PREPAREDNESS AND PHYSICS-RELATED EPISTEMOLOGICAL VIEWS OF INTERNATIONAL PHYSICS MAJORS AT A FINNISH UNIVERSITY

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Abstract

The aim of this research is to depict foreign entrant students' preparedness for studies in an international Master's degree programme of physics at a Finnish university in order to lay the ground for a research-based development of the study programme. Interviews were conducted with the academic staff involved in the programme to investigate their views on the international physics students as learners. Conceptual tests were deployed to assess international students' conceptual understanding of the areas fundamental to acquiring a solid expertise in physics. To enrich the data, a survey was conducted to obtain information about students' physics-related epistemological views. Both qualitative and quantitative methods were used for the data analysis. The main results suggest that the entrant international students comprise a very heterogeneous group with regard to their preparedness for commencing physics studies. The staff were specifically concerned with the international students' pre-knowledge of physics, a notion that is supported by the test results. Suggestions based on present findings are made for further development of international degree programmes such as the one considered in this article.
Keywords: *epistemological views, higher education, international students, postgraduate studies, pre-knowledge*.

Introduction

Over the past three decades the Finnish Ministry of Education has issued policies with guidelines for the internationalisation of higher education (Saarinen, 2012; Ministry of Education, 2009). One of the distinctive marks of such a development is the annual intake of international degree-seeking students exceeding 20 000, with a total of 295 000 international students in Finnish higher education institutions in 2015 (EDUFI, 2017). To accommodate the entrants, numerous degree programmes, largely taught in English, have been established across the country (Saarinen, 2012; Gill & Kirkpatrick, 2013).

In spite of the internationalisation, little has been done to investigate the functionality and quality of the English-medium degree programmes offered at the Finnish higher education institutions. It was not until 2012 that the Finnish Higher Education Evaluation Council produced the first evaluation of international degree programmes in Finnish institutions of higher education (Pyykkö *et al.*, 2013) that undoubtedly seek to offer quality education. To achieve this objective, the international degree programmes need to undergo rigorous research-based evaluation and development.

In line with the common trend, the Finnish university, in which this research was conducted, has initiated an international Master's degree programme in physics in 2010. The initiative has entailed new challenges for the department staff. Since the launch of the programme, the majority of its international students have come from South Asia and Africa.

This has created a cultural contrast in the lecture halls and classrooms—a situation that the staff cannot overlook. From the learning perspective, even more significant is the academic culture of the country of origin, because it shapes the individual students' views and approach to physics.

Students' pre-knowledge and skills may be notably diverse in a cohort, such as the one targeted here, especially at the beginning of their studies at any educational establishment. By the same token, epistemological views, such as those about physical knowledge construction (Redish, 2004), may vary considerably, having been formed by the educational conventions of the students' country of origin. Thus, the groups that annually enter the programme are heterogeneous in numerous respects, confronting the educational practices with new challenges. Having provoked much discussion amongst the academic staff, the question of how to respond to the challenges created by such a heterogeneous student population duly calls for a research into student pre-knowledge, skills, and epistemological views of physics, *e.g.*, whether physical knowledge essentially consists of concepts or formulas (Elby, 2011). In pursuit of an effective consideration of such factors in the planning and implementation of instruction, the first research question was formulated as follows:

RQ1: What is the entrant international physics students' preparedness for studying and learning?

In this article, 'preparedness' is used as an inclusive term for students' pre-knowledge of physics, and also their problem-solving, experimental, reporting, and mathematical skills. To address the research question, the students' preparedness for studying and learning has been examined from two standpoints. The staff's views of the preparedness of the photonics students is probed using interviews, and the level of the students' conceptual understanding of physics is examined by means of conceptual tests.

Theoretical Framework

Pre-knowledge

Physics is a highly structured discipline, which means that physics content can be best learned by following a cumulative study approach, *i.e.*, by constructing the new knowledge upon, and intertwining it with, the existing schemata. In order to effectively advance students' learning of physics, they require a solid basis upon which to construct new concepts and models. This means that student pre-knowledge plays an essential role in their taking hold of new concepts and models, and in developing a deeper understanding of the subject matter (McDermott & Redish, 1999; Mestre, 1994).

Research in physics education has revealed that student comprehension of the fundamental concepts can remain inadequate despite the efforts of even the most experienced teachers. McDermott and Redish (1999) provide an overview of numerous studies dealing with university students' conceptual understanding, concept formation, and problem-solving skills in physics, as well as with the development of the actual teaching of physics. Based on reports from the United States, Brazil, Israel, Sweden, India, and South Africa—to mention only a few—it seems that the ineffectiveness of conventional lectures is a global issue. To quote McDermott (1991), *"what the instructor says or implies and what the student interprets or infers as having been said or implied are not the same"*. The problem becomes even clearer if students in the group have largely different views about learning physics and about the discipline itself.

Epistemological Views

In the present research, *epistemological views* refer to students' ways of understanding or thinking about knowledge, its formation and constructing, and about learning. An e*pistemology* is formed by a set of epistemological views that a person holds regarding a subject, for example, physics (*cf.* Hofer & Pintrich, 1997; May & Etkina, 2002).

Beside students' pre-knowledge, their epistemological views (*e.g.*, pieces *vs.* coherence of knowledge) also have an effect on learning (May & Etkina, 2002; Elby, 2011). Students that possess a high proportion of expert-like views about physics are likely to be active and *"critical learners"*, whereas those who mostly hold *"folk views"* tend to fall into the category of the "*passive learner*" (Halloun, 2001). Students' views play a role in their adoption of productive cognitive and behavioural strategies (Paulsen & Feldman, 2007). Moreover, favourable views about physics reportedly correlate with students' learning gain and course achievement (Halloun, 2001; Lising & Elby, 2005; Perkins, Adams, Pollock, Finkelstein, & Wieman, 2004). From the perspective of the students' learning and academic achievement, the second research question is therefore relevant:

RQ2: What kind of epistemological views do the entrant students hold in regard to physics?

The physics-related epistemological views held by physics majors have been systematically examined since the late 1990s, when the Maryland Physics Expectations Survey (Redish, Saul, & Steinberg, 1998) was published. For the past two decades, extensive studies in the field have produced several validated surveys (Halloun, 2001; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Elby, 2006; Adams *et al.*, 2006). Research suggests that student views about physics and about studying and learning physics affect their attitudes and views about teaching as well as their own learning. Based on their views, students choose study methods that, in turn, determine the depth of their understanding of the subject matter (Redish *et al.*, 1998). Furthermore, Stathopoulou and Vosniadou (2007) note that sophisticated epistemological views, such as constructivist rather than absolutist/objectivist, are *"a necessary (although not a sufficient) condition"* for gaining conceptual understanding in physics.

Motivation and Interest

In surveys that probe student views about the nature of physics and of learning physics, motivation and interest are often included as variables because they are regarded as key elements that guide the learning of physics.

In an extensive review article, Pintrich (2003) has introduced five generalizations concerning the factors that motivate students in the classroom. The first family of social–cognitive constructs consists of "*adaptive self-efficacy and competence perceptions*." Students who believe that they can do well and are persistent in their efforts are likely to succeed in a given task. In contrast, those who think they will achieve less and be unsuccessful, will engage in a learning task at a lower cognitive level than students who are confident in their academic skills.

Another construct listed by Pintrich (2003) is that concerned with "*high levels of interest and intrinsic motivation*." A distinction is often made between personal and situational interest. The former refers to the individual's own disposition with regard to enjoying or being attracted to a certain activity. Personal interest, in turn, is regarded as being a more unchanging variable that describes a psychological state of being interested in a subject as a result of the interestingness of the subject. Pintrich refers to several reports (*e.g.*, Eccles, Wigfield, & Schiefele, 1998;

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Hidi, 1990; Pintrich & Schunk, 2002) showing that high levels of personal interest and intrinsic motivation are positively linked to academic performance and cognitive processing.

