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# Teaching Celestial Navigation in the Age of GNSS

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ABSTRACT: Over the past two decades, we have witnessed the astounding development of Global Navigation Satellite Systems (GNSS). Celestial navigation has gradually been declining, displaced by the availability of these new, accurate, and easy-to-use electronic systems. Nonetheless, according to the International Convention on Standards of Training, Certification and Watchkeeping (STCW), deck officers onboard merchant ships must have been trained in the observance of celestial bodies to plot the ship's position and to calibrate compass error. It is a real challenge in the current context to which lecturers in nautical astronomy can respond through innovation in their teaching methods. A new approach to training students in celestial navigation at the Nautical College of the University of the Basque Country is discussed in this paper. It has already achieved promising results in comparison with the traditional teaching methodology, and is both efficient and effective. The adoption of institutional measures is also proposed to ensure that the competence acquired in the training phase is at all times present throughout professional practice.

## 1 INTRODUCTION

In 1995, the US Global Positioning System (GPS) was declared fully operational, superseding its forerunner, Transit. It provides three-dimensional fixes, with global coverage and unparalleled accuracy. Likewise, the Soviet GLONASS (Global Navigation Satellite System) was developed with similar coverage and precision. In the last 20 years we have witnessed the evolution of these first systems and the launch of new ones, such as the European Galileo or the Chinese BeiDou systems (Bonnor, 2012).

In consequence, celestial navigation, less accurate and more complex than GPS, is no longer essential and has, within only two decades, become an ancient seafaring art, its chronometers and sextants now relics of the past.

In fact, Global Navigation Satellite Systems (GNSS) and particularly GPS are currently the primary source for plotting a ship's position on the high seas. Additionally, it is connected to virtually all navigation equipment on the bridge. There is clearly excessive reliance upon a single source of electronic information that, if it were to fail, could place the ship's safety at risk. Apart from GNSS receiver malfunctions and other vulnerabilities of the onboard systems, GNSS could also be exposed to unintentional or malicious interference, resulting in possible denial of service over large areas or, even worse, resulting in the delivery of fake and misleading information (Thomas et al., 2012; Grant et al., 2009). Governments and industry are reacting to potential threats that could affect position, navigation, and timing (PNT) data reception due to unreliable or unavailable GPS signals. There are improvements to system robustness and its augmentation through other complementary

terrestrial PNT services such as eLoran (Psiaki and Humphreys, 2016; Bartlett et al., 2015).

In this context, it is undeniable that having alternatives to GNSS is very necessary. As far as maritime navigation is concerned, following the recommendations of the US Coast Guard, after a GPS signal outage, it is vital "to remember to use all available means for navigation and to maintain proficiency so you can still navigate should your primary GPS fail" (USCG, 2016). Along the same lines, increasing concerns over GPS hacking and malfunctions have led the US Navy to reinstate classes on celestial navigation in autumn 2015 for all new recruits (Alexander, 2015).

Clearly, GNSS vulnerability implies a need for alternative means of plotting a position at sea, and the experts agree that celestial navigation, as it was in the past, is still suitable for this purpose, as it does not depend on the electrical supply nor its disposition is at the mercy of another will that the own one. So, despite all opposition, nautical astronomy is an obligatory subject for deck officers onboard merchant ships in compliance with the International Maritime Organization (IMO) Convention on Standards of Training, Certification and Watchkeeping (STCW). As a matter of fact, in the deliberations of the IMO Sub-Committee on Standards of Training and Watchkeeping (STW 39, March 2008), a proposal was made by Norway to delete the requirement of celestial navigation from chapter II of the STCW Code (IMO STW, 2008a). Without reaching any conclusion in the discussion, the committee agreed to further discussion of the matter at the STW 40, held in November 2008. The STW was then invited to consider some proposed amendments to Chapter II of the STCW Code submitted by China, which suggested maintaining the mandatory requirement on knowledge and skills with respect to celestial navigation, but restricted to observations of the sun and stars, to determine the ship's position, while improving the method for celestial navigation calculation (electronic nautical almanac and celestial navigation calculation software) (IMO STW, 2008b). Eventually, the 2010 Manila Amendments to the STCW Code maintained the ability to use celestial bodies to determine the ship's position as a fundamental part of competency: Plan and conduct a passage and determine position, for ocean-going navigation. In accordance with the STCW Code (IMO, 2011), among other skills and abilities, an officer on navigational watch should have the "Ability to use celestial bodies to determine the ship's position and compass errors", in order to ensure safe passage. Celestial navigation may be omitted for the issue of restricted certificates for service on near-coastal voyages. In oceanic navigation it is primarily used as a backup to satellite systems.

