonics Education, according to their level of necessity.” In this Likert-type evaluation, 1 indicates “dispensable”, 5 indicates “indispensable”. According to the degree of necessity of skills and attitudes evaluated by experts (n=20), mean and variance statistics has been calculated and analysis results have been shown in the Table 9.

Table 9

Skills and Attitudes in Photonics Education: The Second Round Delphi Findings

Theme	Codes/ Skills	N	Mean	Variance
Science Process Skills	Observation	20	4,5000	,263
	Making inferences	20	4,6000	,253
	Experimenting	20	4,5500	,261
	Experiment planning / Identifying variables	20	4,5000	,474
	Drawing a graph / Using data and creating models	20	4,5000	,368
	Data Collection and Analysis	20	4,6500	,239
Engineering Design Skills	Product/project development skills	20	4,3500	,450
	Problem solving skills	20	4,5500	,366
	Literature review and research skills	20	4,3500	,345
Thinking Skills	Inquiring	20	4,7000	,326
	Analytical thinking skills	20	4,6500	,345
	Critical thinking skills	20	4,6500	,345
	Creative thinking skills/creativity	20	4,8000	,168
	Scientific thinking skills	20	4,8000	,168
	Mathematical thinking skills	20	4,6000	,358
Technical Skills	Psychomotor skills	20	4,2500	,513
	Optical experiment setup designing skills	20	4,5000	,579
	Device usage skills	20	4,4500	,471
Other 21st Century Skills	ICT / Computer usage / informatics / software skills	20	4,4500	,366
	Communication skills and collaboration	20	4,0500	,682
	Time management	20	4,1500	,661
	Entrepreneurship and leadership	20	3,8000	,800
Scientific Literacy	Scientific curiosity / Interest in the field, curiosity	20	4,7000	,326
	Appreciation of daily life usage and familiarity	20	4,2500	,724
	Reasoning in the field of science and technology	20	4,3500	,555

Similar to the consensus definition used by Krijtenburg-Lewerissa et al. (2019), shown in Table 3, in this analysis mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the necessity of skills and attitudes. Therefore, for all the skills and attitudes concensus regarding their necessity is reached in Table 9.

4.2.3. Skills and Attitudes for Photonics: Results of Delphi Study:

The Delphi process showed that in photonics education, experts were suggesting students to acquired science process skills, engineering design skills, thinking skills, technical skills, 21st century skills, and science literacy in general. Data collection and analysis as science process skills is considered important, while problem solving skills as engineering design skills; creative thinking skills/creativity and scientific thinking skills as thinking skills; ability to design optical experiment setups as technical skill, ICT (Information and Communications Technology) skills as 21st century skills; scientific curiosity and interest in the field as science literacy are featured. While these skills are currently used in science education, the purpose here is to determine the skills that should be highlighted in photonics education, considering that it will be useful in understanding, using, and developing photonics in the future. The experts are consulted with this rationale. As understood from the quotation of P1 which is "This (skill) is not only for photonics but in general...", the experts also evaluated the skills from this point of view, parallelly.

The attitudes related to Photonics are associated with the science literacy goals; therefore, this theme was named as science literacy. Yet, photonics literacy may be a more suitable caption for this theme, and codes under this theme can be used as the definition of photonics literacy.

The second round of the Delphi showed that all the skills and attitudes mentioned in the first round had reached a consensus regarding their necessity. Furthermore, the skills that the most frequently mentioned on first round, also showed consensus regarding their suitability by statistics (mean ≥ 3.5 and variance ≤ 1). These results may indicate the stability of the opinions of the experts.

4.3. Teaching Methods Used in Photonics Education

In this section, the teaching methods can be use in photonics education are presented based on the expert opinions from Delphi process.

4.3.1. Teaching Methods Used in Photonics Education: The First Round Delphi Findings:

In the interviews with experts during the first round of the Delphi process, the suitable teaching strategies and methods for Photonics Education were asked via question 3 "*How does Photonics could be taught effectively in schools or universities?*" and its alternative question "*What could be the teaching techniques for effective photonics education?".* The answers from experts are giving in the Table 10. The answers of the experts were analyzed within the sub-groups and given in the table based on this analysis. Thus, the columns are organized by sub-groups of experts which are education, photonics, industry and their combination of their ideas are given under the heading "form".

Table 10

Teaching Methods Can Be Used in Photonics Education from the First Round Delphi Findings

EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Code	**f**	**Code**	**f**	**Code**	**f**	**CODE**	**f**
With experiments	3	With experiments	7	With experiments	4	With experiments	11
Project-based learning	2	Project-based learning	3	Project-based learning	4	Project-based learning	9
		With demonstrations	6	With demonstrations	1	With demonstrations	7
Context-based approach: Real-life events and developments should be integrated	3	Context-based approach: Real-life events and developments should be integrated	1	Context-based approach: Real-life events and developments should be integrated	3	Context-based approach: Real-life events and developments should be integrated	7
Training in a Laboratory Environment	2	Training in a Laboratory Environment	1	Laboratory-assisted training	3	Laboratory work	6
Computer- based Learning and Simulations	2	Technology and visual support such as animation, animation, visualization, video, virtual reality, VR	3			Computer and Technology Aided Learning (Simulation, animation, visualization, video, virtual reality, VR as well as technology and visual support)	5
Problem-Based Learning	1	Light-based application studies, or problem-based investigations	1	Problem-Based Learning	3	Problem-Based Learning	5
Inquiry based learning	2	Inquiry based learning	1	Inquiry based learning	1	Inquiry based learning	4
To be benefit from the history of science and examples from scientists	1	To be benefit from the history of science and examples from scientists	1	To be benefit from the history of science and examples from scientists	1	To be benefit from the history of science and examples from scientists	3
Socioscientific topics from the field of photonics are selected and discussed in the classroom environment	1	Discussion	1	Discussion	1	Discussions / Socioscientific topics from the field of photonics are selected and discussed in the	3

EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Code	**f**	**Code**	**f**	**Code**	**f**	**CODE**	**f**
						classroom environment	
Creative Drama	2	Group work	1	Group work	1	Group work	2
Student-centered	2	Technical trips, Lab visits	2	with Experiment Kits	2	with Experiment Kits	2
Techniques such as 6 hats / 6 shoes	1	with posters, boards	1	By discovery	1	Technical trips, Lab visits	2
Constructivist teaching methods	1					Discovery learning	1
						Creative Drama	2
						Student-centered environments	2
						Constructivist teaching methods	1
						Techniques such as 6 hats / 6 shoes	1
						With posters, boards	1

The answers to the questions towards teaching methods are show that the expert groups have similar opinions. Project (f=9) and problem-based (f=5) lessons, daily life integrations to classrooms through context-based learning (f=7), inquiry-based learning (f=4) environments that enable investigations and higher thinking, discussions in classrooms (f=3), experiments (f=11) and demonstrations (f=7) in laboratory (f=6) or classrooms and web or computer aided learning environments (f=5) are some of the recommendations from the experts.

The experts suggested to visualize the subjects because of the abstract nature by experimentation and computers. Some quotations supporting this idea are:

> *The laboratory environment should definitely be. This is a very difficult subject to learn without being visualized. It can also be better understood when computer aided. (E1)*
>
> *It will be permanent when to be able to show what is being told through experimentation at that moment. ... In fact, the ideal is for the students to practice and discover themselves. (P7)*

Problem and project-based lessons another most recommended methods according to the table. Expert I2, suggested both:

> *It would be beneficial to give students responsibility with practice-oriented studies and to receive feedback. This can be based on a problem or a project. During*

the education process, students should be provided with access to some tools. This can be a problem sometimes, (therefore) tools that combine with everyday toys can also be used. For example, magnifying glass or simple circuits. Positive attitudes and skills should be developed on theoretical knowledge until university. (I2)

Although argumentation and discussion are not the same, they were coded together when sub-groups' ideas united. The opinion on suggesting argumentation on classroom was developed by saying that:

Okay, photonics has come to the fore as a marvel of technology, but are there any harms? That is… opportunities can be created for them(students) to think about their positive and negative aspects. ... So, this technology is coming, for example, we can expect a barcode reader to discuss whether it is harmful to the environment, does it harm people or living things, or what problems it may cause, in general. In the case of production, consumption and waste of a photonic product, the damage it causes to the environment can be discussed. (E3)

According to the E5 creative drama can be used in classrooms as follows:

Drama can be used to reinforce scientific theory after learning. For example, students may be asked to dramatize photon movements. (E5)

In addition to these ideas stated the idea on how the teacher can be as follows:

There should be an interactive student-teacher relationship. It is important for the teacher to be scientifically literate, and they should make book recommendations. …. It is possible to select experiments that students want: There are ready-made experiments, students choose the ones to do in the classroom. These can be demonstration type experiments. (P8)

The instructor should know the teaching methods and techniques well and use the one that best serves the purpose. S/he should adjust the lesson well according to the environment: should take into account the readiness and social-cultural levels of the students. Unless the student is open to receiving (knowledge), even the most equipped teacher cannot teach it. (E2)

Based on the answers of the experts in the first round of Delphi, the survey form that used in the second round had been constituted. For the survey items, the content analysis of the Table 10 was done by the researchers again and some ideas are consolidated with each other. This second analysis process enabled to reduce the number of survey items and make it easier to answer. The final version of the first-round teaching methods which experts recommended to use answers are given in the Table 11.

Table 11

Survey Items of Teaching Methods for Photonics Education from the First Round Delphi Findings

Teaching Methods	f
Laboratory work	11
Project-based Learning	9
Context-based Learning	7
Demonstration	7
Problem-Based Learning	5
Computer-aided Learning / Web-based Learning	5
Inquiry-based learning	4
Integration of the history of science and the life of scientists	3
Argumentation	3
Group work / Cooperative Learning	2
Field Trips, Technical trips, Advanced Lab visits	2
Creative Drama	2

In the final form of the survey used in second round of Delphi, 12 teaching method and strategy listed as survey items.

4.3.2. Teaching Methods Can Be Used in Photonics Education: The Second Round Delphi Findings:

In the second round of the Delphi, experts were asked to "Evaluate the teaching strategies, methods and techniques that can be used in Photonics Education according to the degree of suitability.". Experts evaluated the teaching methods that had been stated in the first round. In this Likert-type evaluation, 1 indicates "not suitable", 5 indicates "very suitable". According to the degree of suitability of teaching method evaluated by experts (n=20), mean and variance statistics has been calculated and analysis results have been shown in the Table 12.

Similar to the consensus definition used by Krijtenburg-Lewerissa et al. (2019), mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the importance of a concept, in this analysis mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the suitability of the teaching method, variance > 1 indicates that no consensus is obtained concerning the suitability of the teaching method as shown in Table 3. Therefore, in all the teaching methods but "Creative Drama" concensus regarding the suitability of the teaching method is reached in Table 12. There is no consensus is obtained concerning suitability of the "Creative Drama" in the Photonics Education according to the evaluations of the experts.

Table 12

Teaching Methods in Photonics Education: The Second Round Delphi Findings

Teaching Methods	N	**Mean**	**Variance**
Laboratory work	20	4,7500	,197
Inquiry-based learning	20	4,5000	,474
Context-based learning	20	4,4500	,471
Problem-based learning	20	4,4000	,358
Project-based learning	20	4,4000	,463
Field trips, Technical trips, Advanced Lab visits	20	4,4000	,674
Computer-aided Learning / Web-based Learning	20	4,2500	,513
Demonstrations	20	4,2500	,724
Integration of the history of science and the life of scientists	20	4,1000	,516
Cooperative Learning / Group-working	20	4,1000	,621
Argumentation	20	3,9500	,576
Creative Drama	20	**3,3000**	**1,695**

As seen in the Table 12, experts found 11 teaching methods suitable for the photonics education teaching environments, especially which are; the laboratory work, context-based learning, inquiry-based learning, problem-based learning, project-based learning and field-trips.

Kruskal-Wallis Test was conducted to examine the differences on the suitability of "Creative Drama" rankings according to the expert sub-groups (education, photonics, industry). No significant differences (Chi square = 3.780, p = .151, df = 2) were found among the three sub-groups of experts with mean rank score of 9.83 for education, 8.25 for photonics, 14.17 for industry.