According to Pintrich (2003), motivation is also dependent on whether the subject or task carries some importance for the learner. Students are motivated if the tasks, activities, and materials used in the teaching are useful and meaningful for them. The last group of motivational generalizations are *goals* (Pintrich, 2003). Students may have various personal goals, specific objectives related to an achievement context, *e.g.*, school (Urdan & Schoenfelder, 2006). A student with mastery goals is oriented toward developing competence, skills, and understanding by using self-referenced standards (Pintrich, 2003). On the other hand, a student with performance goals compares him/herself to other students striving for recognition and demonstrating high abilities (Pintrich, 2003). Research has shown that students possessing mastery goals are more persistent with regard to learning difficulties, are more intrinsically motivated, and use more deep-level cognitive strategies than students with performance goals (Urdan & Schoenfelder, 2006).

Methodology of Research

Context

The research was conducted at the department of Physics and Mathematics at a Finnish university in 2013. The department provides a two-year degree programme in photonics physics intended for students with a BSc degree. More specifically, the programme specialises in *photonics*, a branch of physics that is concerned with the generation, transmission, modulation, amplification, and detection of light within the wavelength range of UV, visible light, and IR (Saleh & Teich, 2007). The extent of the programme is equivalent to 120 credits; according to the European Credit Transfer and Accumulation System, one credit corresponds to approximately 27 hours of work (European Commission, 2017). The programme consists of theoretical studies, practical laboratory work, and a Master's thesis (see Table 1). The graduates are qualified to work as experts in research and development in the photonics industry, as well as to pursue an academic career.

ISSN 1822-7864 (Print) ISSN 2538-7111 (Online)

Table 1. Contents of the Master's Degree Programme in physics at the department.

Course	Credits
Advanced Measurements and Laboratory Practice	17
Colour Science	4
Communication Skills	4
Components for Optical Telecommunications	4
Data and Error Analysis in Natural Sciences	2
General studies (*e.g.*, MatLab™ Fundamentals)	3
Industrial and Biomedical Optics	4
Laser Physics	4
Light and Matter	4
Material Physics	4
Mathematical Methods for Photonics	4
Micro- and Nanophotonics	4
MSc Thesis in Photonics	30
Nonlinear Optics	4
Optical Design I: Geometrical Optics	4
Optical Design II: Numerical Modelling	2
Optoelectronics	4
Photonics and Optics Fundamentals	4
Physical Optics	4
Quantum Optics	4
Quantum Physics	4
Undergraduate Seminar in Physics	2
Total	120

Most courses are taught in a lecture format in a classroom setting. They include weekly exercise sessions during which homework is checked and worked through. By solving exercise problems, students can obtain extra points up to of 10% of the course exam score. Laboratory work is done both individually and in small groups. While writing their Master's thesis, most students engage in laboratory practice. Students are also encouraged to apply for internships either at the department, another university, a photonics-related company, or a research institute.

Target Groups

Looking into the academic staff's views about students as learners provides answers to the first research question regarding student preparedness. A consent to participation in the interview was received from 14 out of 15 staff responsible for teaching in the degree programme. In order to particularise the research results and be able to contrast responses from staff with different status and teaching experience, the interviewees were grouped and labelled as professors, other senior staff, and other personnel (Table 2).

Table 2. Staff groupings. The number of participants is given in parentheses.

Professors (6)	Other senior staff (4)	Other personnel (4)
Professors (5)	Senior lecturers (2)	Postdoctoral researcher
Associate professor	Senior researchers (2)	Project researcher
		Early-stage researcher
		Chief engineer

Another group of respondents consisted of the international entrant students of 2013. All 14 of them agreed to participate in the present study. The students represent four Asian and two African nationalities, and held either a Bachelor's or Master's degree in science or engineering, majoring in a variety of subjects (Table 3).

Table 3. The major subjects and degrees of the 2013 entrants. One of the students holds a BSc degree in both physics and optics & optoelectronics, hence 15 degrees in total.

Major subject	Degree	*N*
Physics	MSc BSc	4 3
Optoelectronics (engineering)	BSc	2
Electrical engineering	BSc	2
Electronics	BSc	2
Engineering physics	BSc	1
Optics & optoelectronics	BSc	1
Total		15

Methods and Data Analysis

While following the design-based research strategy (*e.g.*, Barab & Squire, 2004), both qualitative and quantitative methods for data collection and analysis were employed. Using the semi-structured interview (Galletta, 2013), information was gathered about the staff views concerning international students' preparedness. In order to gain insight into the students' pre-knowledge and epistemological views, conceptual surveys were used. A mixed methods approach was opted for to gather versatile information (Creswell & Plano-Clark, 2010; Morse, 2003) in order to better understand the international photonics students as learners.

Views of staff

To investigate the staff perspective on how the starting levels of the international physics students have been taken into account, a semi-structured interview was conducted with 14 staff. The focus of the interview was in students' preparedness for photonics studies. Also, the students' attitudes toward studying and learning physics were targeted. The questions (see Appendix A) were based on those suggested for curriculum development by Anderson and Rogan (2011). The interviews, with an average duration of 52 minutes, took place either in the staff members' offices or in a department conference room.

In processing the data, content analysis (Krippendorff, 2004) was used to produce a concise description that summarises the findings, providing a general picture of the international photonics students at the department. To verify the results, each respondent was asked for comments on the summary compiled from the interviews within his own group (Table 2). The summaries were sent to all staff individually prior to the second interview. After analysing the data from the first interview round, the results were cross-checked with the statements and comments from the second round. The resulting remarks were included as revisions in the summary, separately for each group.

Entrant students' conceptual understanding and views of physics

Since the launch of the degree programme in 2010, the department staff has noticed that not nearly all entrants exhibit sufficient pre-knowledge of physics. This is in spite of the fact that they hold a BSc or MSc degree in (a specialised field of) physics or engineering. Similar opinions were frequently expressed during the staff interviews. Hence, to complement the interviews with quantitative data concerning students' pre-knowledge of physics, a set of tests in optics, electromagnetism, and Newtonian mechanics was employed. Additionally, students' views of physics and physics learning were studied. The following sections introduce the instruments that were used.

Optics. Evaluating the pre-knowledge of basic optics is justified because the degree programme comprises a range of advanced optics-related courses (Table 1). In order to succeed in their studies, it is vital for the entrant students to have a grasp of the basic optical phenomena. The local students, for their part, are prepared for MSc studies in photonics by taking a mandatory Bachelor's level photonics course.

Since no suitable test was available for measuring student understanding of the fundamental optics concepts and principles, a test (Appendix B) adapting Knight's introductory physics (Knight, 2004) and applicable problems from various studies (Kryjevskaia, Stetzer, & Heron, 2011; Ambrose, Shaffer, Steinberg, & McDermott, 1999; Wittmann, Steinberg, & Redish, 1999; Wosilait, Heron, Shaffer, & McDermott, 1999; Wosilait, 1996) was employed. Prior to administration, all of the test items were approved as appropriate and solvable on the basis of Bachelor's level optics by an experienced physics professor.

The optics test was administered in a classroom setting at the beginning of the fall semester. After giving a short introduction to the Fundamentals of Optics and Photonics course, the lecturer assigned the remaining time for the students to take the test. Thus, they had received essentially no instruction in the subject at the department. Since none of the participants were native English speakers, it was assumed that they would need extra time to complete the test, which they did in 52–80 minutes. Indeed, the language seemed to cause some difficulties, as some participants asked for clarification of a few test items. Not only was this an issue with the optics test but also with the validated instruments. Hence, assistance was provided on request to help students have a clear understanding of the items.

In analysing the responses, special attention was paid to the students' reasoning. In 20 of the 30 items, students were specifically asked to explicate their reasoning. Both the correct and incorrect answers to these items were scored zero if no due reasoning was provided. Each correct answer added one point to the total score. Most of the items were qualitative, only three of them required some elementary algebra.

According to the themes covered, the items were clustered into four categories: (i) Basic concepts, (ii) Superposition of waves, (iii) Interference, and (iv) Diffraction. The categories consisted of 10, 4, 14, and 9 items, respectively. The category-wise, overall, and individual scores were calculated along with the standard deviations.