However, it is an undeniable fact that many Merchant Navy deck officers make little or no use of celestial navigation despite their training. This situation is possibly due to an excessive reliance on GNSS, combined with a perspective on celestial navigation as an ancient, obsolete method of positioning that is complicated to study and tedious in practice, achieving an accuracy of only 1 or 2 miles (Peacock, 2011; Malkin, 2014). In the words of a student from the academic year 2010/11:

"I understand the importance of celestial navigation today, but on board commercial vessels it is so rarely used that if I ever really needed it, the truth is that I'd probably not be able to recall a thing. That's why I would only devote time to critical points on the celestial navigation course".

There is an evident lack of consistency between the competences related to celestial navigation that students are required to develop during their instruction period and the ones required in the current professional practice. Inevitably, this fact conditions the students' attitude towards the learning of the discipline. As Carson-Jackson (2010) pointed out, "adult students have a strong sense of self, and need to know why learning is required and how it immediately affects their work. This need for immediacy and relevancy is fundamental in developing training interventions for adult learners". However, apart from the compliance with IMO's STCW, it is very difficult to find arguments to convince students about why learning celestial navigation is required in practice. Therefore, addressing this situation must be twofold. On the one hand, teaching celestial navigation must undoubtedly adapt to these changing times, adjusting the curriculum in duration and contents, stripping away complexity from the explanations of its foundations and reducing the methods and problems exposed to the minimum necessary. On the other hand, institutional intervention is needed to ensure the necessary coherence between education and practice.

So, this paper reports and discusses an innovative approach to the teaching of celestial navigation, designed on the basis of these criteria and intended to facilitate practical learning of this matter. An approach successfully applied over the past five years on the Degree of Navigation at the Nautical College of the University of the Basque Country. Some ideas about how institutional support can be offered are also put forward in the conclusions chapter.

## 2 METHODOLOGY

The main purpose of this study is to explore the influence of the teaching-learning approach in the celestial navigation course on students' academic performance and perceptions.

Traditionally, the celestial navigation course at the Nautical College of the University of the Basque Country was delivered focussing on transferring the instructor's knowledge to passive students. Lecturing while requiring students to be passive, silent, isolated, and in competition with each other; a system commonly referred to as the old paradigm of teaching (Jonson et al., 2006). The construction of the European Higher Education Area seemed the perfect occasion to transit towards a new paradigm, which, according to these authors, focuses attention to several aspects, including:

- Knowledge is discovered, constructed, transformed, and extended by students.
- Students are active constructors of their own knowledge.
- Learning is a social enterprise in which students need to interact with the instructor and classmates.

- Instructor effort is aimed at developing student´s competencies.
- Education is a personal transaction among students and between the instructor and students as they work together.
- All the above best take place within a cooperative context.
- Teaching is assumed to be a complex application of theory and research requiring considerable instructor training and continuous refinement of skills and procedures.

Details about the design and implementation of the new approach are depicted in section 3. The main features that distinguish the old paradigm from the new one, as applied to the celestial navigation course, are shown in Table 1.