4.3.3. Teaching Methods Used in Photonics Education: Results of Delphi Study:

Delphi process revealed that when teaching photonics, experts found suitable instructor to use laboratory work, project-based learning, context-based learning, demonstration, problem-based learning, computer-aided learning or web-based learning, inquiry-based learning, integration of the history of science and the life of scientists, argumentation, cooperative learning, field trips such as technical trips, advanced lab visits. According to the results of second round data laboratory work, inquiry-based learning, and context-based learning are the most favorable teaching methods in photonics education. Although creative drama suggested in the first round by two experts from education sub-group, in the second round of Delphi consensus was not obtained concerning suitability of the "Creative Drama" in the Photonics Education.

Experts are also found to gave importance to integrate history of science and the life of scientists into the photonics lessons. Findings on this issue appear under different themes as well.

Argumentation is also found to suitable for photonics education. However, statistical analysis show that it is the least suitable or favorable method compared to others.

The order of teaching methods in Table 11 based on the frequencies are consistent with the order of teaching methods in Table 12 based on the mean values. This might be the indication of consistency of the answer in the first and second round of the Delphi.

4.4. Evaluation Methods in Photonics Education

In this section, the evaluation methods can be use in photonics education are presented based on the expert opinions from Delphi process.

4.4.1. Evaluation Methods in Photonics Education: The First Round Delphi Findings:

The fourth question of the interviews had been asked to experts in the first round of the Delphi was "*What could be the evaluation techniques for effective photonics education?"* and alternative question was "*How does Photonics Education could be evaluated effectively in schools or universities*?". The answers of the experts were analyzed within the subgroups and merged for the survey form used in the second round as shown in Table 13.

As seen in the Table 13 projects (f=8), assignments (f=4), exams (f=3), experimental design questions (f=4) are the most suggested evaluation methods can be used in the photonics education according to the experts.

Table 13

Evaluation Methods Used in Photonics Education from The First Round Delphi Findings

	EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**Code**	**f**
Methods that can be used for evaluation	Projects (to be carried out in a classroom environment)	1	Projects	3	Projects (e.g. idea/product development to make daily life easier)	4	Projects	8
	Exams consisting of open-ended questions	1	Exams	3	Exams consists of both open-ended and test questions	1	Exams	5
	Test reports	1	Assignments	2	Product-based assignments	1	Assignments	4
	Pre-post assessments: measurement at entry and exit, before and after application	1	Quizzes	2	Quizzes / Pop-quizzes	1	Quizzes / Pop-quizzes	3
	Group worksheets	1	Assignments (Research-based)	1	Internships and training record book	1	Class discussions	2
	Observation forms	1	Project-based assignments	1			Group worksheets	1
	concept maps, concept cartoons to support conceptual learning	1	Application assignments: Involve calculation and design	1			Observation forms	1
	Classroom discussions	1	Class discussions	1			Test reports	1
	Rubrics	1	Project competition	1			Project competition	1
Question types	Questions to measure experimental skills	1	Experimental, experiment set-up questions	2	Experimental, experimental design questions	1	Experimental design questions	4
	Open-ended exam questions	1	Open-ended exam questions	1	Open-ended questions	1	Open-ended exam questions	3
	Context-based, scenario-based questions related to everyday life	1			Questions students can comment on	2	Reason-Comment questions (Questions students can comment on)	2
					Test questions	1	Context-based, scenario-based questions	1

		related to everyday life	
Questions for measuring knowledge	1	Test questions	1
		Knowledge questions	1

Examples of the expert opinions that point to evidence of using project as evaluation are given below:

Project-based assignments are appropriate. For example, tool development assignment with light-matter interaction. ... Assignment can be given to develop a tool to measure the brew of tea, where absorbance, spectroscopy come into play. ...(P3)

They (students) may be asked to develop a product or idea that will make daily life easier. (I1)

In addition to these ideas on evaluation methods, I3 suggested that during the evaluation multiple evaluation methods can be used to assess all student's knowledge as stating:

Students may not transfer what they know in the same way. Therefore, different test conditions can be applied. Evaluation should not be based on a single method, but by all possible methods. (I3)

The opinion of E3, who also believe the evaluation should be part of the education throughout the process, is as follows:

In the project development part, some tools should be used to evaluate both the product and the process. What is the process, how did the student progress, what did he do? At each level, it is necessary to support it with the written scores. Perhaps the student may be asked to prepare a portfolio. There is a progress that will not come out overnight, test reports can also be included in the portfolio. The articles can be included also, with the evaluation of these articles, reflections. Eventually, a product will emerge. I also think that the product should be evaluated. (E3)

After the analysis of opinions of expert on evaluation methods and strategies can be used in photonics education, 23 items selected by researchers to use in the survey part of the Delphi process.

4.4.2. Evaluation Methods in Photonics Education: The Second Round Delphi Findings:

In the survey, 23 items for evaluation methods can be used in Photonics Education are asked to evaluate to experts via the question: "Evaluate the evaluation strategies, methods and techniques that can be used in Photonics Education according to their degree of suitability.”. In this Likert-type evaluation, 1 indicates “not suitable”, 5 indicates “very suitable”. According to the degree of suitability of evaluation method evaluated by experts (n=20), mean and variance statistics has been calculated and analysis results have been shown in the Table 14.

Table 14

Evaluation Methods Can Be Used in Photonics Education: The Second Round Delphi Findings

Theme	Code	N	Mean	Variance
Methods that can be used for evaluation	Project competitions	20	4,3500	0,239
	Experiment reports	20	4,3500	0,345
	Assignments (short-term, weekly assignments)	20	4,3000	0,432
	Classroom discussions	20	4,3000	0,432
	Project assignments (to be carried out outside the classroom)	20	4,3000	0,537
	Research papers (long-term)	20	4,3000	0,747
	Assignments (product-based, including calculation and design)	20	4,2500	0,408
	Projects (to be carried out in a classroom environment, related to achievement)	20	4,2500	0,513
	Observation Forms	20	4,1500	0,555
	Exams consisting of open-ended questions	20	4,1000	0,726
	Pre-post assessments	20	4,0500	0,471
	Internships and training record book	20	4,0000	0,737
	Group worksheets	20	3,9500	0,366
	Rubrics	20	3,9500	0,787
	Concept maps and concept cartoons	20	3,9000	0,411
	Portfolios	20	3,8500	0,345
	Exams consists of both open-ended and test questions	20	**3,4000**	**1,411**
	Exams consisting of test questions	20	**2,4000**	**1,095**
Question Types	Experimental, experimental design questions	20	4,3500	0,450
	Questions that enable to apply and use knowledge	20	4,3500	0,450
	Reason-Comment questions (Questions students can comment on)	20	4,5000	0,474
	Knowledge questions	20	4,0000	0,632
	Context-based, scenario-based questions related to everyday life	20	4,3500	0,661

As seen in the Table 14, all the evaluation methods and strategies except from the ones includes test questions found suitable to use in photonics education. There is no consensus is obtained concerning suitability of the “Exams consists of both open-ended and test questions” and “exams consisting of test questions” in the Photonics Education according to the evaluations of the experts (variance >1).

According to the analysis results given in Table 14, organizing project competitions, using experiment reports, giving short-time (e.g., weekly) assignments, providing classroom discussions, giving project assignments carried out outside the classroom, assessing long-term research papers are the most favorable evaluation techniques can be used in the Photonics education suggested by experts of this research. Experts are also found to give importance to experimental design questions and questions that enable students to apply and use their knowledge.

4.4.3. Evaluation Methods in Photonics Education: Results of Delphi Study:

The Delphi study analysis showed that experts in this study suggested non-traditional evaluation methods in the Photonics education such as projects, assignments that promote product design, evaluations that use of knowledge in the field and experimental design skills. These evaluations can be used for both knowledge and skills mentioned in previous sections. For example, experimental set up design skills was suggested under the theme of technical skills, project design and problem-solving skills under the engineering skills are directly related to given answers in this section. Therefore, possible to say there is a consistency in experts’ suggestions in objectives, learning methods and evaluation techniques.

4.5. Informal Settings in Photonics Education

In this section, the findings from the Delphi study are presented under the informal settings theme of Photonics Education.

4.5.1. Informal Settings in Photonics Education: The First Round Delphi Findings:

In the first round of Delphi, experts were asked “What are the informal (out-of-school) activities that can be designed at schools/universities for photonics education?”. According to their answers, the findings about the suitable informal activities to promote photonics education are presented in Table 15 below.

In the Table 15 the frequency of the answers of experts are presented according to their expert sub-groups; education (n=6), photonics (n=9), and industry (n=8) and the consolidated answers (n=23) for the questionnaire form.

Table 15

Informal Settings in Photonics Education from the First Round Delphi Findings

	EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**Code**	**f**
Field Trips and Visits	Industry/ Factory Visits	3	Company/ Factory visits	3	Industry / Company / institution / organization visits	6	Company/ Factory visits	12
	Science and Technology Center & Science Museum Visits	5	Science Museums Visits	1	Science and Technology Center Visits	2	Science and Technology Center and Science Museums visits	8
	Medical Device Center, Laboratory, Research Center	1	Laboratory/ University Laboratory visits	2	Laboratory trips	1	Laboratory/ Research Center visits	4
	University trips	1			Institute visits	1	University/ Institute visits	2
					Science Technology Fairs	2	Science Technology Fairs	2
					Observatory visit	1	Observatory visit	1
					Museum tour	1	Museum tour	1
Media & Broadcasting	Science and technology magazines, popular science readings, reviews, and research	1	Science magazines, posters, posters, magazines, models, popular science books	2	Popular science journals	1	Readings, reviews and research from science magazines, posters, magazines, popular science books	4
					Social Media Platforms such as YouTube, Instagram	1	Social Media Platforms such as YouTube, Instagram	1
Observation and Demonstration Experiment Activities	Nature observations: such as sun, color	1	Observing nature/everyday life: such as the northern lights	2	Physical observation in the schoolyard or in houses e.g., rainbow	2	Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)	5

	EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**Code**	**f**
	Interesting events to arouse curiosity about the Light	1	Experimentation of reflection, interference, refraction and diffraction phenomena	1	Experiments that can be carried out on the subject	1	Demonstration experiment activities associated with the nature of light	2
	Astronomical events such as, types of telescopes, observation	1	Astronomical Observation Activities: outdoor observation activities	1			Astronomical Observation Activities, observations with different telescopes	3
			Making and using Telescope	1				
In-school Activities	Project Assignments	1	Project assignments	1	Project assignments	2	Project Assignments	4
	School Exhibitions	1	Science Festivals	1	Contests and rewards	2	Contests and rewards	2
	Class Discussions: socio-scientific scenarios can be given and discussion environment can be created	1	Awareness-raising activities	2			Science Festivals	1
			Teaching of upper classes to lower classes / peer training (voluntarily)	1			School Exhibitions	1
			Student societies and clubs	2			Student clubs	2
							Teaching of upper classes to lower classes / peer training	1
							Class Discussions	1
							Awareness-raising activities	2

	EDUCATION (n=6)		PHOTONICS (n=9)		INDUSTRY (n=8)		FORM (n=23)	
Theme	**Code**	**f**	**Code**	**f**	**Code**	**f**	**Code**	**f**
School-University-Sector Cooperation & Outreach	Inviting speakers to schools: online activities and seminars	3	To invite people from relevant companies, universities and/ or sectors on photonic technologies, to organize seminars	3	Inviting experts in the field / people who have made a career in this field to the school	3	To organize interviews or virtual meetings on photonic technologies by inviting relevant companies from the university and/or sector	9
	Requesting videos from field workers	1	Career planning activities	1	Planning career days	1	Career day / career promotion events	2
			Visiting companies on Light Day / Door open days	1	Private sector cooperation	1	Companies working in the field of photonics organize special activities for students (such as light day activities, door open days, demo huts)	3
			Creation of demo huts in companies	1				
							Requesting videos from field workers	1
Government-backed enhancements					Establishment of central laboratories	1	Establishment of central laboratories	1
					Government-sponsored internships	1	Government-sponsored internships	1

As can be seen from the Table 15, experts suggest company and factory visits (f = 12, 52%), Science and Technology Center and Science Museums visits (f =8, 35%) and laboratory or research center visits (f=4, 5%) as field trips. According to the experts, company, factory or laboratory visits can be used to introduce the field of photonics and its applications in our life and can see how engineers and researchers work in this field. The examples of the expert opinions that point to evidence of these views are as follows:

Industry visits might be useful to students appreciate where photonic technologies are used in daily life. (I8)

Students can tour the technology company or facility and can meet with engineers. For this, a trip outside the city may be required (giving examples from large *companies). For example, LED TV production is seen on site and how the engineer works here can be seen. Engineers explain how it works. (P8)*

Trips to both the science center and the places where the devices are produced and used can be included. We did something similar in the nanotechnology module. We added a laboratory trip to our study. Because they see its real use: how scientists use it there... Also, when they go there, they get shares from those people, listen to research, for example, or learn how the device is used. (E2)

Based on the frequency differences, experts from the educational background found science and technology museums more suitable as informal photonics education site. The opinions of E4 for science museums on how they can ben used for photonics education is as follows:

Optical parts of science museums can be visited. Of course, students should go consciously, and the questions to be asked should be prepared. The objectives that have continuous should be chosen [objectives in the curriculum and trip should be match], it should be ensured that they [students] understand the value of the information. (E4)

Experts also find beneficial the school-university-sector cooperations. Under that theme they suggest invited speakers (f=9), career days (f=2) and special activities for students held by companies working in the field of photonics, such as light day activities, door open days, demo huts (f=3). Below some of the related opinions are given:

Sometimes it is not very practical to go to the laboratory, for example, there can be a device in a small room, for example, it is not very practical for twenty students to enter. As another method, those speakers can sometimes be invited to the school. If there is a large number of students, if this is not possible in practice, different alternatives can be considered, such as visiting, the speaker's coming, maybe the speaker sending small videos, "Look, I'm in the laboratory" [saying], or even if he doesn't come, maybe meeting the students with a live zoom link. (E2)

People can visit companies in International Day of Light events. Companies can organize "open doors" at certain times. Activities that raise awareness… for example, companies can create a demo hut with interesting experiments. (P4)

The final version of the suggested informal education settings which is located in the survey used in the second round of the Delphi after the holistic content analysis of the experts' opinions by combining the similar ideas in the first round is presented in Table 16.