Electromagnetism. In order to investigate the students' knowledge of central ideas of electromagnetism, a validated instrument known as the Conceptual Survey of Electricity and

Magnetism (CSEM, Maloney *et al.*, 2001) was employed on account of its broad coverage of the domain. Mastering the key ideas of electromagnetism at an introductory level enables students to grasp more advanced concepts in optics and photonics. Students can develop their understanding of light and its properties, and also the interaction between light and matter, if they possess sufficient pre-knowledge of underlying concepts, principles, and laws, such as Coulomb interaction, electric and magnetic fields, electric potential, the superposition principle, and, most importantly, the four laws enveloped in Maxwell's Equations.

The CSEM consists of 32 multiple choice items, clustered into 11 conceptual areas (Maloney *et al.*, 2001). Students' responses were entered into a spreadsheet template, displaying both the overall scores and the detailed scores for each area, along with the standard deviations. The CSEM was administered to the students in a classroom setting one week after they had taken the optics test. Since not all of the participants could be present on the same day, half of them took the test after lectures on the appointed day and the rest of them on the following day. The time taken to complete the test was 43–70 minutes.

Newtonian mechanics. Newtonian mechanics can be regarded as one of the gateways to constructing an understanding of more advanced fields of physics. Its elementary concepts and principles are applicable in a range of physical phenomena, including those of optics and photonics. It is, therefore, reasonable to expect of the entrant students a mastery of Newton's Laws, basic kinematics, and the superposition principle. To assess their conceptual understanding of these topics, the Force Concept Inventory (FCI, Hestenes, Wells, & Swackhamer, 1992) was employed.

Although the FCI was administered at the beginning of the spring semester, its function as a pre-test of Newtonian concepts was warranted, since there is no instruction in classical mechanics at any stage of the photonics programme. The students took the test after lectures in a classroom setting.

To analyse the FCI data, a spreadsheet template similar to that used for the CSEM was utilised. Entering the students' answers as raw data yielded the percentages and the standard deviations of correct responses for 8 categories, and also the overall result (all test items included). Also, the individual scores were calculated for each of the test items.

Views about physics and learning physics. As with their pre-knowledge, students' views concerning physics and learning physics inasmuch as their views affected their learning outcomes needed to be explored. To this end, using the Colorado Learning Attitudes about Science Survey (CLASS), developed by Adams *et al.* (2006), seemed appropriate.

The CLASS consists of 41 statements about physics and learning physics on a five-point Likert scale. The survey suited the purpose of this study since it covers the main factors that impact student learning (Table 4). In the current version, 26 items address 8 categories that characterise various aspects of student thinking.

Table 4. The factors that affect learning discussed during the staff interviews and their counterparts in the Colorado Learning Attitudes about Science Survey.

Factors that impact learning	Coinciding categories in the attitude survey (CLASS)
Preparedness	Problem-solving, general Problem-solving confidence Problem-solving sophistication Conceptual connections Applied conceptual understanding
Motivation and interest	Personal interest Sense-making / Effort
Views about physics and learning	Sense-making / Effort

The participants responded to the questionnaire at the beginning of a fall semester in two sessions, immediately after taking the CSEM test. During the session, a few students asked to clarify the meaning of the control item. One of the students left this item unanswered, whereas five of them did not answer favourably. Suspecting that the six students did not actually understand the meaning of the item, it was double-checked with each of them in person. As a result, one of the respondents was discarded while the remaining five were approved for the analysis.

For data analysis, the Likert scale was collapsed to a three-point scale as the responses ‘strongly agree’ and ‘agree’ were treated the same (similarly for ‘strongly disagree’ and ‘disagree’) (Adams *et al.*, 2006). The responses were then compared with those of experts and the coinciding answers were regarded as favourable. Scoring above 80% indicated an ‘expert view’ in a given category, whereas scores below 50% were considered to be typical of novices. The category-wise scores, the overall scores, and the standard deviations were calculated using a spreadsheet template.

Due to the small number of participants, one cannot generalise the results. However, the results can be compared with the views of the staff to find out whether the two types of data sets are mutually supportive. Considering the limitations of a small sample size, the FCI, CSEM, and CLASS results can be set against those of previous studies.

Research Results

International Students as Seen by Academic Staff

There are three separate parts in the description, one from each staff group. The students are depicted from the perspective of their learning and described in terms of qualities mentioned by their teachers. Despite some generalizations, the descriptions portray the primary features and qualities of the students as learners. This article seeks to provide a general representation of the views of *all* of the respondents, attempting also to convey the subtleties of their opinions.

By professors

According to the professors, the international students are highly motivated and generally very active in class. Some, however, are merely going through the motions, *i.e.*, undertaking only the mandatory tasks and lacking initiative. Some of the students seem to have a low academic self-concept. By the same token, their independent thinking appears to be rare. Their overall physics pre-knowledge and conceptual understanding seem to be too poor—and even insufficient—for them to succeed in photonics studies. Yet there is also a small proportion of the entrants who do have a solid background in physics.

The students’ mathematical skills are also widely considered to be weak. Especially their grasp of complex numbers and matrix algebra is found to cause difficulties. However, the issues concerned with mathematical skills are not considered insurmountable. Poor performance in reporting is generally noticed by the professors. In addition, the students are claimed to have low experimental skills, whereas their problem-solving in a laboratory context has not raised concerns amongst the professors.

The general learning preparedness of the international students is regarded as moderate. In the professors’ opinion, there is a deep division in IT skills (*e.g.*, computation) amongst the population. Students’ note-taking skills are also expected to be more advanced than is the case. Although most of the students are very interested in studying, few seem to focus on gaining a profound understanding of the subject matter. Instead, in their ardent pursuit of top grades, they exhibit a strong tendency to learn by rote. In summary, the international photonics students form a very heterogeneous group, with a considerable diversity in their skills and pre-knowledge.

Comparison between Finnish and international students. The professors see the international students as much more active and the student group as more heterogeneous and prone to rote learning than their Finnish counterparts. The Finnish students' conceptual understanding and their overall pre-knowledge of physics are said to be better-structured and more uniform than those of the international students'. Some differences are seen in their written reports, in which the Finnish students perform better. It should be noted that the Finnish students typically write reports in their native language, whereas the international students are required to report in English, which is a second language for most. The Finns also exhibit a greater awareness of the need to understand the content than do their international peers. Likewise, the Finnish students' mathematical skills are said to be better, albeit diverse.

Revisions from the second interview. A majority of the professors generally agreed with the description presented above. A few of them noted that the international students' weaknesses are slightly overemphasised, while others said that the picture is realistic. Furthermore, it was noted that there are no clear differences in the mathematical skills of the Finnish and the international students. While most teachers in this group advocated learning styles and teaching methods that support an understanding of contents, rather than merely memorizing all of the lecture materials, there was also an opinion in favour of rote learning and cramming for the exams, based on the notions that for most students advanced physics is too complex to comprehend during the course.

By other senior staff

According to the other senior staff, the international students display a high interest in studying, and are mostly active. The students readily communicate with staff members both within and outside the classroom settings. They tend to memorise the course contents rather than demonstrate a deep approach to learning. The students are performance-oriented, although some are perceived as keen to increase their understanding of the subject matter. Their conceptual understanding is referred to as poor, as a result of which difficulties might occur in their application of their knowledge–an aspect pointed out by some of the other senior staff.

The international students' attitude towards studying appears to be positive, and they are said to be hard-working as well as motivated. The students tend to achieve high scores in exams, yet their reporting performance is low. Some of them are strongly dependent on guidance and supervision in advancing their work.

The physics pre-knowledge of the students appears diverse according to half of the other senior staff. In contrast, the insufficiencies in the students' mathematical skills are noted by a majority of the teachers in this group. The students' reporting and experimental skills cause considerable concern. Additionally, the students' problem-solving abilities are deemed to be low.