Table 1. Main differences between the traditional and the new teaching systems

| | Traditional teaching approach | New teaching approach |
|---|---|---|
| Focus on | Teaching | Learning |
| Students | Passive | Active |
| Nature of learning | Individual | Cooperative |
| Academic year (semester) | 2 (2) | 3 (2) |
| Credits | 6 | 6 ECTS |
| Total teaching time (teacher) | 60 hours | 60 hours |
| Total learning time (student) | Undetermined | 150 hours |
| Teaching methodology | Lectures | Active learning |
| Assessment | Final exam | Continuous assessment |

Starting from the hypothesis of a strong relationship between the teaching-learning strategies and the academic performance of our students, the aim of this analysis is twofold. On the one hand, we wish to verify whether the proposal and the designed activities are effective for the acquisition of the defined learning outcomes. On the other hand, we wish to confirm that the methodology influences students' involvement and favours positive attitudes, interest and motivation towards the learning of celestial navigation.

Some objective indicators and other measures of student perceptions were used to measure the effectiveness of the new methodology implemented in the celestial navigation course. In the preparation of this comparison, the results obtained over the past 5 years of traditional teaching (2006/07 to 2010/11) were collated with the past 5 years in which the active methodologies were applied (2012/13 to 2016/17). It has to be pointed out that throughout the whole period the same lecturer was the unique teacher of the subject.

Information was gathered on all the students enrolled in the celestial navigation course. Table 2 shows the size of the cohorts. Women were represented all years, ranging from 13.6% to 37.5% of the cohorts, and averaging a 19.8% of the students' intake in the whole period. Gender-specific results were not observed, so they were not analysed separately.

A set of main standard indicators were selected to measure the course outcomes, namely: Success Rate (SR), Efficiency Rate (ER), Attrition Rate (ATTR) and Attendance Rate (AR). They have been applied for the celestial navigation course, following the definition given in the 2016 Spanish Official Catalogue of University Indicators (MECD, 2016).

SR represents the percentage of regular attendees achieving course competences and associated learning outcomes at threshold standard or above.

ER represents the percentage of total enrolled students that passes, achieving course competences at least at threshold level.

SR and ER are both necessary and it is important to examine them together. It could be the case of having a high SR and a low ER, which, if not explained, would indicate that the teaching performance would have not been so successful.

ATTR refers to the percentage of students enrolled one specific year that, having failed, does not register again in the next two years.

AR represents the percentage of enrolled students that attends face-to-face classes on a regular basis. It provides an important piece of information as it is posited that class attendance is closely related to academic achievement.

Student perceptions are of the outmost importance as they are primary drivers of the attitudes and behaviours of our students, including those associated with academic performance (Tudor et al., 2010; Ferritto, 2016). A better understanding of how students perceive their course experience may inspire educators to adjust the course planning and to develop an environment that contributes to the optimization of their academic outcomes.

Table 2. Number of students enrolled in the celestial navigation course (2006/07 to 2016/17)

| | Traditional teaching approach | | | | | New teaching approach | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 06/07 | 07/08 | 08/09 | 09/10 | 10/11 | 12/13 | 13/14 | 14/15 | 15/16 | 16/17 |
| Male | 19 | 31 | 29 | 36 | 42 | 5 | 23 | 13 | 15 | 14 |
| Female | 3 (13.6%) | 6 (16.2%) | 9 (23.7%) | 9 (20%) | 6 (12.5%) | 3 (37.5%) | 8 (25.8%) | 4 (23.5%) | 4 (21,1%) | 4 (22.2%) |
| Total | 22 | 37 | 38 | 45 | 48 | 8 | 31 | 17 | 19 | 18 |