Table 16

Survey Items of Informal Settings in Photonics Education from the First Round Delphi Findings

Theme	CODE	f
Field Trips and Visits	Company/ Factory visits	12
	Science and Technology Centres and Science Museums	8
	Laboratory/ Research Center	4
	University/ Institute	2
	Science Technology Fairs	2
	Observatory visit	1
	Museum tour	1
Media & Broadcasting	Readings, reviews and researches such as science magazines, posters, posters, magazines, models, popular science books	4
	Social media platforms such as YouTube, Instagram	1
Observation and Demonstration Experiment Activities	Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)	5
	Astronomy-Observation Activities, observations made using different telescopes	3
	Intriguing, wide-ranging demonstration experiment events associated with the nature of light	2
In-school Activities	Project Assignments / Competition	4
	Contests and rewards	2
	Student clubs	2
	School Exhibitions	1
	Science Fairs	1
	Teaching of upper classes to lower classes / peer training: with volunteering	1
School-University-Sector Cooperation (Outreach)	To organize interviews or virtual meetings on photonic technologies by inviting relevant companies from the university and/or sector	9
	Companies working in the field of photonics organize special activities for students (such as light day activities, door open days, demo huts)	3
	Career day / career promotion events	2
Government-backed enhancements	Establishment of central laboratories	1
	Government-sponsored internships	1

4.5.2. Informal Settings in Photonics Education: The Second Round Delphi Findings:

The items related to out-of-school environments in photonics education in the questionnaire form created by bringing together the ideas in the first round of Delphi were evaluated by experts. The participants were asked to evaluate the items by asking "Evaluate the informal (out of school) activities that can be performed in Photonics Education according to their degree of suitability.". Items were listed as unsuitable (1) to very suitable (5). Mean and variance statistics of the items of informal settings of photonics education are given in Table17.

Table 17

Informal Settings in Photonics Education: The Second Round Delphi Findings

Informal Settings	N	Mean	Variance
Laboratory/ Research Center visits	20	4,7500	0,197
Company/ Factory visits	20	4,6500	0,239
Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)	20	4,6500	0,239
Special activities for students held by companies	20	4,6000	0,253
Science Technology Fair/ Expo	20	4,5500	0,471
Interviews or virtual meetings with people from university and/or sector	20	4,5000	0,263
Demonstration experiment events	20	4,4500	0,261
Astronomy-Observation Activities	20	4,4500	0,366
Science and Technology Center and Science Museum visits	20	4,4000	0,358
University/ Institute visits	20	4,4000	0,463
Observatory visit	20	4,4000	0,674
Science Fairs (on Schools)	20	4,3500	0,450
Career day / career promotion events	20	4,3500	0,239
Project Assignments/ Competition	20	4,1500	0,555
Central laboratories	20	4,1500	0,976
Laboratory videos	20	4,1000	0,621
Museum tour	20	4,0500	0,787
School Exhibitions	20	4,0500	0,682
Government-sponsored internships	20	4,0500	0,787
Student clubs	20	3,9000	0,726
Peer training	20	3,9000	0,726

As the mean ≥ 3.5 and variance ≤ 1 indicates a consensus regarding the importance of a concept, all the items of informal settings are considered as important for photonics education. In this round of Delphi, experts had a change to evaluate other opinions. The results of the second-round show that all 21 items under the informal education theme is found suitable by the experts. According to mean values of the items based on their evaluations, "Laboratory/ Research Center visits", "Company/ Factory visits" "Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)", "Special activities for students held by companies" and "Science and Technology Expositions/ Fairs" are found the most suitable informal education settings for Photonics Education.

4.5.3. Informal Settings in Photonics Education: Results of Delphi Study:

The results of informal settings of Photonics Education theme of Delphi study showed that, visits to laboratories, research centers, companies, factories studied on photonics technologies and Science and Technology Center and Science Museums are found suitable for dissemination of photonics to students. Also, activities held by sector- university- school cooperation such as special open door, demo hub, interview activities held by companies or universities to show students how the employees on this field work, and where photonics technologies produced, and use are favorably recommended by experts. Another outdoor activity strongly recommended by experts are activities bring students together for creating curiosity about science, for example, observing daily life and natural phenomena related to light (such as sun, color, rainbow) in the school gardens or suitable places or Science and Technology Fairs/ Expo.

The opinions on informal settings can be used in Photonics Education are consistent within the first and second round of the Delphi. Most frequently mentioned informal settings ideas on first round, also showed consensus regarding their suitability by statistics (mean ≥ 3.5 and variance ≤ 1). These results may indicate the stability of the opinions of the experts.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. Photonics Concepts in Photonics Education Framework

The research question "*What are the essential concepts in Photonics that should be taught in primary and secondary schools' science education?*" is examined and the findings, results and discussions have been delivered. In middle school level (grades 5^{th} -8^{th}) 12 concepts, in high school level (grade 9^{th}- 12^{th}) 28 concepts and for university level 17 course and subjects are reached to consensus on their necessity as given in Table 6. As a conclusion of the Delphi process on photonics concepts, teaching optics and electronics in lower level by cooperating photonics into daily life examples implicitly and teaching photonics related subjects in the high school is a suggested way of acquiring conceptual knowledge on photonics. The Science and Physics curricula in Turkey resemble this result except for the requirement of daily life examples of photonics in the science education curriculum (MoE, 2018a; MoE, 2018b). Also, quantum mechanics is introduced to students in upper secondary school curricula of England, Italy, USA, Germany, Norway, Netherlands (Krijtenburg-Lewerissa et al., 2019). On the other hand, the studies on photonics education show that in lower levels such as elementary and middle school levels, photonics technologies can meet with the students effectively (Andre, & Jones, 2019; Dreyer et al.,2016; Hasegawa, & Tokumitsu, 2016; Nakadate, et al., 2019). The difference between the findings of this study and literature might be caused from the literature is based on outreach activities and informal educational activities like boot-camps.

The analysis of the answers of experts during the interviews revealed that, experts mainly importance the context of teaching subjects rather than the concepts itself. For instance, as understand from the given excerpts from the interviews, experts advocate the transfer of concepts that can be associated with daily life, or/and events and people in the history of science to the classroom environment for photonics education. Li et al., (2017) also believes that incorporating with history of science and humanistic approaches is a good way to students acquire theoretical and conceptual knowledge.

The lack of consensus in the eliminated answers does not indicate the dispensability, unnecessity or redundancy of the subject. In these items, the variance value should have been greater than one in order to form a consensus on the dispensability of the subject. However, no further research had been conducted to explain the reason for the items with no consensus. It has been concluded that in-dept interviews and discussions with experts are necessary to reveal this ambiguousness.

5.2. Photonics Related Skills and Attitudes in Photonics Education Framework

The research question "*What are the learning outcomes in terms of skills and attitudes that should be included in photonics education in primary and secondary schools?*" is examined and the findings, results and discussions have been delivered. There are 25 skills and attitudes related Photonics revealed from the Delphi process. The skills are coded under the themes science process skills, engineering design skills, thinking skills, technical skills, 21st century skills, and attitudes are themed as science literacy.

The experts from Photonics and Industry cared about the ability to design experiment setup and experimenting with this setup, identifying variables, and summarizing the results. These opinions conform to results of Serna et al. (2019) on summary of the required skills in photonics technicians and lab engineers based on interviews and discussions with industry, and related study analysis. According to Serna et al. (2019), their industrial partners stated the importance of lab organizational skills, data organizing, interpretation and reporting using Microsoft Office tools, similarly. Furthermore, there are studies for students to acquire similar technical skills (Chang, et al., 2011; Gilchrist & Alexander, 2017), scientific methods (Lan et al., 2017) in reviewed literature.

Research skills (Massa et al. 2019) and problem-solving skills (Chang, et al., 2011; Donnelly & Massa 2015; Viera-González et. al, 2019) are suggested engineering design skills by experts of this research and studies on photonics education for the future employees of this area. In related works some products, designs or projects are developed by students however, "project development skills" could not be found as a term. Engineering design skills might be more suitable for this code to generalized for future studies. In this study, as the theme covered all these skills, "project development skills" have not been changed.

Under the thinking skills theme, inquiring (Chang, et al., 2011), critical thinking skills (Donnelly & Massa, 2015), creative thinking skills/creativity (Gilchrist & Alexander, 2017), scientific thinking skills (Lan et al., 2017), mathematical thinking skills (Gilchrist & Alexander, 2017) are compatible with the studies to disseminate photonics to younger students. Although "analytical thinking skills" couldn't be reached in the literature review, there are expressions pointing out that skills.

The 21st century skills other than those already mentioned under other themes, entrepreneurship and leadership, collaboration, teamworking and communication skills are appeared in related photonics studies in literature (Gilchrist & Alexander, 2017; Viera-González et al., 2019).

Scientific curiosity, interest in the field of photonics, daily life usage and familiarity and reasoning in the field of science and technology, and appreciation the nature of science are the attitudes that experts in this study suggested to acquire to students through Photonics education. Likewise, in their experimental teaching Lan et al. (2017) aimed to promote students' scientific spirit and moral character and improve innovative spirit. Also, attitudes toward STEM are associated and investigated in photonics studies (Gilchrist & Alexander, 2017). Even though, the science and technology is mentioned, engineering and mathematic are referred in skills by the experts and "STEM" have not been directly quoted under this section. This might be due to experts' heavily background on science and engineering, limited acquaintance with education trends. However, this statement is failed to explain experts from education sub-groups. Therefore, the educator's associations of photonics with STEM can be examined.

5.3. Teaching Methods in Photonics Education Framework

The research question "*What are the suitable teaching methods and strategies that would be used in photonics education in primary and secondary schools?*" is examined and the discussion on results of findings will be delivered in this section. The results of the study indicated that laboratory work, project-based learning, context-based learning, demonstration, problem-based learning, computer-aided learning or web-based learning, inquiry-based learning, argumentation, cooperative learning, field trips such as technical trips, advanced lab visits and integration of the history of science and the life of scientists are the suitable teaching methods and environments experts suggested to used when teaching photonics in classrooms. The teaching methods recommended are seen to appropriate for acquiring the skills suggested in previous sections. For instance, inquiry-based learning and laboratory work which are favorable teaching methods, enable suitable environments for developing inquiry, technical skills and science process skills which are suggested skills in photonics education based on this Delphi study. In photonics education, inquiry-based learning is seen to use for promoting scientific literacy and creativity (Cords et al., 2012). Also, inquiry-based learning have been preferred in many studies to introduce Photonics concepts to students (Ali, & Ashraf; 2017; Donnelly, et al., 2018; Fleck, & Hachet, 2015; Magnani, & Donnelly, 2015; Niemela, 2016; Prasad, et al., 2013).