The students' general learning preparedness is said to be reasonable, yet some lack the IT skills needed in the photonics studies. As for their peer cooperation, the students have been seen work together in study groups. However, they still need to adjust to the local academic culture. Students should become accustomed, for instance, to a more interactive and comprehension-oriented approach to studying than mere learning by rote would require. Also, they may need to welcome less authoritative teaching styles than those they may have experienced previously.

Comparison between Finnish and international students. The feature most highlighted by the other senior staff is the international students' tendency to apply rote learning, which is not typical of their Finnish peers. The Finns are better at applying their knowledge to solve both theoretical and practical problems even though their exam scores are, on average, lower than those of the international students.

The international students have quite a positive attitude to studying, and they seem to work harder than the Finnish students. In laboratory settings, however, the Finns are able to work independently and need less support from their supervisor. In addition, the reporting skills of the Finnish students surpass those of their international co-students.

The Finnish students' mathematical skills are regarded as sufficient, unlike those of the international students. In terms of physics pre-knowledge, however, no significant difference between the two groups of students is seen by the other senior staff.

Revisions from the second interview. All of the other senior staff confirmed most of the statements made in the summary above. In the opinion of one, the level of both the international and the Finnish students' skills is not as low as pictured here, nor are the differences between the international and the domestic students as steep as stated in the summary. There was some concern among this group of teachers about overemphasizing the issues, which may be the result of a strong focus on students' differences, level of mastery, and preparedness. There was also doubt expressed as to whether the teachers, having exiguous contact with the students, are properly able to judge them as learners.

By other personnel

The other personnel did not stress the international students' activeness as much as their high motivation. Some teachers mentioned the students' high interest in studying physics. In contrast to this, rote learning had attracted the attention of one of the interviewees. Some of them had noted that student learning was impeded by the use of English as a second language. As for mastering the course materials, the students were only partly pursuing an understanding of the contents, while the majority were performance oriented. This, in turn, may lead to difficulties in their application of their knowledge. In general, the students are seen as hard-working, mostly displaying a positive attitude toward studying.

Students' pre-knowledge of physics is slightly diverse; it is usually poorer in the case of students with a background in engineering than it is for physics majors. The mathematical skills of all of the international students', are, however, explicitly regarded as advanced.

The international students clearly do not shine in the experimental work and reporting –there is a clear need for improvement. Some of them deliver poor reports on measurements, while some students need *"constant guidance and instruction"* in laboratory work. Their IT skills, such as the use of computation or text editing software, are also said to be insufficient. Some of them have displayed bad ethics in their studies.

Comparison between Finnish and international students. Finnish students are mentioned to be more oriented toward understanding the content, although they do not display as much interest in studying as the international students. Similarly, the international students' motivation to study is higher, which shows, for example, in their active search for knowledge.

The physics pre-knowledge of the Finnish students is said to be slightly better, while the international students possess more advanced mathematical skills. The basic skills needed in laboratory work (fine motor skills, in particular) of some international students have been noted to be lower than those of the Finnish students. In addition, the Finns have a more uniform set of reporting skills, and they face fewer problems with computing. The quality of laboratory reports produced by the Finnish students is, on average, higher than that of their international peers.

Revisions from the second interview. Of all the interviewees, the other personnel were the most approving of the above description. Some comments were made in order to update the image of the current situation. Student work ethics has become of less concern, as the issue has already been effectively addressed. The quality of reports was said to have improved lately. In line with an opinion of the other senior staff, it was pointed out that teachers may misjudge students because of misunderstandings caused by cultural differences.

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Student Pre-knowledge Based on Conceptual Tests

Student pre-knowledge was examined using three conceptual tests, the FCI, the CSEM, and the optics test. In the following, the results of the tests administered to the target group are presented.

Student performance in optics

The Basic Concepts category consisted of elementary items of both qualitative (conceptual) and quantitative (algebraic) nature (see Appendix B). Of the four categories, the students clearly handled the Basic Concepts best, although their score of 48% (Table 5) falls short of satisfactory on the department's exam grading scale.

Table 5. Category-wise percentage scores (standard deviation in parentheses) on the optics test.

Category	Score
Basic Concepts	48
Superposition of Waves	13
Interference	13
Diffraction	30
Average	26 (17)

The test items in the remaining categories were qualitative, although use of mathematical representation could help in finding the solutions. In the areas of the superposition principle and interference, the student performance is unsettling.

Inevitably, suspicions rise about the optics test items being overly demanding, or the students being unacquainted with the form of representation. The reliability of the results may be reduced by the test items not being sufficiently multifaceted in form of and approach to each concept.

However, the students entering a Master's degree programme in photonics are expected to be familiar with the elementary concepts such as those probed in the first five items of the optics test (Appendix B). Items #1–7 had to do with a graphical representation of a sinusoidal wave in a time-amplitude domain. A correct answer to these items requires a grasp of the elementary concepts of wave motion–the propagation speed, frequency, and wavelength. One also needs to apply the basic relation of these three quantities. A majority of the students (93%) wrote down the proper equation, $c = f\lambda$, yet 62% of these either failed to correctly interpret the graph for the wavelength, amplitude, or period, or did not eventually use the equation to find the numerical values.

In items #11–17, the students were asked to account for the water displacement caused by two wave sources, and for the type of interference (maximum constructive, completely destructive, or neither) at given points. The task can be solved by using the concepts of path length and phase difference, as well as elementary geometry (the Pythagorean Theorem and the similarity of triangles). Of the five students who referred to the path length difference, the phase difference, or both, only one correctly answered all 7 items.

In the case of double-slit interference (items #22–25), the superposition principle, Huygens' Principle, the concept of path length difference, and some basic trigonometry are required to derive the condition for the maxima/minima of the interference pattern. Treating the double slit as two separate point sources of light and using the top-view geometry of the setup, one can obtain the condition for the first maximum: $\sin\theta = \lambda / a$. Here, is the angle between the main axis (direction of the light incident on the double slit) and the direction to the first maximum, λ is the wavelength, and a is the distance between the two slits. Using the equation one can determine how the original interference pattern would change if a single alteration was made to the apparatus. A common practice, used by 43% of the students, was to treat the problem as if geometrical optics applied. The suggested idea of increasing either the distance between the slits or the width of both slits to produce a "stretched".

Student performance in electromagnetism

Of the 32 items of the Conceptual Survey of Electricity and Magnetism (CSEM), the students achieved the highest average score (69%) in those related to Coulomb's Inverse-square Law (Table 6). The second best results were obtained in the categories of Magnetic field superposition (50%) and Newton's Third Law (45%). In the categories of Induced charge and electric field (#6), and Faraday's Law (#10), the students scored as low as 18% and 20%, respectively.

Table 6. The Conceptual Survey of Electricity and Magnetism (CSEM) results. The category-wise percentage scores (standard deviation in parenthesis) of the international photonics students.

CSEM category	Score
Charge distribution on conductors/insulators	33
Coulomb's Force Law	69
Electric force and field superposition	40
Force caused by an electric field	26
Work; electric potential, field, and force	26
Induced charge and electric field	18
Magnetic force	39
Magnetic field caused by a current	41
Magnetic field superposition	50
Faraday's Law	20
Newton's Third Law	45
Average	37 (15)

In general, students did recall bits and pieces of the subject, but in most cases they were unable to use their knowledge in the proper context. A good example is the CSEM item #32 (Appendix C). To find the solution to the problem, 29% of the students wrote down Ohm's Law, ultimately irrelevant to solving the problem. They seem to have thought of an electric circuit, to which Ohm's Law applies, concluding that the current in the circuit is proportional to voltage. Consequently, they ended up selecting an incorrect answer choice (A). They missed the fact that the case was about voltage, *i.e.*, electromotive force, being induced in the secondary coil due to a time-varying current in the primary coil, a phenomenon described by Faraday's Law of Induction. Approximately one third of the group (36%) did not explicitly state Ohm's Law, yet seemed to have applied a similar erroneous reasoning of voltage being proportional to current, which led them to tick the same answer choice (A). Only 14% of the students settled on the correct solution, realizing that voltage is induced in the secondary coil due to the presence of a fluctuating magnetic field.