The analysis of student perceptions took the information in the standard questionnaire that all students following classes fill in anonymously at the end of each course. In addition to some questions on their interest in the particular subject, its difficulty, etc., students have to evaluate their instructors on a five-point Likert scale using a number of statements associated with teaching planning, teaching methodology, teaching development, teacher interaction with students and learning assessment. This questionnaire is the controversial Student Evaluation of Teaching (SET), the validity and reliability of which at measuring instructional effectiveness has been widely questioned (Spooren et al., 2013). The specific 1-5 rating categories that SET uses for data collection, where '1' is 'strongly disagree' and '5' is 'strongly agree', permit their statistical analysis. However, as these categories differ in quality, not in quantity, an average calculation of these data can, for instance, be quite meaningless and misleading. Hence, the recommendation from Hornstein (2017) to apply good judgement and understanding in the analysis of such statistics. Although the interpretations can be challenged on conceptual and statistical grounds and are therefore all but useless as instruments to measure teacher performance, the results obtained from SET provide instructors with the student opinions on the strengths and weaknesses of their teaching practice. In this sense, we have used SET data as feedback for the improvement of our subsequent teaching, but reviewing the data in the light of the comments collected in the portfolios that students hand in upon completion of each course piece.

The results are shown and discuss in section 4. Their analysis will, in turn, facilitate the decision-making process, in order to continually improve the course planning, detecting factors that prevent good results.

## 3 DESIGN AND IMPLEMENTATION OF THE NEW CELESTIAL NAVIGATION PROGRAMME

### 3.1 *Opportunity to implement a methodological change*

The process of designing new syllabuses to adapt the curricula to the European Higher Education Area (EHEA) ended with the phasing-in of the new programmes in the academic year 2010/11. The EHEA is meant to ensure more comparable, compatible and coherent higher education systems in Europe, placing the emphasis on student learning. It is aimed at greater enhancement of student involvement in self-study and personal learning, for which purpose new teaching strategies are adopted where learning is construed as a constructive -as opposed to a receptive- process.

This changing context provided university lecturers with the opportunity to rethink their activities. Ideally, this would have led to a general cultural change in the universities that would have moved from an educational model focused on teaching towards a model focused on learning. However, the change has been exclusively formal in most Spanish universities and it has hardly been practiced in the classroom. When changes in the teaching practice have occurred, they have usually been facilitated by the voluntary involvement of individual teachers.

The transition in the teacher's role from lecturer to facilitator can be a daunting experience as greater effort is in practice required from them than with other forms of teaching (Savin-Baden, 2003; Ircha and Balsom, 2005). In our college, traditional lecturing was not replaced in all subjects following this revision of the curriculum. The decision was at the discretion of each teacher. Navigational classes were the first to introduce the new methods, so one of the first experiences of active learning for students was nautical astronomy.

Introducing a radical change in the teaching-learning practice is far from easy. As a matter of fact, achieving success in this exercise requires knowledge and understanding and an ability to drive the pedagogical transformation (Biggs and Tang, 2011). In other words, it requires training, perseverance, and institutional support (Jonson et al., 2006; Fernández, 2003). In our case, corporate training was provided through the University's Education Advisory Service that offered *ad hoc* education, technical advice, and support and monitoring throughout the whole process.

### 3.2 *The new programme*

In the design of the new programme, the selection of contents and its sequencing was based upon over 25 years experience as a lecturer of nautical astronomy, the previous knowledge of students, and the evolution of maritime navigation. The instructional methodology was oriented towards active learning, cooperative work, and continuous assessment.

#### 3.2.1 *Context and contents*

Traditionally, the entire teaching process has focused on the transmission of knowledge and information from teachers to students. The accounting unit was measured in terms of the time that lecturers dedicated to the teaching of a subject: 1 credit = 10 teaching hours. The new syllabuses focus on student learning and the system that is adopted (ECTS: European Credit Transfer and Accumulation System) involves the measurement of the average student work time needed to meet the objectives of the programme, including lectures, individual study, teamwork, seminars, problems, essays, projects, internships, etc., as well as exam preparation and examination times and other assessment activities: 1 credit = 25/30 hours of work. In the EHEA, 60 ECTS credits were allocated to the learning outcomes and associated workload of a full-time academic year, so that an average student is expected to devote between 1500 and 1800 hours per year (European Commission, 2015). In the University of the Basque Country 1 ECTS credit is equal to 25 hours.