The teaching methods matched with the literature reviewed are laboratory work (Hamdy et al., 2019; Hasegawa, & Tokumitsu, 2016), project-based learning (Chang, et al., 2011; Chang et al., 2012; Clark et al, 2020; Dehipawala, et al., 2018), demonstration (Phoojaruenchanachai & Sumriddetchkajorn, 2009), problem-based learning (Gilchrist, & Alexander 2019; Massa et al., 2019; Zhu et al., 2019), computer-aided learning or web-based learning (Verlage et al;

2019), discussions (Bieber et al., 2005; Hamdy et al., 2019), cooperative learning (Chang et al., 2011), and field trips (Gilchrist, & Alexander 2019). Context-based learning and argumentation did not find with these names in the literature. These might be because the fact that literature in the field of photonics education mainly derived by non-educational background scientist (Yalçın et al., 2021). Therefore, even though these methods have been used in studies, they might not have been named in this way.

Creative drama is the only teaching strategy which experts did not achieve a consensus on suitability of the method in photonics education. This may be cause by possible difficulties to put the complexity in the quantum world into play, or because experts from photonics and industry have limited idea how it used or may not have witnessed a useful implementation. However, the fact that there was no statistically significant difference between the groups may indicate that the educators did not find it appropriate enough. Nevertheless, considering the possibility that the difference may not occur due to the small sample size, further research is required.

5.4. Evaluation Methods in Photonics Education Framework

The research question "*What are the suitable evaluation methods and strategies that would be used in photonics education in primary and secondary schools?*" is examined and the discussion on results of findings will be delivered in this section. Experts are suggesting the project or assignment-based evaluations enables students to transfer their knowledge to practice. During the evaluation process experts are recommended instructors to give importance to assess students' appreciation of everyday linkage of the photonics concepts, students' skills on product and solution management and experimental set ups and backgrounds of the photonics subjects. The experts in this study consider the assessment of photonics learnings as an on-going or process-wide assessment, instead of relying on a single one-time method.

As mentioned before in literature section, the evaluations of the learnings are mainly restricted in the literature. The evaluations in some studies maintained by personal observations and questionnaires on participants' engagement and enjoyment (Posner et al., 2016). When the purpose of the study is to engage students on photonics this type of evaluations can be found adequate as evaluation should be aligned with the teaching process and objectives in education (Biggs, 2003). On the other hand, for the objectives in experimental learnings on the photonics education, researchers found multiple staged experimental evaluations appropriate (Lan et al., 2017; Niemela, 2016). Similar to the recommendations of the experts in this study, it appears that summative and formative assessment are found useful and deployed in problem-based (Donnelly et al., 2015) and active learning environments (Bieber et al., 2005) which enables on-going evaluations in classrooms. Serna et al., (2019) aimed to assess students reasoning skills, data analysis skills and ability to use laboratory tools by evaluating students' demonstrations and performance during the photonics lab sessions. This kind of evaluation has been one that experts stated will be beneficial in the photonics education process.

According to the Delphi results, effectiveness of using test-questions for the evaluation in Photonics education, have not been reached the consensus. When reviewed literature examined, seen that there are studies used test-questions in their educational process (Abad, Suárez, & Gil, 2015; Belcher, & Donnelly, 2009). In both studies, the test exams are not the only evaluation method used in education process and several special steps are employed to prepare these test questions. Contrary to the opinions of the experts in this study, these steps may have made the test questions useful for photonics training.

5.5. Informal Settings in Photonics Education Framework

As one of the research questions, "What are the suitable informal education environments that would be used in photonics education in primary and secondary schools?" is examined and the findings, results and discussions have been delivered. Based on the answers of the experts in Delphi process, 21 informal education settings have been found suitable for photonics education, as presented in Table 17. The findings of the Delphi process showed that experts recommended field trips to laboratories, research centers, companies, factories studied on photonics technologies where students can interact with engineers and scientists and appreciate the technological usage areas. In the literature reviewed, outreach activities where students meet scientist and developers of this area, participate in activities about photonics, are suggesting raising awareness on photonics, take students' attention on STEM fields career opportunities (Gilchrist & Alexander, 2017; Hasegawa, & Tokumitsu, 2016). Similarly, experts' opinions in the first round on company and factory visits reflects the beneficial use of this visits for introducing the field of photonics and its applications in our life and promoting career options in this field. Also, the experts' opinions indicate the cooperation between the institutions with the employees in the field of photonics, and educators. This type of cooperation is appeared in the literature as "Outreach". Worldwide, outreach activities in informal education environments to disseminate photonics and photonics technologies are arranged and implemented by scientists and employees in this field in cooperation with educators (McKee, et al., 2019). Considering scientists who will work in science centers have considerable experience in teaching and working with younger students and society, Pompea, & Hawkins (2002) recommend they give importance to cooperation with educators in these facilities.

According to Bell, Lewenstein, Shouse, & Feder (2009) informal science education environments provide the opportunity to arouse interest in science, to understand and interpret scientific information, and to pursue lifelong learning, as they are environments where learners seek knowledge and skills in line with their own motivations. Because the fact that the studies on photonics education are paying attention to students be curious about the photonics and their technologies and appreciate the importance in our life, and life-long learning opportunities to learners, possible informal education settings in photonics education is aimed to investigated in this research to set light to future studies.

5.6. Photonics Education Framework

As a conclusion of the Delphi process in this research, Photonics Education Framework has been constructed and given in the Figure 8. In the Figure 8 the five research questions are given as themes, of Photonics Education which are, concepts and skills (merged as objectives), teaching methods, evaluation strategies and informal learning environments. In addition to these themes, on account of the fact that experts took attention to elaborate nature of science and daily life examples within photonics teaching, NOS and authentic examples is added as a theme between objectives and teaching methods.

This framework is believed to be useful answering the purpose of:

(1) introducing the field of photonics to educators to overcome the fact that "research occurring in these fields are often unknown to students and educators" (Gilchrist & Alexander, 2017)

(2) enabling a guideline on the education environment for anyone who teaches photonics or photonics-related subjects in their classes at any level and enhancing limited resources on photonics educational material (Massa & Donnelly, 2008),

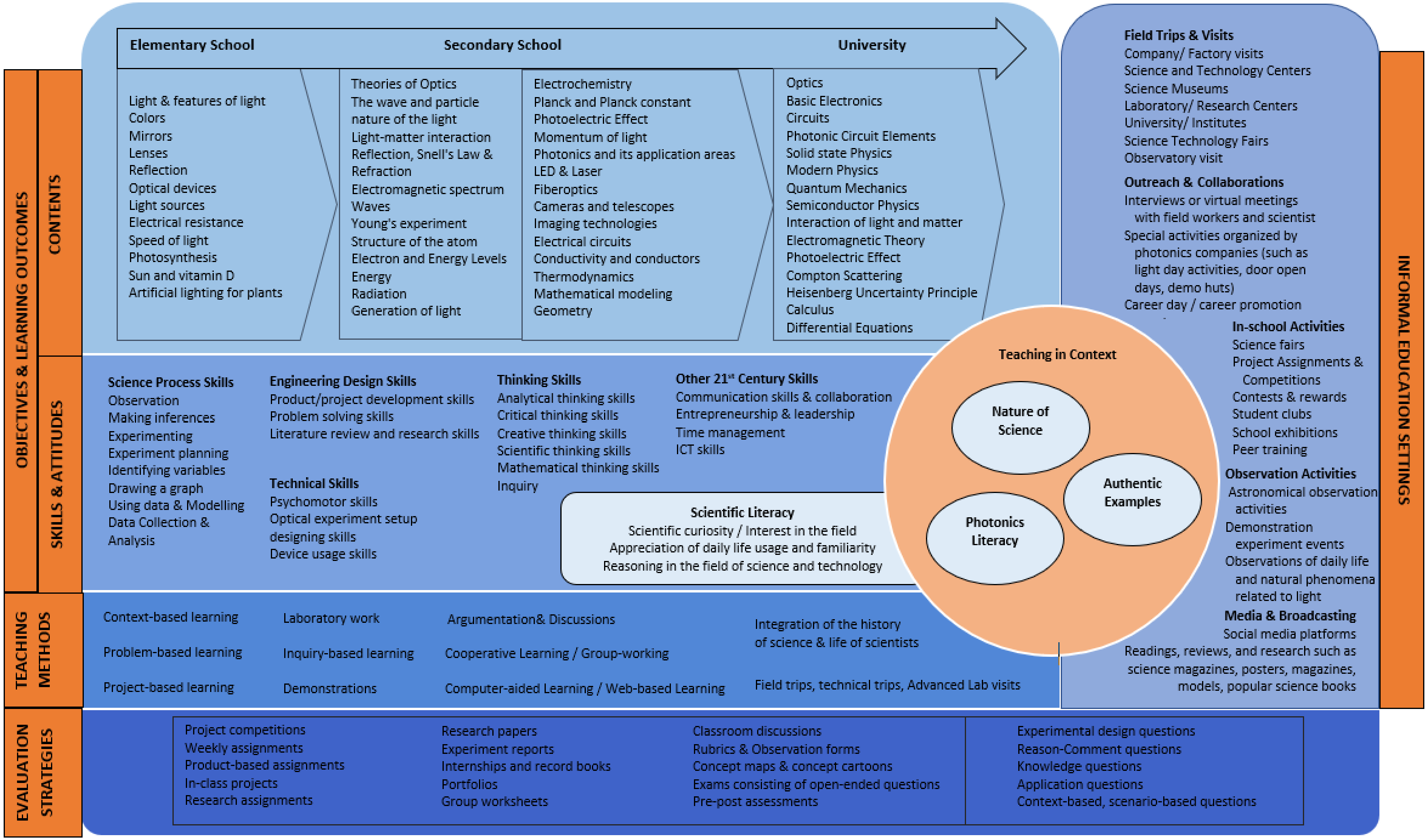
(3) providing suggestions and methods for the scientist and researchers on science and engineering fields who need due to the limited backgrounds in social science methods and pedagogy (Posner et al., 2016)

(4) offering the various alternatives for objectives, teaching methods, evaluation strategies, and informal learning environments in Photonics Education

(5) bringing different stakeholders' ideas together for Photonics Education and promoting collaborations between educators and sector (McCarthy & Moore, 2006).

Figure 8

The Summary of Delphi Process: The Photonics Education Framework



This study reached consensus on how to teach photonics rather than what should be taught in photonics education. More in-depth research focusing directly on which concepts needs to be taught in photonics education with rationales behind the reason they suggested may be required. At the beginning of this study, rationales expected to obtain, and questions are prepared with this idea. However, in order not to tire the participants with repetitive questions and in order to get more satisfying answers to more questions, this was abandoned during the implementation process of interviews.

At the end of Delphi, conducting an in-dept interview and investigating why there was no consensus on some items could better reflect the ideas behind the determination of suitable concepts in this study. For example, it could be asked why experts who gave a high or low Likert score on an item for which no consensus was reached, evaluated it this way. Thus, it could provide an explanation as to whether the unsuitable substances were less related to photonics education, were considered unsuitable at the relevant education level, or could not be agreed upon, if any, because of the other reason behind it. Such an additional post-analysis interviews, which is a limitation due to the restricted schedule in this study, can also be a suggestion to researchers who will do Delphi studies in this or other fields.