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Student performance in Newtonian mechanics

As presented in Table 7, the students performed strikingly poorly in all of the Force Concept Inventory categories. The average of their individual scores was 35% (Table 8). As most of the staff members pointed out in the course of the interviews, there was great variation within the cohort regarding pre-knowledge of physics. This notion is supported by the high standard deviation of 22 percentage points of the FCI individual scores (Table 8). Within the categories, however, there is considerably less variance. The standard deviation of 6 percentage points shows a consistent, albeit weak, mastery down the line (Table 7).

Table 7. International photonics students' performance on the Force Concept Inventory (FCI), category-wise percentage scores (standard deviation in parenthesis).

FCI category	Score
Kinematics	33
Newton's First Law	40
Newton's Second Law	39
Newton's Third Law	25
Superposition	41
Solid contact force	39
Fluid contact force	46
Gravitation	39
Average	38 (6)

For example, two items included in categories #1, #3, and #8 appeared to be some of the most challenging for the students. Only 14% of the cohort selected the correct answer to both items.

The first item was about a rocket drifting in outer space. After the engine is turned on, creating a constant thrust, the rocket moves along a certain trajectory, shown in one of the five answer choices. Students were asked to mark the option that they think corresponds to the path of the rocket. At the next stage, the engine is turned off at a given point, causing the thrust to instantly drop to zero. The students had to decide which of the five optional paths the rocket would now follow. A majority of the respondents resorted to common-sense concepts, such as impetus (an imaginary intrinsic force that keeps things moving) and the idea that gravity starts acting on bodies only after impetus dissipates. This misconception contradicts Newton's First Law.

The second item concerns a situation where a large box moves across a horizontal floor with a constant speed as it is being pushed by a constant horizontal force. Students are asked to determine the magnitude of the exerted force relative to other forces acting on the box. A common mistake (43%) here was the belief that force causes a body to accelerate to terminal velocity, a response that implies that Newton's Second Law is not understood. More specifically, these students claimed that, in a situation where a body is being pushed at a constant speed, the constant force exerted on the body by an agent must be greater in magnitude than the total force resisting the motion.

ISSN 1822-7864 (Print) ISSN 2538-7111 (Online)

Individual performance in conceptual tests

While the group average on all three tests is strikingly low, individual scores in Table 8 reveal that there are three students who clearly performed better than the others. The three students have the highest average in all tests as well as in the average calculated from the two best. Their relatively high scores indicate a good general knowledge of BA level physics in comparison to the rest of the group. Interestingly, student S10 has the highest total percentage for the CSEM and the FCI combined, yet falls 3 percentage points short of the group average on the optics test.

Table 8. International photonics students' individual performance in the conceptual tests. Scores are presented in percentages, along with the standard deviations. Three of the students (in boldface) stand out from the rest of the population.

Test \ Student	**S1**	S2	S3	S4	S5	**S6**	S7	S8	S9	**S10**	S11	S12	S13	S14	Average
Optics	**53**	10	7	17	33	40	13	30	20	20	30	27	3	20	23 ± 14
CSEM	**53**	34	25	38	53	**63**	13	28	22	**50**	41	38	13	34	36 ± 15
FCI	37	17	10	23	37	**70**	13	30	47	**87**	37	40	23	17	35 ± 22
Average of the best two	**53**	26	18	31	45	**67**	13	30	35	**67**	39	39	18	27	
Average of all	**48**	20	14	26	41	**58**	13	29	30	**52**	36	35	13	24	

As shown in Tables 5 and 6, there is a substantial variation in student performance across *test categories* in optics as well as in electricity and magnetism. In Table 8 the same phenomenon recurs for the *individual scores* in the same domains. For the FCI, the category-wise and student-wise average scores are rather similar, 38% and 35%, yet the corresponding standard deviation values (6% vs. 22%) are considerably different. In other words, the cohort's FCI performance was consistent in different categories, while the individual overall scores varied greatly.

However alarming the test results may be, one is to also acknowledge that the tests that employed are designed to measure conceptual understanding of the fields at issue. While being an important part of mastering physics, problem-solving at a qualitative level represents merely one facet of expertise in the discipline. The optics test, the CSEM, and the FCI are not designed to test students' competence in using, *e.g.*, calculus or Matlab™ to solve problems presented in a mathematical form. Succeeding in both the CSEM and the FCI requires that the respondent understands the meaning of the basic laws and principles of physics condensed in formulas. Yet many of the students (71% for the CSEM, 57% for the FCI) tried to find answers by writing mathematical representations as answers to some of the items. Their practice thus exhibits a tendency for mechanistic, formula-centred problem-solving. For the tests implemented, this approach did not prove to be very functional − it lead to a correct response in 56% of the attempts on the CSEM and 33% on the FCI.

One of the factors that might, in part, explain the international students' poor achievement in the tests is their early specialization. There were students in the 2013 cohort who held a degree in engineering prior to admission to the university or who had majored in a specialised field, such as electronics, rather than in general physics (Table 3). These students may had forgotten the basics of physics that they once learned, since they might not have been dealing with these topics for an extended period of time. The case of CSEM item #32 (Appendix C) described above supports this assumption. The students did recall several details of basic electricity: they knew that the relationship between the current, potential difference, and resistance of the component is somehow related to the given situation; they could give an algebraic representation of this relationship (Ohm's Law); they applied this knowledge correctly in selecting answer A, provided that they had first made the mistake of thinking that answer choices A through E represent the voltmeter reading in the primary coil. Another reason for picking choice A may be a belief that induced voltage is proportional to time-varying current, in which case the students failed to bring Ohm's Law into its proper context. Instead, they applied Faraday's Law of Induction.

Students' Views about Physics

As mentioned above, the CLASS answers of one of the respondents had to be discarded. For the remaining 13 students, the CLASS results reveal the most expert-like views with regard to their personal interest in physics (category #1, Table 9). In addition, in the category of making sense of physics and the effort they are willing to put into studying the subject (#6), the students are very close to expert-like thinking. A relatively low standard deviation of 8 percentage points in personal interest indicates that the whole group has a decent level of intrinsic motivation toward studying the subject. The group is also quite coherent in their views about sense-making and effort (#6), with the second lowest standard deviation of 13 percentage points. All of these results are consistent with the views of the staff.

Table 9. Percentages and standard deviations of favourable answers to the Colorado Learning Attitude about Science Survey (CLASS) items. The category-wise scores closest to the expert level of 80% are in boldface.

Category	Score
Personal interest	**78** ± 8
Real world connection	62 ± 23
Problem-solving, general	**71** ± 17
Problem-solving confidence	**71** ± 25
Problem-solving sophistication	57 ± 21
Sense-making / Effort	**75** ± 13
Conceptual connections	53 ± 25
Applied conceptual understanding	40 ± 28
Overall	56 ± 28

A feature worth noticing is that in no single category do the students attain 80%, considered to be the expert level. Their scores in the areas of conceptual connections (category #7) and applied conceptual understanding (#8) remain at the novice level (50%), which was one of the concerns that the staff members brought up. In addition, the high standard deviation of 28% of the overall score substantiates the staff's notions of the international student groups being heterogeneous.

Students' problem-solving (#3) and their confidence in it (#4) are among the closest to the expert level. Regarding these two areas, there is a discrepancy between the students' own views and those of the staff members. Yet the level of problem-solving sophistication (#5) suggests that students' problem-solving abilities may not, in fact, be as advanced as their confidence (#4) would suggest. This notion brings balance to the contradiction and supports the staff's observations regarding the lack of problem-solving skills.

Discussion

The aim of this research was to obtain a detailed description of the foreign entrant students of the international MSc degree programme in photonics as learners—their preparedness for photonics studies in terms of pre-knowledge and skills, and their motivation and physics-related epistemological views. The combination of staff interviews and conceptual tests offered a wide perspective on the students' strengths and deficiencies. The results support the initial hypothesis of the international photonics student group being highly heterogeneous in terms of preparedness and physics-related epistemological views. On the other hand, the low student performance on conceptual tests was indeed surprising.