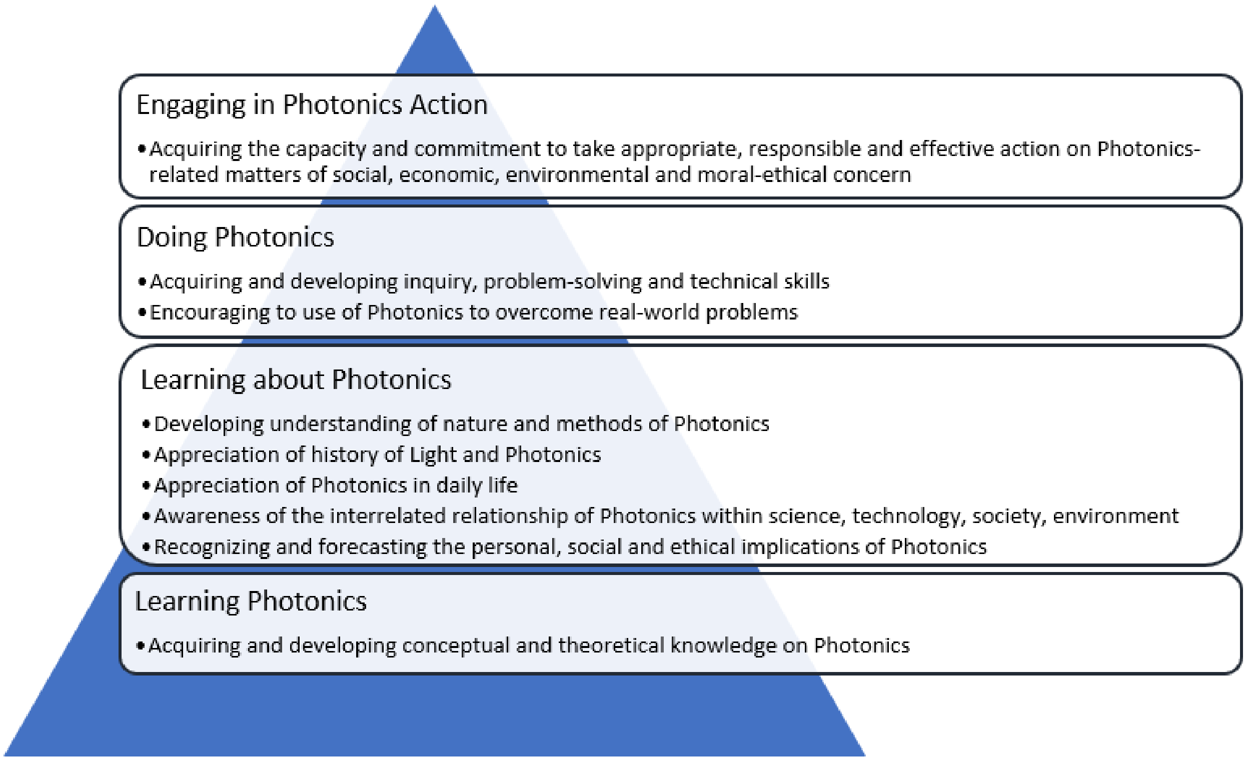
5.7. Fundamental Approach for Teaching Photonics

Photonics have central role in sustainable development and sustainable future (Kalyani, & Charan,2014; Sala,2015; Wessler & Tober, 2011). The lack of satisfactory emphases on linkage of Photonics with sustainability has been surprising for researchers. It is thought that the reason for this may be due to the structure of the questions. The only answer about associating photonics with sustainability was implicitly expressed by an educator. This expert suggested for the discussions in the classroom environment about the harms and benefits of photonics to the environment in production, use and consumption situations by using argumentation method. In the literature also, it is seen that sustainability is not sufficiently highlighted in studies on photonics education. Rasa et al. (2022) recommend more future-oriented studies and research to establish links with quantum technologies in science education and sustainability, socioscientific issues, future-oriented pedagogies. Also, by working on futures thinking with teachers, it can be expected to make pedagogical contributions to teachers' visions on the societal issues that will bring to the classroom environment (Varpanen, Laherto, Hilppö, & Ukkonen-Mikkola, 2022). By bringing socioscientific problems related to photonics to the classroom, the teachers can plan classroom environments in which students develop skills that Lawale & Bory-Adams (2010) considers the basis of sustainability education such as critical thinking and problem-solving skills, ability to deal with risks and uncertainties.

McCarthy & Moore (2006) suggest that education have a central role in sustainable development and meeting todays and futures need, the help of educators in the light areas are inevitable. For a sustainable future, scientifically literate people who can analytically thinking the effects of scientific and technological developments on society and the environment and can take an active part in socioscientific issues as citizens by are needed in society (Hodson, 2011; Jenkins 1999; Mansour, 2009). However, in the studies on photonics education including this, based on the literature and opinions of experts', contributing students' scientific literacy mainly aimed for developing scientific knowledge on photonics, encourage in STEM careers, developing skills such as inquiry, problem-solving. Nevertheless, some expressions in the study point out some requirements in photonics: for example, defining photonics literacy. Therefore, on the basis of Hodson's (2011) framework on science education for scientific literacy, incorporating the reviewed literature and the framework of the photonics education constructed as result of this study a *Framework for Photonics Literacy* is developed and presented in Figure 9.

Figure 9

Photonics Education Framework for Photonics Literacy



The description of *Photonics Education Framework for Photonics Literacy* presented in Figure 9 indicates that in this study; learning photonics, learning about photonics and doing photonics is discussed adequately, while engaging in photonics is examined in a narrow scope. Therefore, more studies are needed to suggest how students, future citizens, can acquire the capacity and commitment to take action on Photonics related matters of social, economic, environmental and moral-ethical concern. Furthermore, the Photonics Education Framework for Photonics Literacy can be improved by previous and future studies. Nevertheless, it is believed that this framework might enlighten the future of Photonics Education.

REFERENCES

Abad, E., Suárez, P., & Gil, J. (2015). A game-based educational method relying on student-generated questions. *arXiv preprint arXiv:1501.06439*.

Adam, A., Zuidwijk, T., & Urbach, P. (2017, May). Bringing optics to Fab Labs in Europe. In *Education and Training in Optics and Photonics* (p. 104523M). Optical Society of America.

Ali, R., & Ashraf, I. (2017, May). Active learning in optics for girls. In *Education and Training in Optics and Photonics* (p. 104520L). Optical Society of America

Andre, L. B., & Jones, T. (2019, May). The disassembly and re-purposing of unwanted consumer electronics: low-cost tools for optics outreach. In *Education and Training in Optics and Photonics* (p. 11143_66). Optical Society of America.

Aydın, S., Sarıkaş, A., Ak, A., Yayla, A., Kesen, U., & Oral, B. (2019). Fiber optic training program with intensive experiments using both real laboratory and simulation environments. *Computer Applications in Engineering Education*, *27*(6), 1419-1428.

Belcher, B. K., & Donnelly, J. (2009, August). Restarting a high school photonics program. In Novel Optical Systems Design and Optimization XII (Vol. 7429, pp. 236-247). SPIE.

Bell, P., Lewenstein, B., Shouse, A., & Feder, M. A. (2009). *Learning sciences in informal environments: People, places and pursuits.* Washington: National Academies Press.

Bieber, A. E., Marchese, P., & Engelberg, D. (2005). The laser academy: An after-school program to promote interest in technology careers. *Journal of Science Education and Technology*, *14*(1), 135-142.

Bonner, S. E. (1999). Choosing teaching methods based on learning objectives: An integrative framework. *Issues in Accounting Education*, *14*(1), 11-15.

Borich, G.D. (2017). *Effective teaching methods: research-based practice*. (9th eds.). Pearson Education, Inc.

Bunch, R. M., & Joenathan, C. (2018, September). Lighting education and outreach at Rose-Hulman Institute of Technology. In *Optics Education and Outreach V* (Vol. 10741, p. 1074102). International Society for Optics and Photonics.

Bybee, R. W. (2010). What is STEM education?. *Science*, *329*(5995), 996-996.

Chang, S. H., Chen, M. L., Kuo, Y. K., & Shen, Y. C. (2011). A Simulation-Based LED Design Project in Photonics Instruction Based on Industry–University Collaboration. *IEEE Transactions on Education*, *54*(4), 582-589.

Chang, S. H., Wu, T. C., Kuo, Y. K., & You, L. C. (2012). Project-based learning with an online peer assessment system in a photonics instruction for enhancing led design skills. *Turkish Online Journal of Educational Technology-TOJET*, *11*(4), 236-246.

Chiappetta E.L., Koballa T.R. & Collette A.T. (1998). *Science instruction in the middle and secondary schools* (p.102). New Jersey: Prentice-Hall.

Chu, H. E., Treagust, D. F., & Chandrasegaran, A. L. (2009). A stratified study of students' understanding of basic optics concepts in different contexts using two-tier multiple-choice items. *Research in Science & Technological Education*, *27*(3), 253-265.

Clark, L.H. & Starr, I.S. (1996) *Secondary and middle school teaching methods*. (Chapter 5 & 6) New Jersey: Prentice Hall

Cords, N. & Fischer, R.& Euler, M. & Prasad, A. (2012). Teaching optics with an intra-curricular kit designed for inquiry-based learning. *Physics Education*, *47*(1), 69-72. DOI:10.1088/0031-9120/47/1/69.

Cornu, B. (1995). New technologies: integration into education. In *Integrating information technology into education* (pp. 3-11). Springer, Boston, MA.

Çepni, S. (2018). *Araştırma ve proje çalışmalarına giriş [Introduction to research and project work]*. Trabzon: Pegem Publishing.

Çepni, S. (2021). Proje, Tez ve Araştırma Makalelerinin Kavramsal ve Kuramsal Çerçevesi Nasıl Yapılandırılmalı?. *Fen Matematik Girişimcilik ve Teknoloji Eğitimi Dergisi*, *4*(3), 203-216.

Çepni, S. and Ormancı, Ü. (2018). *The world of the future.* Çepni, S. (Ed.), From Theory The application is in STEM + A + E Education (p.1-32). Ankara: Pegem Academy. Retrieved from https://doi.org/10.14527/9786052410561.01

De Carvalho, V., Martins, V. H., Fabris, L. V. M., Muller, M., & Fabris, J. L. (2019). Promoting optical fibre sensor technology with educational experimental setup. *Physics Education*, *54*(4), 045005.

De la Barra, L., & Wilson, K. L. (2010). Introducing Modern Optics and Photonics Engineering in the Elementary Classroom: An Australian Perspective. *In Frontiers in Education* (p. EJ).

Dehipawala, S., Sullivan, R., Armendariz, R., Shekoyan, V., Tremberger Jr, G., Lieberman, D., & Cheung, T. (2018, September). Assessment of high-school engineering education outreach program employing project-based learning in astronomy and bio-optics within a college setting. In *Optics Education and Outreach V* (Vol. 10741, pp. 116-132). SPIE.

Delbecq, A.L., Van de Ven, A.H. & Gustafson D.H. (1986). *Group techniques for program planning: A guide to Nominal Group and Delphi processes*. Middleton, Wisconsin: Green Briar Press.

Donnelly, M. J., & Donnelly, J.F. (2019, May). Enlightening students: optics applications in the math classroom. In *Education and Training in Optics and Photonics* (p. 11143_56). Optical Society of America.

Donnelly, M. J., Donnelly, J. F., & Park, J. M. (2018, September). Seeing the light: Introducing optics/photonics through middle school mathematics. In Optics Education and Outreach V (Vol. 10741, pp. 42-48). SPIE.

Donnelly, J., Magnani, N., & Robinson, K. (2016, September). Dumpster Optics: teaching and learning optics without a kit. In *Optics Education and Outreach IV* (Vol. 9946, pp. 157-163). SPIE.

Donnelly, J. F., & Massa, N. M. (2015, June). The PBL Projects: Where we've been and where we are going. In *Education and Training in Optics and Photonics* (p. IND10). Optical Society of America.

Dreyer, E. F., Aku-Leh, C., Nees, J. A., Sala, A. L., Smith, A., & Jones, T. (2016, September). IYL project: pinky-powered photons. In *Optics Education and Outreach IV* (Vol. 9946, pp. 89-97). SPIE.

Dulmes, S., & Kellerhals, W. (2017). Regional Photonics Initiative at the College of Lake County. *Community College Journal of Research and Practice*, *41*(6), 348-350.

European Commission. Photonics and our daily life. (2020). Available at: https://ec.europa.eu/digital-single-market/en/photonics-and-our-daily-life (Accessed March 10, 2022).

Fleck, S., & Hachet, M. "Helios: a tangible and augmented environment to learn optical phenomena in astronomy," Proc. SPIE 9793, Education and Training in Optics and Photonics: ETOP 2015, 979331 (8 October 2015); doi: 10.1117/12.2223249

Florensa, C., Martí, M., Kumar, S. C., & Carrasco, S. (2013, July). “The magic of light!”-An entertaining optics and photonics awareness program. In *Education and Training in Optics and Photonics* (p. EWF2). Optica Publishing Group.

Gauthier, J. C., Rilling, M., Allain, G., Jobin, F., Côté, A., Dallaire, X., ... & Michaud-Belleau, V. (2018, September). An optics and photonics exhibit that reunites, educates and, engages: a meeting with light. In *Optics Education and Outreach V* (Vol. 10741, p. 107410A). International Society for Optics and Photonics.

Gilchrist, P. O., & Alexander, A. B. (2017, May). Solar cell and photonics outreach for middle school students and teachers. In *Education and Training in Optics and Photonics* (p. 1045205). Optical Society of America.

Gilchrist, P. O., & Alexander, A. B. (2019, May). Optometry outreach for diverse middle school students. In *Education and Training in Optics and Photonics* (p. 11143_156). Optical Society of America.

Gilchrist, P. O., Young, T. V., Bowles, A. T., Brady, P. K., & Grable, L. L. (2017, May). Middle and High School Teachers' Implementation Reflections of Photonics and Optics Curriculum in a Qualitative Study. In *Education and Training in Optics and Photonics* (p. 104523K). Optical Society of America.

Green, R. A. (2014). The Delphi technique in educational research. *Sage Open*, *4*(2), https://doi.org/10.1177/2158244014529773

Hakola, L., Immonen, K., Sokka, L., Välimäki, M., Smolander, M., Mäntysalo, M., ... & Venetjoki, P. (September 2020). Sustainable materials and processes for electronics, photonics and diagnostics. *In Electronics Goes Green 2020+*. Berlin

Hall-Wallace, M., Regens, N. L., & Pompea, S. M. (2001, November). The university of arizona's collaboration to advance teaching technology and science (CATTS): Lesson for photonics education collaborations. In *Education and Training in Optics and Photonics* (p. PS514). Optica Publishing Group.

Hamdy, S. W., Hirokawa, T., Chan, P., Jin, W., Rosborough, V., Stanton, E., ... & Bowers, J. E. (2019, May). Light-based educational outreach activities for pre-university students. In *Education and Training in Optics and Photonics* (p. 11143_71). Optical Society of America.

Hasegawa, M., & Tokumitsu, S. (2016, September). Continuous outreach activities performed by a student project team of undergraduates and their program topics in optics and photonics. In *Optics Education and Outreach IV* (Vol. 9946, pp. 122-130). SPIE.

Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of advanced nursing*, *32*(4), 1008-1015.

Henriksen, E. K., Angell, C., Vistnes, A. I., & Bungum, B. (2018). What is light?. *Science & education*, *27*(1), 81-111.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International journal of science education*, *25*(6), 645-670.

Hodson D. (2011). *Looking to the Future: building a curriculum for social activism*. Rotterdam, The Netherlands: Sense Publishers.

Hoffman K., (2020). Evolutionary Transitions and the Move to The Next Age. https://www.gavstech.com/evolutionary-transitions-and-the-move-to-the-next-age/

How, M. L. (2022). Advancing Multidisciplinary STEM Education with Mathematics for Future-Ready Quantum Algorithmic Literacy. *Mathematics*, *10*(7), 1146.

Hurd, P. D. (2000). Science education for the 21st century. *School Science and Mathematics*, *100*(6), 282-288.

International Year of Light 2015 (n.d.) *International year of light and light-based technologies: why light matters*. https://www.light2015.org/Home/WhyLightMatters.html

Jenkins, E. W. (1999). School science, citizenship and the public understanding of science. *International journal of science education*, *21*(7), 703-710.

Johnstone, W., Culshaw, B., Walsh, D., Moodie, D., & Mauchline, I. (2000). Photonics laboratory experiments for modern technology-based courses. Proceedings of the IEEE, 88(1), 41-54.

Jones, M. G., Blonder, R., Gardner, G. E., Albe, V., Falvo, M., & Chevrier, J. (2013). Nanotechnology and nanoscale science: Educational challenges. *International Journal of Science Education*, *35*(9), 1490-1512.

Kalyani, V. L., & Charan, C. (2014). Green Photonics–A Broad Overview and Future Aspects. *Journal of Management Engineering and Information Technology (JMEIT), 1*(1), 9-14.

Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects (Free Executive Summary)* Engineering Education; National Academy of Engineering and National Research Council ISBN: 978-0-309-13778-2

Kılkış, Ş., Krajačić, G., Duić, N., Montorsi, L., Wang, Q., & Rosen, M. A. (2019). Research frontiers in sustainable development of energy, water and environment systems in a time of climate crisis. *Energy conversion and management*, *199*, 111938.

Krijtenburg-Lewerissa, K., Pol, H. J., Brinkman, A., & Van Joolingen, W. R. (2019). Key topics for quantum mechanics at secondary schools: a Delphi study into expert opinions. *International Journal of Science Education*, *41*(3), 349-366.

Lan, L., Liu, S., Zhou, H. J., & Peng, M. Z. (2017, May). Experimental teaching reforms of optical fiber communication based on general education. In *Education and Training in Optics and Photonics* (p. 104524Y). Optical Society of America.; doi: 10.1117/12.2269486

Lawale, S., & Bory-Adams, A. (2010). The decade of education for sustainable development:

Towards four pillars of learning. *Development*, *53*(4), 547–550. https://doi.org/10.1057/dev.2010.76

Lederman, N. G., Schwartz, R., & Abd-El-Khalick, F. (2015). Nature of science, assessing of. *Encyclopedia of science education*, 694-698.

Lee, C. (2021). Photonics: The key to a more sustainable world. *Electro Optics*, (316), 26. https://link.gale.com/apps/doc/A693152131/AONE?u=anon~4b99d5f0&sid=googleScholar&xid=78d544d5

Li, X., Wang, K., Yang, Q., & Si, K. (2017, May). Light-based science and technologies and human civilization: an optical course for general education. In *Education and Training in Optics and Photonics* (p. 104521K). Optica Publishing Group.

Lobato, L., Vidal, J., Miquel, A., Lizana, A., Peinado, A., Estévez, I., ... & Yzuel, M. J. (2015, June). Multidisciplinary educational activity based on optical experiments conducted within an art context. In *Education and Training in Optics and Photonics* (p. ETM06). Optical Society of America.

Lorey, D. E. (Ed.). (2002). *Global environmental challenges of the twenty-first century: Resources, consumption, and sustainable solutions.* Rowman & Littlefield Publishers.

Lyu, B. (2017, May). Simulation and visualization of fundamental optics phenomenon by LabVIEW. In *Education and Training in Optics and Photonics* (p. 104523R). Optica Publishing Group.

Magnani, N., & Donnelly, J. (2015, June). Teaching reflection to teachers and students. In *Education and Training in Optics and Photonics* (p. ETM08). Optical Society of America.Mansour, N. (2009). Science-technology-society (STS) a new paradigm in science education. *Bulletin of science, technology & society*, *29*(4), 287-297.

Massa, N. M., Donnelly, J. F., & Mullett, G. J. (2019, May). Problem-based learning in advanced photonics manufacturing: Bringing real-world applications into the classroom. In *Education and Training in Optics and Photonics* (p. 11143_102). Optical Society of America.

McCarthy, J., & Moore, R. A. (2006). Optical engineering for children–a structured approach. *European journal of engineering education*, *31*(6), 741-746.

McFarlane, D. A. (2013). Understanding the challenges of science education in the 21 st century: new opportunities for scientific literacy. *International letters of social and humanistic sciences*, *4*, 35-44.

McKee, M., Magnani, N., & Posner, M. T. (2019, May). OPTIKS: Outreach for professionals who teach in informal environments and K-12 schools. In Education and Training in Optics and Photonics (p. 11143_20). Optica Publishing Group.

Mešić, V., Hajder, E., Neumann, K., & Erceg, N. (2016). Comparing different approaches to visualizing light waves: An experimental study on teaching wave optics. *Physical Review Physics Education Research*, *12*(1), 010135.

Miles, M.B., & Huberman, A.M. (1994). *Qualitative data analysis: An expanded sourcebook.* London: Sage

Ministry of Education. (2018a). *Science course curriculum*. Ankara.

Ministry of Education. (2018b). *Science physics curriculum*. Ankara.

Nakadate, S., Tokuyama, Y., Kume, Y., Shibuya, M., Chen, J., Azuma, Y., & Moriyama, T. (2019). A color mixer for mixed color education and its outreach activities. *Optical Review*, *26*(5), 478-486.

National Research Council. (2012). A Framework for K-12 Science Education: Practices. *Crosscutting Concepts, and Core Ideas*, 1-401.

Nelson, J. D., Kosc, T. Z., & Nelson, P. C. (2019, May). The Optics Suitcase: educational outreach tool for inspiring careers in light. In *Education and Training in Optics and Photonics* (p. 11143_97). Optical Society of America.

Niemela, J. J. (2016, September). Active learning in optics and photonics. In *Optics Education and Outreach IV* (Vol. 9946, pp. 198-206). SPIE.

Nof, S. Y., Cheng, G. J., Weiner, A. M., Chen, X. W., Bechar, A., Jones, M. G., ... & Zhang, X. C. (2013). Laser and photonic systems integration: Emerging innovations and framework for research and education. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *23*(6), 483-516.

Oktavia, R., & Halim, A. (2018, September). Light Emitting Diode (LED) as an essential prop component for STEM education in the 21st century: A focus for secondary school level. In *Journal of Physics: Conference Series* (Vol. 1088, No. 1, p. 012060). IOP Publishing.

Orlich, D. C., Harder, R. J., Callahan, R. C., Trevisan, M. S., & Brown, A. H. (2012). *Teaching strategies: A guide to effective instruction*. Cengage Learning.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What “ideas-about-science” should be taught in school science? A Delphi study of the expert community. *Journal of research in science teaching*, *40*(7), 692-720.

Panayiotou, C. (2019, May). Increasing photonics awareness for youngsters using technology boot camps. In *Education and Training in Optics and Photonics* (p. 11143_103). Optical Society of America.

Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3rd ed.). Thousand Oaks, California: Sage Publications Inc.

Peccianti, M. (2021). Grand Challenges in Photonics: Route to Light. *Frontiers in Photonics, 1*, 626728. doi: 10.3389/fphot.2020.626728

Phoojaruenchanachai, S., & Sumriddetchkajorn, S. (2009, June). Elevation of optics and photonics education in Thailand. In *Education and Training in Optics and Photonics* (p. EMCB1). Optical Society of America.

Photonics Leadership Group (2020). Future horizons for photonics research 2030 and beyond. Available at: https://photonicsuk.org/wp-content/uploads/2020/09/Future-Horizons-for-Photonics-Research_PLG_2020_b.pdf (Accessed August 1, 2020).

Pompea, S. M., & Carsten-Conner, L. D. (2015, June). Teaching Optics Concepts through an Approach that Emphasizes the "Colors of Nature". In *Education and Training in Optics and Photonics* (p. OUT01). Optical Society of America.

Pompea, S. M., & Hawkins, I. (2002, May). Increasing science literacy in optics and photonics through science centers, museums, and web-based exhibits. In Seventh international conference on education and training in optics and photonics (Vol. 4588, pp. 554-560). SPIE.

Posner, M. T., Jantzen, A., van Putten, L. D., Ravagli, A., Donko, A. L., Soper, N., ... & John, P. V. (2017, May). Cathedral outreach: student-led workshops for school curriculum enhancement in non-traditional environments. In *Education and Training in Optics and Photonics* (p. 1045207). Optica Publishing Group.

Posner, M. T., John, P. V., Standen, D., Wheeler, N. V., Van Putten, L. D., Soper, N., ... & Brambilla, G. (2016, September). Reflecting photonics: reaching new audiences through new partnerships–IYL 2015 and the Royal Horticultural Society Flower Show. In *Optics Education and Outreach IV* (Vol. 9946, p. 994603). International Society for Optics and Photonics.

Prasad, A., Debaes, N., Fischer, R., & Thienpont, H. (2013, July). Developing intra-curricular photonics educational material for secondary schools in Europe. In *Education and Training in Optics and Photonics* (p. ETuB4). Optical Society of America.

Poulin-Girard, A. S., Boudreau, G., Landry, J., Veillette, A., Guérard, M. A., Thériault, G., & April, A. (2018, September). Ten years of photonic games: lessons learnt. In *Optics Education and Outreach V* (Vol. 10741, pp. 78-85). SPIE.

Quan, F. (2012). Green photonics. *Journal of Optics*, *14*(2), 024001.

Rasa, T., Palmgren, E., & Laherto, A. (2022). Futurising science education: Students' experiences from a course on futures thinking and quantum computing. *Instructional Science*, *50*(3), 425-447.

Resnick, J., & Monroy-Ramírez, F. A. (2017, August). Teaching the concept of dispersion by diffraction of light to elementary school students. In *14th Conference on Education and Training in Optics and Photonics: ETOP 2017* (Vol. 10452, p. 104523I). International Society for Optics and Photonics.