Previous studies have shown that student pre-knowledge is an important factor that affects student learning (*e.g.*, Shapiro, 2004). It is, therefore, noteworthy that, according to the academic staff interviewed in this research, many international students have entered the degree programme being insufficiently prepared. In particular, concern is raised by the students' inadequate pre-knowledge of physics, reporting skills, and low problem-solving competence.

The scores on the conceptual tests presented above support the respondents' remarks about low pre-knowledge of physics. The FCI scores of the entrants remain significantly below those achieved by rather similar cohorts in previous studies (*e.g.*, Hestenes *et al.,* 1992). Similarly, a study conducted in 30 different institutions in the United States reports CSEM post-test averages to have been 7 and 10 percentage points higher (in an algebra-based introductory physics course and a calculus-based course) than that of the present target group (Maloney, O´Kuma, Hieggelke, & Van Heuvelen, 2001).

The issue of conceptual knowledge is of major importance. Physics concepts are the constituents of theories, whereas laws, rules, and principles describe the interrelations between concepts. Mathematical formalism, in turn, provides the means for a quantitative representation of those interconnections (Elby, 2011). Hence, in educating Masters of Science students in photonics, conceptual knowledge and understanding should not be overlooked. The ability to think in qualitative as well as quantitative terms enables physicists to predict, interpret, and evaluate both theoretical and experimental results. Furthermore, it provides help in designing optical structures and apparatus, and also in understanding the associated phenomena. This makes conceptual reasoning, along with quantitative understanding, distinctive of expert physicists. Mestre (1994) describes a typical expert vs. novice response to a physics problem: an expert would begin by identifying the relevant concepts to describe the phenomenon and to determine the applicable principles and laws to be used in finding the solution. A novice, on the other hand, attempts to reproduce a set of formulas with which he or she is already familiar from similar contexts. Usually, this indicates that the person has not attained a deeper understanding of the physics content, unable to relate the abstract representations to physical phenomena (Ambrose, Heron, Vokos, & McDermott, 1999).

Aside from pre-knowledge, student learning is influenced by motivation and interest, as well as by views of physics and physics learning (*e.g.*, Levesque, Copeland, Pattie, & Deci, 2010; Sharma, Ahluwalia, & Sharma, 2013). The significance of motivation and interest has also been observed by the staff interviewed in this research. It was noted during the interviews that entrant students' motivation to succeed in photonics studies seems to help them cope with the academic challenges that they face. In addition, the results obtained from the CLASS survey, indicating relatively high levels of personal interest in studying physics, are in line with the findings from the interviews.

Interestingly, the interview data shows that the international students avidly pursue top grades. At the same time, the Finnish students are said to outperform their international peers in problem-solving, which should indicate high exam and course grades. Yet for the Finns, on average, the exam results remain lower than those of their international peers. Clearly the course assessment fails in giving a reliable estimate of student performance. Indeed, despite the staff's best efforts, the department's course exams have not been very successful in testing students' ability to transfer their knowledge, *i.e.*, to apply it in unfamiliar contexts. Rather, exams seem to measure the ability simply to reproduce the course material. Exam questions of this kind encourage students to resort to memorization as their learning strategy. Consequently, the current mode of assessment is likely to yield good grades but hardly to help students engage at a deeper cognitive level, resulting in poor subject knowledge.

The aforementioned results provide an in-depth understanding of the primary challenges as well as the strengths of the international students. In the process of development, high personal interest and motivation can be used as the key assets to tackle the discovered challenges. The strengths of the international students can be guided so that their learning practices and orientations would shift toward more productive ones. In order to achieve this, the entrant students need a firm start with the exercises, lecture materials, teaching practices, and assessment emphases that will help them renew their approaches to studying and learning. Due to the international students' strong performance/grade orientation, the role of assessment becomes all the more central (*cf.* Anderson, 2007). Since summative assessment will probably remain the primary type of student assessment, more attention should be paid to exam formulation. The long tradition of testing students with exam questions that closely resemble those given in lectures and worked out in exercise sessions does not serve current educational purposes. In designing exams, the worked-out examples and problems should be revised in a way that their solving would require application of course material, rather than its reproduction. Such revisions would foster students' creative problem-solving skills and direct their learning toward a more in-depth concept formation.

In an attempt to equalise the pre-knowledge differences among the student population, new courses introducing the basics of optics and photonics and mathematical methods have already been added to the curriculum since 2013. The new courses aim primarily at reinforcing the basic knowledge and skills, but they can also be used as opportunities to develop teaching activities and modes that promote active learning, such as seminars, assignments, problem-based learning, and group work (*cf.* Anderson & Rogan, 2011). The staff of the department now faces the task of finding and implementing modes of teaching that will help students internalise effective learning strategies in order to produce a higher learning gain and deeper understanding. There seems to be a demand for hybrid courses that would link theory to practice in a more concrete way, courses in which the knowledge required in laboratory work would be covered by theoretical studies and reasoning. The suggested approach could also advance conceptual understanding and theory formation. What is more, laboratory work and practices would be more closely tied to the lecture course contents.

As for the course materials, it is necessary to emphasise the relevance of content to the students so as to help sustain their motivation (Pintrich, 2003). Furthermore, the staff needs to focus on core knowledge and pivotal concepts for the efficient formation of more advanced knowledge structures (Anderson & Rogan, 2011).

Conclusions

The Master's degree programmes intended for students from different (academic) cultures cannot be based on the same curriculum models as those designed for a more homogeneous (national) groups of students. National conventions and operational models may

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not be functional for cohorts of students with various academic and cultural backgrounds, since the entrant international students may not possess sufficient pre-knowledge, as has been shown by the case examined here. However, by investigating students' epistemologies, factors such as high-level personal interest, can be discovered and then utilised in curricular modifications. With heterogeneous groups such as considered here, the academic staff faces the task of evaluating lecture materials, educational practices, and assessment, all of which are required to shape the instruction in order to achieve the learning objectives. By the same token, a comprehensive analysis and understanding of learning styles and pre-knowledge is needed to train highly competent graduates in physics as well as other academic fields.

The results of this research highlight the need for the staff to raise their awareness of and consider students' epistemologies in teaching. The unproductive epistemological views that students exhibit in their attitudes and orientations to studying, *e.g.*, memorisation, can be readily detected by staff. Addressing them in an appropriate way, however, seems to remain the future challenge.

Given the limitations of this study, further research is suggested in order to explore how the research model presented here can be applied to other international Master's programmes, particularly those with a high international-domestic student ratio.

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APPENDIX A: Excerpt from the interview protocol used in the first interview with staff

STUDENTS AS LEARNERS

Let's consider the entrants to the photonics programme since 2010.

1. What kind of general view do you hold of the entrant students in the programme?
    - How do they regard studying/ the teaching/ the teachers?
    - How does their learning appear to you?
2. Have you observed any differences between Finnish and international students regarding these matters? Please elaborate.

ENTRANT STUDENTS' PREPAREDNESS

Knowledge and skills

3. Based on your experience, how would you describe the starting level of the physics knowledge and skills of the entrants?
4. What kind of possible differences have you noticed in the physics knowledge and skills of the Finnish and international students?
5. Based on your experience, how would you describe the mathematics knowledge and skills of the entrants?
6. What kind of possible differences have you noticed in the mathematics knowledge and skills of the Finnish and international students?
7. Based on your experience, how would you describe the experimental and reporting skills of the entrants?
8. What kind of possible differences have you noticed in the experimental and reporting skills of the Finnish and international students?

GENERAL READINESS FOR STUDYING AND LEARNING

9. How would you characterise the entrant students' studying and learning readiness?
   - What strengths and developing areas have you observed in their readiness?
10. What kind of possible differences have you noticed in the experimental and reporting skills of the Finnish and international students?

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11. Have the prerequisites been discussed among the staff?
12. In your opinion, what kind of starting knowledge and skills in physics are required of freshmen?
13. What kind of mathematical knowledge and skills should freshmen have in your opinion?
14. What kind of experimental and reporting skills should the freshmen have in your opinion?
15. What type of general studying and learning readiness does the Master's Degree Programme require in your opinion?
16. In your opinion, what significance do language skills have?
    - How do you think the English skills of the freshmen have affected their studies and learning?
    - What kind of possible differences have you observed in the learning of Finnish and international students using English?
17. What are these students like as learners?
18. What does the learning of these students appear to be like?
    - What is the focus of their studies?

APPENDIX B: The optics test

A sinusoidal wave is shown in Figure 1. Mark the following quantities in Fig. 1:

1. Wavelength.
2. Amplitude.
3. Mark a dot • at the point where the phase is $\pi/2$ (assuming that the phase is zero at the origin).

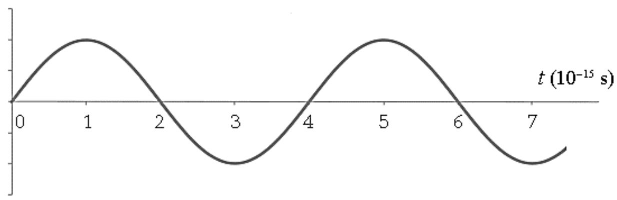

Figure 1.

4. Given that Fig.1 represents an electromagnetic (EM) wave propagating at the speed of light (3×10^8 m/s), what is the magnitude of the wavelength?
5. What is the period of the wave pictured in Fig. 1?
6. Explain the concept of the frequency of wave motion in your own words.
7. What is the magnitude of the frequency of the EM wave pictured in Fig. 1?

In Fig. 2 there are shown two pulses on a string approaching each other, both traveling at 10 m/s.

8. Draw snapshot graphs of the string at the three times indicated.

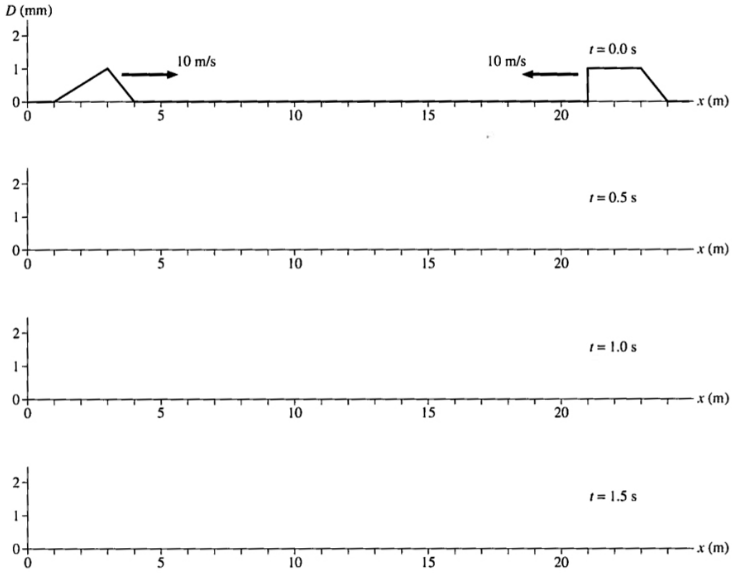

Figure 2.

A wave-front pattern emitted by two loudspeakers is shown in Fig. 3. The circular lines represent maximum (positive) displacement of air molecules.

9. Mark a dot • at the points where there is maximum constructive interference.
10. Draw an open circle ◦ at points where there is complete destructive interference.

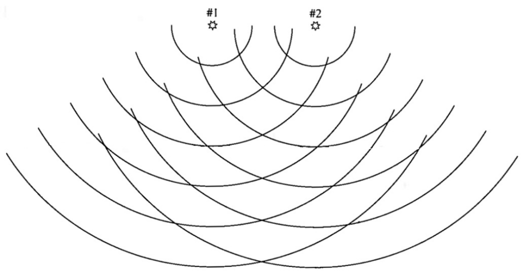

Figure 3.

Circular water waves are generated in a large ripple tank by two small objects that tap the surface of the water. These sources move up and down regularly and in unison (*i.e.*, the sources have the same frequency and are in phase. The distance between the sources is 2.5λ, (Fig. 4) where λ represents the wavelength of the waves generated by the sources.

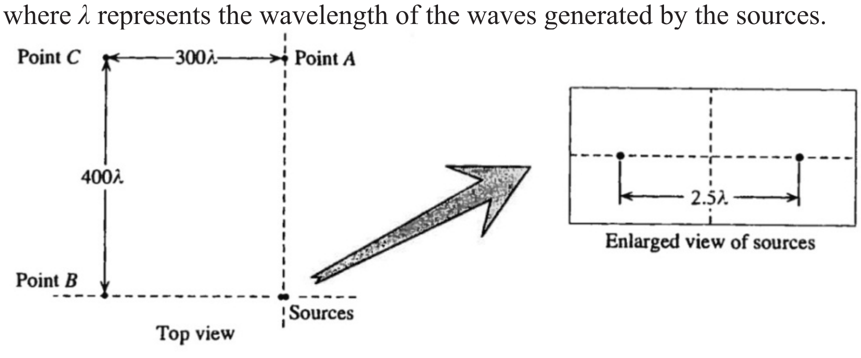

Figure 4.

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For each of the lettered points (*A*, *B*, and *C*)

i. Determine whether there is *maximum constructive interference*, *completely destructive interference*, or *neither* at that point.
ii. Find the phase difference between the waves from the two sources at that point.

Explain. Clearly explain any approximations that you use.

Point *A*:
11. i:
12. ii:
Point *B*:
13. i:
14. ii:
Point *C*:
15. i:
16. ii:

17. At which of the three lettered points would the water surface move the *most*? Explain.

Light from a laser passes through two very narrow slits, as shown in the top-view diagram on the right (Fig. 5). The photograph shows what appears on a screen that is distant from the mask. The screen is bright at points *X* and *Y*, and dark at point *Z*.

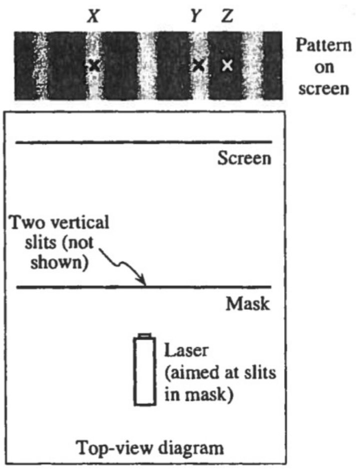


Figure 5.

18. In the box provided on the right (Fig. 6), show what would appear on the same part of the screen if the left slit were covered. Explain your reasoning.

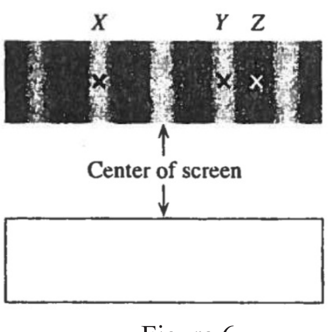


Figure 6.

In particular, if the left slit were covered, would the brightness at each of the following points increase, decrease, or stay the same? Explain your reasoning in each case.

19. Point *X*:
20. Point *Y*:
21. Point *Z*:

A *single change* is made to the apparatus presented in Fig. 5, resulting in the new pattern on the screen shown on the right (Fig. 7).

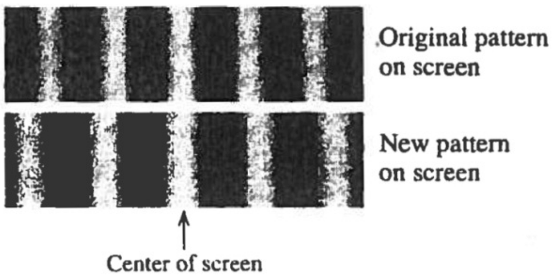


Figure 7.