Ross, R., Whittington, J., & Huynh, P. (2017). LaserTag for STEM Engagement and Education. *IEEE Access*, *5*, 19305-19310.

Rutherford, F.J.I. (1964) The role of inquiry science teaching. *Journal of Research in Science Teaching*.2. 80-84

Sala, Anca L., 2014 "Developing a photonics education program at college level from the ground up," Proc. SPIE 9188, Optics Education and Outreach III, 918803 (15 September 2014); doi: 10.1117/12.2061426

Sala, A. L. (2015, June). Expanding Photonics Education in the International Year of Light. In *2015 ASEE Annual Conference & Exposition* (pp. 26-714).

Sala, A. L., Dreyer, E. F., Aku-Leh, C., Jones, T., Nees, J. A., & Smith, A. (2016, September). Celebrating the International Year of Light in Michigan. In *Optics Education and Outreach IV* (Vol. 9946, pp. 13-19). SPIE.

Sánchez-López, M.d.M., García-Martínez, P., Espinosa, R., Carnicer, J., Arias, J., & Moreno, I. (2016, September). Outreach activities on light science and technology at TecnOpto-UMH during the International Year of Light. In *Optics Education and Outreach IV* (Vol. 9946, p. 994604). International Society for Optics and Photonics.

Sanmarti-Vila, L., García-Matos, M., Beduini, F., & Carrasco, S. (2016, September). Collaborative outreach. In *Optics Education and Outreach IV* (Vol. 9946, pp. 174-184). SPIE.

Sanmartí-Vila, L., Tognetti, S., Beduini, F., & Carrasco, S. (2020). CARLA, the career launch hub to promote careers in photonics. *Journal of Physics: Photonics*, *2*(3), 031005.

Saskatchewan Education. (1991). *Instructional Approaches: a framework for professional practice.* Regina,SK: Saskatchewan Education

Sebak, A., Haj Bakry, S., Alshebeili, S., Fathallah, H., & Alajlan, S. (2014). Case study: KACST technology innovation center in radio frequency and photonics. *Innovation, 16*(2), 250-262.

Serna, S., Hidalgo, N., Tjan, J., McComber, K., Kimerling, L., Verlage, E., ... & Longacre, J. (2019, May). A modular laboratory curriculum for teaching integrated photonics to students with diverse backgrounds. In *Education and Training in Optics and Photonics* (p. 11143_142). Optical Society of America.

Stirling, C. J., Donko, A. L., Baktash, N., Grabska, K., Rosales, A. L. C., Clarke, D. T., ... & Posner, M. T. (2018, September). Student-led outreach and public engagement activities at the University of Southampton to celebrate the inaugural International Day of Light. In *Optics Education and Outreach V* (Vol. 10741, p. 107410B). International Society for Optics and Photonics.

Suzuki, Y., Hagen, N., & Otani, Y. (2019, May). Exploratory science learning in a high school curriculum, using structured materials and light polarization. In *Education and Training in Optics and Photonics* (p. 11143_78). Optical Society of America.

Thériault, G., & Galibois, S. (2019, May). The intricate and symbiotic relationship between Educational institutions and the Industry. In *Education and Training in Optics and Photonics* (p. 11143_146). Optical Society of America.

United Nations Conference on Environment and Development (UNCED). (1992). United Nations Conference on Environment & Development. In *Results of the world conference on environment and development: Agenda 21* (p. 351). Rio de Janerio , Brazil. https://doi.org/10.1007/s11671-008-9208-3

Varpanen, J.; Laherto, A., Hilppö, J., Ukkonen-Mikkola, T., (2022). *Teacher Agency and Futures Thinking. Educ. Sci.* 12, 177. https://doi.org/10.3390/educsci12030177

Vasquez, J. A., Sneider, C. I., & Comer, M. W. (2013). STEM lesson essentials, grades 3-8: Integrating science, technology, engineering, and mathematics (pp. 58-76). Portsmouth, NH: Heinemann.

Verlage, E., Saini, S., Agarwal, A., Serna, S., Kosciolek, R., Morrisey, T., & Kimerling, L. C. (2019, May). Web-based interactive simulations and virtual lab for photonics education. In Education and Training in Optics and Photonics (p. 11143_136). Optical Society of America.

Viera-González, P. M., Martínez-Contreras, J. I., Ponce-Hernández, G., & Sánchez-Guerrero, G. E. (2019, May). Optics for everyone: measuring the results after five years of work.

In *Education and Training in Optics and Photonics* (p. 11143_129). Optical Society of America.

Vogt, A. (2019, May). Your precious engineers will be increasingly disabled by a shortage of optics technicians. What can be done?. In *Education and Training in Optics and Photonics* (p. 11143_60). Optical Society of America.

Wessler, B., & Tober, U. (2011, April). Green photonics: the role of photonics in sustainable product design. In *SPIE Eco-Photonics 2011: Sustainable Design, Manufacturing, and Engineering Workforce Education for a Green Future* (Vol. 8065, pp. 353-360). SPIE.

Wong, N. H., Tong, A. S., Posner, M. T., & Ravagli, A. (2017, May). Modular and extensible lesson on fiber optics for youths. In *Education and Training in Optics and Photonics* (p. 104520S). Optica Publishing Group.

World Commission on Environment and Development. (1987). Report of the World Commission on Environment and Development: Our Common Future. In *Our common future*.

Yalcin, H. A., Cepni, S., & Aydemir, U. (2021). A Thematic Review of the Present Photonic Education. *Education and Training in Optics and Photonics*, W4B-2.

Zhu, J., Liu, R., Liu, Q., Zheng, T., & Zhang, Z. (2019). Engineering students' epistemological thinking in the context of project-based learning. *Ieee transactions on education*, *62*(3), 188-198.

APPENDICES

Appendix-A: Interview Form

PARTICIPATION APPROVAL FORM OF THE PHOTONICS EDUCATION SURVEY

The purpose of this survey is to collect expert opinions on how photonics education can be most effective in schools. The interview consists of five open-ended questions. The participants' views will be only used for academic purposes, and their personal information will be kept secret. Please do not hesitate to mail your questions, opinions, and thoughts to researchers.

We hope that this study will be helpful for the development of the field of photonics by integrating it into education, and we think that your participation and ideas will be important for this purpose.

Thank you for your valuable contribution.

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Statement of Consent: Please tick the box stating that you have voluntarily participated in the study and you have given permission for the comments written below to be used in the study.

I participate in the study voluntarily, and I allow my views to be used for the study.

THE PHOTONICS EDUCATION INTERVIEW

1. What are the essential concepts in photonics that should be taught in science education? Please state at least 3 concepts at any level and your *justification/rationale* for choosing these subjects.
   <u>Alternative Question</u>: Which of the knowledge on photonics do you think students should acquire in elementary, secondary, and college levels?

2. What are the essential objectives regarding skills and attitudes in photonics that should be taught in science education? Please state at least 3 objectives and their grade levels also please state at least 3 objectives and their grade levels also indicate the reason why you think they are important.

   <u>Alternative Question 1</u>: What skills and attitudes do you think the individuals in society and employees in photonics-related fields should have? Please state why such skills and attitudes would be important for an individual to acquire, in the justification/rational column. Also please indicate that in which grades individuals should acquire these skills and attitudes.

   <u>Alternative Question 2</u>: What skills and attitudes would you expect the individuals have acquired to understand and use photonic technologies? Please, state why such skills and attitudes would be important for an individual to acquire, in justification/rational column. Also please indicate that in which grades individuals should gain these skills and attitudes.

3. How does Photonics could be taught effectively in schools or universities? Please justify your answer and state the grade levels. More than one answer will be beneficial.

   <u>Alternative Question</u>: What could be the teaching techniques for effective photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.

4. How does Photonics Education could be evaluated effectively in schools or universities? Please justify your answer and state the grade levels. More than one answer will be beneficial.

   <u>Alternative Question</u>: *What could be the evaluation techniques for effective photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.*

5. What are the experiments, activities and informal (out-of-school) activities that can be designed at schools/universities for photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.

Appendix-B: Questionnaire Form

PARTICIPATION APPROVAL FORM OF THE PHOTONICS EDUCATION SURVEY

The purpose of this survey is to collect expert opinions on how photonics education can be most effective in schools. The survey consists of five open-ended questions. The participants' views will be only used for academic purposes, and their personal information will be kept secret. Please do not hesitate to mail your questions, opinions, and thoughts to researchers.

We hope that this study will be helpful for the development of the field of photonics by integrating it into education, and we think that your participation and ideas will be important for this purpose.

Thank you for your valuable contribution.

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Statement of Consent: Please tick the box stating that you have voluntarily participated in the study and you have given permission for the comments written below to be used in the study.

I participate in the study voluntarily, and I allow my views to be used for the study.

THE PHOTONICS EDUCATION SURVEY

1. What are the essential concepts in photonics that should be taught in science education? Write at least 3 concepts at any level and your *justification/rationale* for choosing these subjects.
(If you do not want to answer this question, you may consider answering the alternative question below.)
Alternative Question: Which of the knowledge on photonics do you think students should acquire in elementary, secondary, and college levels? Please state why such knowledge would be important for an individual to know, in the justification/rationale column.

Elementary School Subjects (5th-8th Grades) (7-14 years)	**Justifications/Rationales** (indicate *why this knowledge would be important for an individual to know*)
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.
Secondary School (High School) Subjects (9th-12th Grades) (15-18 years)	**Justifications/Rationales** (indicate *why this knowledge would be important for an individual to know*)
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.
College/University School Subject (18+ years)	**Justifications/Rationales** (indicate *why this knowledge would be important for an individual to know*)
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.
Click or tap here to enter text.	Click or tap here to enter text.

2. What are the essential objectives regarding skills and attitudes in photonics that should be taught in science education? Please state at least 3 objectives and their grade levels also please state at least 3 objectives and their grade levels also indicate the reason why you think they are important in the justification/rationale column.
(If you do not want to answer this question, you may consider answering the alternative questions below.)
<u>Alternative Question 1</u>: What skills and attitudes do you think the individuals in society and employees in photonics-related fields should have? Please state why such skills and attitudes would be important for an individual to acquire, in the justification/rational column. Also please indicate that in which grades individuals should acquire these skills and attitudes.
<u>Alternative Question 2</u>: What skills and attitudes would you expect the individuals have acquired to understand and use photonic technologies? Please, state why such skills and attitudes would be important for an individual to acquire, in justification/rational column. Also please indicate that in which grades individuals should gain these skills and attitudes.

Skills/Attitudes	**Level**	**Justifications**
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.

3. How does Photonics could be taught effectively in schools or universities? Please justify your answer and state the grade levels. More than one answer will be beneficial.
(If you do not want to answer this question, you may consider answering the alternative questions below.)
<u>Alternative Question</u>: What could be the teaching techniques for effective photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.

Teaching techniques/strategies	**Level**	**Justifications**
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.

4. How does Photonics Education could be evaluated effectively in schools or universities? Please justify your answer and state the grade levels. More than one answer will be beneficial.
   (If you do not want to answer this question, you may consider answering the alternative questions below.)

   <u>*Alternative Question*</u>: *What could be the evaluation techniques for effective photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.*

Evaluation methods/techniques	**Level**	**Justifications**
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.

5. What are the experiments, activities and informal (out-of-school) activities that can be designed at schools/universities for photonics education? Please justify your answer and state the grade levels. More than one answer will be beneficial.

Experiments/ Activities/ informal (out-of-school) activities	**Level**	**Justifications**
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.
Click or tap here to enter text.	Choose an item.	Click or tap here to enter text.

THANK YOU FOR YOUR PARTICIPATION AND CONTRIBUTIONS.

Appendix-C: Survey Form & Items

1. Topics that can be taught to students in photonics education
Middle School Subjects
Light and features of light
Wave and particle property of light
Particle property of light
Wave property of light
Speed of light
Reflection
Colors - RGB
The relationship between temperature and color
Mirrors
Diffraction
Lenses
Electrical Resistance
Electricity Transmission
Circuits: Parallel and series coupling
Electric Current
Lighting - Kelvin, Lumens concepts
Electron
Photosynthesis
Sun and vitamin D, (association with biophotonics)
Periodic table and elements
Semiconductors
Energy and energy conservation; Energy production and consumption
Optical devices (Camera, microscope, telescope)
Light sources: Bulb, LED, laser
Semiconductor devices (laser, led, detector)
Fiberoptic
Led
Lasers and their application areas
Detectors
Photon
Why is the sky blue?
What color light should be used in which room?
Differences between LED and lamp
Artificial lighting for plants
Loading information into the light: fiberoptics, music CD
Laser reflection
3D cinema
Photography
Glasses with polarized and UV protection
High School Subjects
Theories of Optics
Reflection, Snell's Law and Fracture
Light-matter interaction
Electromagnetic spectrum
Waves

Young's experiment
Structure of the atom
Electron and Energy Levels
Radiation
Energy
Generation of light
Electrochemistry (electron relationship with valence/conductivity band)
Planck/Planck constant
Photoelectric phenomenon
The wave and granular nature of light
Momentum of light
Photonics and its application areas
Led
LASER
Fiberoptic
Conductivity/conductors
Electrical circuits
Thermodynamics
Simple P-N joint
Spectrum, Spectroscopy
Geometry
Mathematical modeling
Statistics
Imaging technologies
Telescope construction
Camera and lenses
University Topics
Photonic Circuit Elements
Electrical and electronics courses
Basic Sciences & Engineering
Basic optics
Geometric Optics
Modern physics
Quantum mechanics
Semiconductor physics
Solid state physics
Circuit Lessons
Calculus
Differential Equations
Interaction of light and matter
Electromagnetic Theory
Signal processing
Photoelectric
Heisenberg
Compton
LED, diode (transistor, P-N junction, microelectronics)
The Nature of Science
The cycle of science and technology influencing each other should be given.
It should be given with the knowledge of historical development.
Important scientists should be given in connection with the subjects.

General ideas
Both the particle and wave properties of the light should be given at the same time.
The existing topics of optics and physics in the curriculum are sufficient, photonics topics should be added to these subjects.
Classical physics hinders students' learning. Modern physics can be taught directly to the new generation.
2. Skills and attitudes that can be gained to students with Photonics Training
Scientific Process Skills
Ability to make observations
Ability to make inferences
Ability to experiment
Experiment planning / Identifying variables
Drawing a graph / Using Data and creating models
Data Collection and Analysis capability
Engineering Design Skills
Product, Project Development Skills
Problem/problem solving skills
Literature Review and Research Skills
Thinking Skills
Inquiring
Analytical thinking skills
Critical and critical thinking skills
Creative thinking skills/creativity
Scientific thinking skills
Mathematical thinking skills
Technical skills
Dexterity / motor skills
Ability to Design Optical Test Setups
Device handling skills
Other Skills Other Than 21. Century skills
Computer usage / informatics / software skills
Problem-solving skills
Communication skills and collaboration
Time management
Entrepreneurship / leadership
Science Literacy
Scientific curiosity / Interest in the field, curiosity
Use and familiarity in everyday life
Reasoning in the field of science and technology
The nature of science
3. Teaching strategies, methods and techniques that can be used in photonics education
Laboratory-assisted training
Project-based learning
Problem-based learning
Context-based approach (context-based)
Inquiry based learning
Computer Aided Learning / Web-aided learning (Technology and visual support such as simulation, animation, animation, visualization, video, virtual reality, VR)
Argumentation: Socioscientific (controversial) topics from the field of photonics are selected and discussed in a classroom environment

Cooperative learning/Group work
Technical trips, Advanced Laboratory visits
Creative Drama
Demonstrations
Benefiting from the history of science and the lives of scientists
4. Assessment approaches and techniques that can be used in photonics training
Methods that can be used for evaluation
Exams consisting of open-ended questions
Exams consisting of test questions
Mixed (open-ended and multiple choice) exams
Projects (to be carried out in a classroom environment, related to achievement)
Project assignments (to be carried out outside the classroom, non-attainable)
Research papers (long-term)
Assignments (short-term, weekly assignments)
Assignments (product-based, including calculation and design)
Classroom discussions
Observation Forms
Test Reports
Group worksheets
Product selection files (portfolio)
Rubrics
Project Competitions
Internships and internship books
Concept networks, concept maps, concept caricatures to support conceptual learning
Process-oriented assessments: measurement at entry and exit, before and after application
Question Types
Open-ended questions
Test questions
Experimental questions / Experimental setup questions
Context-based, scenario-based questions related to daily life
Comment questions (Questions students can comment on)
Questions that measure knowledge
Questions that enable the application and use of knowledge
5. Informal learning environments that can be used in photonics training
Field Trips and Visits
Science and Technology Centres and Science Museums
Company/ Company/ Factory visits
Laboratory/ Research Center
University/ Institute
Science Technology Fairs
Observatory visit
Museum tour
Observation and Demonstration Experiment Activities
Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)
Intriguing, wide-ranging demonstration experiment events associated with the nature of light
Astronomy-Observation Activities, observations made using different telescopes
In-school Activities
Competitions / Project Competitions
Science Festivals
School Exhibitions

Student societies and clubs
Teaching of upper classes to lower classes / peer education (voluntarily)
School-University-Sector Cooperation
To organize interviews orvirtual meetings on photonic technologies by inviting relevant people from universities and/or sectors
Career day / career promotion events
Companies working in the field of photonics organize special activities for students (such as light day activities, door open days, demo huts)
Requesting lab videos from field workers
Government-backed enhancements
Establishment of central laboratories
Government-sponsored internships

Appendix-D: Photonics Teaching Table

PHOTONICS CONCEPTS	
Elementary School Level	Light and features of light
	Colors
	Mirrors
	Lenses
	Reflection
	Optical devices (Camera, microscope, telescope)
	Light sources: Light bulb, LED, laser
	Speed of light
	Photosynthesis
	Sun and vitamin D, (association with biophotonics)
	Artificial lighting for plants
	Electrical Resistance
Secondary School Level	Theories of Optics
	The wave and particle nature of the light
	Light-matter interaction
	Reflection, Snell's Law and Refraction
	Electromagnetic spectrum
	Waves
	Young's experiment
	Structure of the atom
	Electron and Energy Levels
	Energy
	Radiation
	Generation of light
	Electrochemistry
	Planck and Planck constant
	Photoelectric Effect
	Momentum of light
	Photonics and its application areas
	LED
	LASER
	Fiberoptics
	Cameras and telescopes
	Imaging technologies
	Electrical circuits
	Conductivity and conductors
	Thermodynamics
	Mathematical modeling
	Geometry
University Level	Optics
	Geometric Optics
	Circuit Lessons
	Basic Electrical and Electronics courses
	Basic Sciences & Engineering Courses
	Photonic Circuit Elements
	Solid state Physics
	Modern Physics
	Quantum Mechanics
	Semiconductor Physics
	Calculus

	Interaction of light and matter
	Electromagnetic Theory
	Photoelectric Effect
	Compton Scattering
	Heisenberg Uncertainty Principle
	Differential Equations
Nature of Science Ideas	The cycle of science and technology influencing each other should be given.
	Historical development should be given.
	Important scientists should be given in connection with the subjects.
SKILSS & ATTITUDES	
Science Process Skills	Observation
	Making inferences
	Experimenting
	Experiment planning / Identifying variables
	Drawing a graph / Using data and creating models
	Data Collection and Analysis
Engineering Design Skills	Product/project development skills
	Problem solving skills
	Literature review and research skills
Thinking Skills	Inquiring
	Analytical thinking skills
	Critical thinking skills
	Creative thinking skills/creativity
	Scientific thinking skills
	Mathematical thinking skills
Technical Skills	Psychomotor skills
	Optical experiment setup designing skills
	Device usage skills
Other 21st Century Skills	ICT / Computer usage / informatics / software skills
	Communication skills and collaboration
	Time management
	Entrepreneurship and leadership
Science Literacy	Scientific curiosity / Interest in the field, curiosity
	Appreciation of daily life usage and familiarity
	Reasoning in the field of science and technology
TEACHING METHODS	
Laboratory work	
Inquiry-based learning	
Context-based learning	
Problem-based learning	
Project-based learning	
Field trips, Technical trips, Advanced Lab visits	
Computer-aided Learning / Web-based Learning	
Demonstrations	
Integration of the history of science and the life of scientists	
Cooperative Learning / Group-working	
Argumentation	
Discussions	
EVALUATION METHODS	
Methods that can be used for evaluation	Project competitions
	Experiment reports
	Assignments (short-term, weekly assignments)

	Classroom discussions
	Project assignments (to be carried out outside the classroom)
	Research papers (long-term)
	Assignments (product-based, including calculation and design)
	Projects (to be carried out in a classroom environment, related to achievement)
	Observation Forms
	Exams consisting of open-ended questions
	Pre-post assessments
	Internships and training record book
	Group worksheets
	Rubrics
	Concept maps and concept cartoons
	Portfolios
Question Types	Experimental, experimental design questions
	Questions that enable to apply and use knowledge
	Reason-Comment questions (Questions students can comment on)
	Knowledge questions
	Context-based, scenario-based questions related to everyday life
INFORMAL SETTINGS	
Field Trips and Visits	Company/ Factory visits
	Science and Technology Centres and Science Museums
	Laboratory/ Research Center
	University/ Institute
	Science Technology Fairs
	Observatory visit
	Museum tour
Media & Broadcasting	Readings, reviews and research from science magazines, posters, magazines, models, popular science books
	Social media platforms
Observation and Demonstration Experiment Activities	Observations of daily life and natural phenomena related to light (such as sun, color, rainbow)
	Astronomy-Observation Activities, observations made using different telescopes
	Intriguing, wide-ranging demonstration experiment events associated with the nature of light
In-school Activities	Project Assignments / Competition
	Contests and rewards
	Student clubs
	School Exhibitions
	Science Fairs
	Teaching of upper classes to lower classes / peer training: with volunteering
School-University-Sector Cooperation and Outreach	To organize interviews or virtual meetings on photonic technologies by inviting relevant companies from the university and/or sector
	Companies working in the field of photonics organize special activities for students (such as light day activities, door open days, demo huts)
	Career day / career promotion events

Appendix-E: Ethics Committee Permission

BURSA ULUDAĞ ÜNİVERSİTESİ
ARAŞTIRMA VE YAYIN ETİK KURULLARI
(Sosyal ve Beşeri Bilimler Araştırma ve Yayın Etik Kurulu)
TOPLANTI KARARI

OTURUM TARİHİ
22 Ekim 2021

OTURUM SAYISI
2021-09

KARAR NO 27: Eğitim Bilimleri Enstitüsü Müdürlüğü'nden alınan Matematik ve Fen Bilimleri Eğitimi Anabilim Dalı Fen Bilgisi Eğitimi Bilim Dalı yüksek lisans programı öğrencisi Hümeyra Azize YALÇIN'ın "Fen Bilimleri Eğitimine Yönelik Fotonik Eğitimi Çerçevesinin Belirlenmesi: Bir Delphi Çalışması" konulu tez çalışması kapsamında uygulanacak görüşme sorularının değerlendirilmesine geçildi.

Yapılan görüşmeler sonunda; Eğitim Bilimleri Enstitüsü, Matematik ve Fen Bilimleri Eğitimi Anabilim Dalı Fen Bilgisi Eğitimi Bilim Dalı yüksek lisans programı öğrencisi Hümeyra Azize YALÇIN'ın "Fen Bilimleri Eğitimine Yönelik Fotonik Eğitimi Çerçevesinin Belirlenmesi: Bir Delphi Çalışması" konulu tez çalışması kapsamında uygulanacak test ve görüşme sorularının fikri, hukuki ve telif hakları bakımından metot ve ölçeğine ilişkin sorumluluğu başvurucuya ait olmak üzere uygun olduğuna oybirliği ile karar verildi.

Prof. Dr. Ferudun YILMAZ
Kurul Başkanı

Prof. Dr. Abamüslim AKDEMİR
Üye

Prof. Dr. Doğan ŞENYÜZ
Üye

Prof. Dr. Ayşe OĞUZLAR
Üye

Prof. Dr. Vejdi BİLGİN
Üye

Prof. Gülay GÖKGÖZ
Üye

Prof. Dr. Âlev SINAR UĞURLU
Üye

RESUME

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Member of Scientific and Professional Organizations: None

Projects and Meetings Attended: None

Publications: A Thematic Review of the Present Photonics Education Yalçın H.A., Çepni S.,Aydemir U. (2021). The Education and Training in Optics and Photonics Conference (ETOP),Washington,United StatesOf America,8 - 10 September 2021

15.08.2022
Hümeyra Azize YALÇIN