For each of the following quantities, determine whether a change in that quantity could produce the new pattern shown.

If so: Should the quantity be increased or decreased? Explain your reasoning.
If not: Explain why not.

22. The distance between the slits.
23. The wavelength of the laser light.
24. The width of both slits.
25. The distance from the mask to the screen.

A mask with a single vertical slit is placed between a laser and a screen, as shown in the top-view diagram, below right (Fig. 8). The photograph above the diagram shows the resulting pattern on the screen.
H is the distance between the dark spots on either side of the center of the pattern, measured by placing a ruler against the screen. (See the photograph.)

26. Is the slit width *greater than*, *less than*, or *equal to* λ, the wavelength of the laser light? Explain your reasoning.

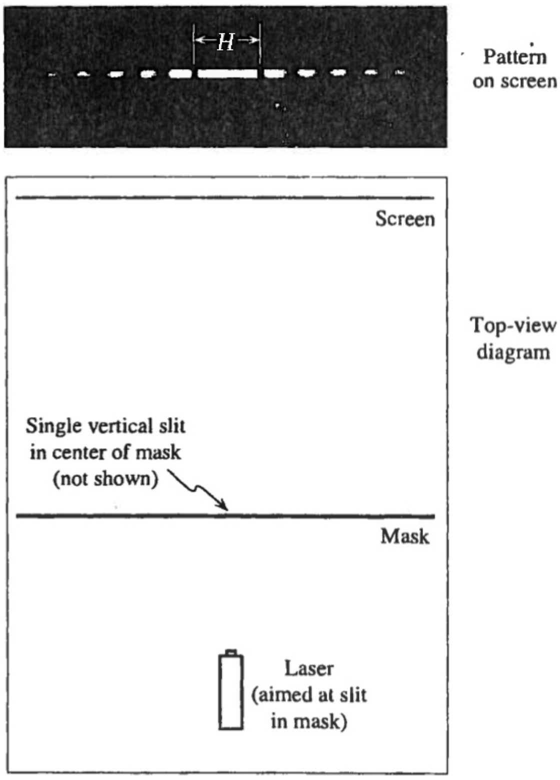


Figure 8.

In the following questions, consider how a *single change* to the *original* apparatus would affect the distance *H* (described above).

27. If the right half of the slit were covered (so that no light could pass through that side), would the distance *H increase*, *decrease*, or *stay the same*? Explain.
28. The pattern at the top of the page was produced by a laser that emits red light. If the laser were replaced by a laser that emits green light (*i.e.*, light with a shorter wavelength), would the distance *H increase*, *decrease*, or *stay the same*? Explain.
29. If the screen were moved further from the slit (using the original laser), would the distance *H increase*, *decrease*, or *stay the same* as in the original situation? Explain.
30. If the intensity of the (original) laser were increased, would the distance *H increase*, *decrease*, or *stay the same* as in the original situation? Explain.

References to the test items:

#1–5, 7	Knight, 2004
#8	Kryjevskaia *et al.*, 2011; Wittman *et al.*, 1999
#9–10	Wosilait, 1996
#11–17	Ambrose *et al.*, (1999b)
#18–21	Wosilait *et al.*, 1999; Wosilait, 1996
#22–25	Wosilait, 1996
#26–30	Wosilait *et al.*, 1999

APPENDIX C: The CSEM item #32

A variable power supply is connected to a coil and an ammeter, and the time dependence of the ammeter reading is shown (Fig. 9). A nearby coil is connected to a voltmeter.

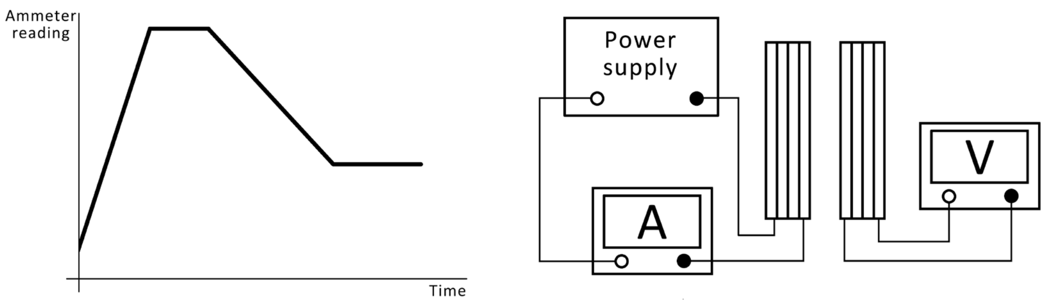
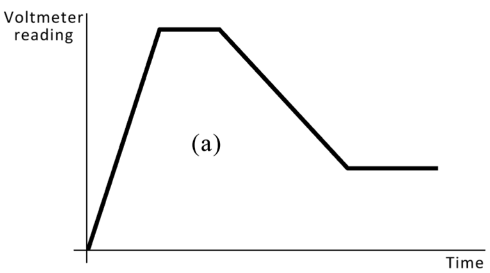
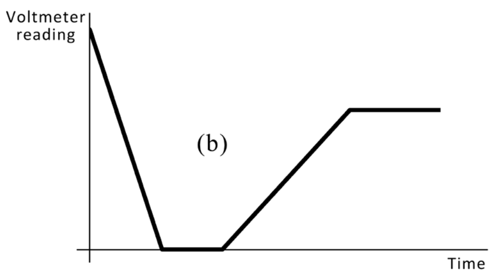


Figure 9.

Which of the following graphs correctly shows the time dependence of the voltmeter reading?





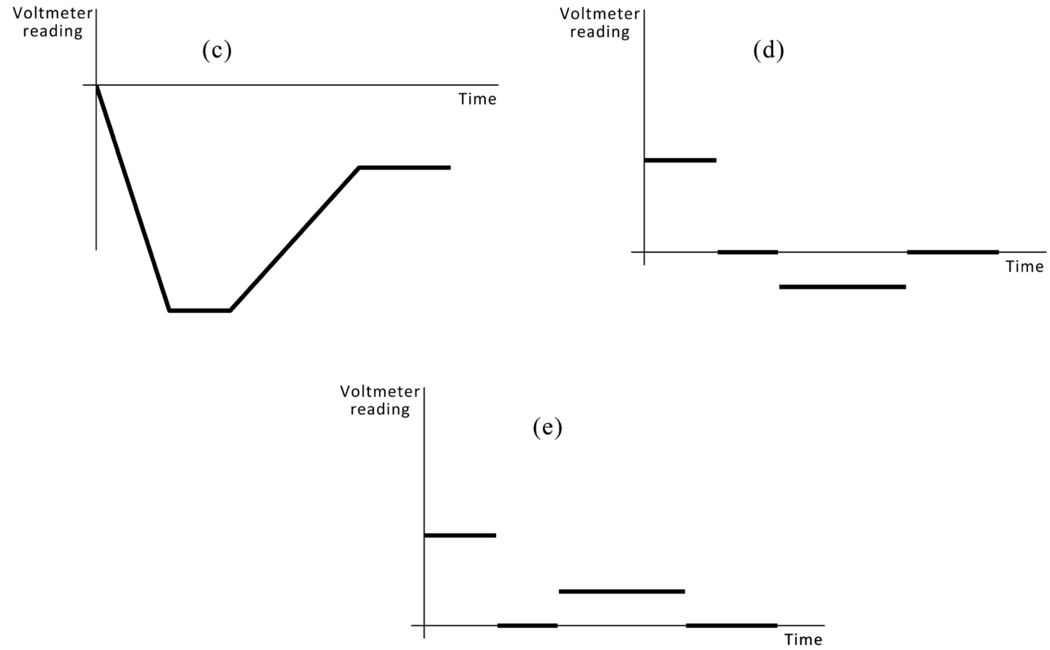


Figure 10.

(Figures 9 and 10 are modified from the 8/9/99 CSEM Form H)

Received: *April 13, 2017*　　Accepted: *June 26, 2017*

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