The 4-year Bachelor's Degree in Navigation consists of 240 ECTS credits. The course module of 'Celestial Navigation' is taught in the second term of the third year, with a workload of 6 ECTS credits. Then, undergraduate students are mature enough and motivated to finish the class period as the fourth and

last year is mainly devoted to the internship and the graduation project. Students come to this course with relevant prior knowledge on spherical trigonometry, geodesy, and navigation (dead reckoning and coastal navigation).

The foundations of modern celestial navigation are rooted in developments that took place up until the 19th century. Very little has been done since, and it is mainly related to technological developments applied to the fabric of sextants and chronometers or the availability of tables or calculators to ease the calculations to obtain a fix. As mentioned above, celestial navigation is clearly in decline following the development of GNSS. As a matter of fact, the edition of modern treaties or handbooks is scarce, and most recent contributions continue to point in that direction, suggesting the use of software for further facilitation of the necessary computations (Vulfovich and Fogilev, 2010; Peacock, 2011; Bell, 2013). The days when celestial navigation occupied the lion's share of the maritime navigation curriculum are definitely over. The period of study has already been reduced to 6 ECTS credits (i.e. a mere 2.5% of the degree) and within this time frame students must grasp the core concepts of the subject and the procedures needed to plot the position of a ship from the observance of celestial bodies.

Reformulating the study programme, the main issue lies in clearly defining the course learning outcomes, and choosing and sequencing the contents accordingly, ensuring both an adequate balance between theory and practice and an appropriate time span devoted to each element.

Guided by the STCW Code (IMO, 2011) and the Model Course 7.03 (IMO, 1999), learning outcomes were enumerated (see Appendix 1), in order to cater to the requirements of competence-based training, with the following specific competences in mind:

1 Determine the position and the accuracy of the resultant position plotted by celestial observations.
2 Calibrate compass error using celestial bodies.

Targeting the defined learning outcomes, the contents were organized as if they were the pieces of a puzzle, thus:

1 Do I understand the problem that celestial navigation addresses?
2 Do I have the necessary knowledge of navigational astronomy?
3 Do I know how to obtain the coordinates of a celestial body, tabulated in the Nautical Almanac, corresponding to the time of its sight?
4 Do I know when and how to take a sight (angular measurement with a sextant) and to determine the observed altitude of a celestial body?
5 Can I specify the exact Greenwich Mean Time (GMT) at the instant I observed the celestial body, by using a marine chronometer?
6 Can I solve the navigational triangle for sight reduction?
7 Do I understand the lines of position (LOP) used in modern celestial navigation?
8 Can I perform the process of sight reduction precisely and obtain a fix within commonly accepted parameters of accuracy? Can I calculate the compass error using celestial bodies?

The term consists of 15 weeks. The 6 ECTS credits assigned to the subject represent 150 hours of self-study and presential classes, of which 60, at 4 hours/week, are presential. The estimated working hours that an average student should devote to each 'piece of the puzzle' are shown in Table 3.

Table 3 Planning of scheduled activities by puzzle piece, with estimated private study in single student hours (presential classroom hours in brackets)

| | WEEK | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Course & Project presentation | 2 (2) | | | | | | | | | | | | | | |
| Piece 1 | 4 (2) | | | | | | | | | | | | | | |
| Piece 2 | | 36 (12) | | | | | | | | | | | | | |
| Piece 3 | | | | 13 (6) | | | | | | | | | | | |
| Piece 4 | | | | | | 16 (6) | | | | | | | | | |
| Piece 5 | | | | | | | | 5 (2) | | | | | | | |
| Piece 6 | | | | | | | | 4 (2) | | | | | | | |
| Piece 7 | | | | | | | | | 12 (3) | | | | | | |
| Piece 8 | | | | | | | | | | 58 (25) | | | | | |

Once the main question has been addressed and the contents skilfully chosen, sequenced and time-spanned, attention should be focused on the main innovation, which refers to the pedagogical approach.

### 3.2.2 *New methodological and assessment strategy*

Aspiring to fulfil the learning outcomes, the course is delivered seeking students' active involvement in their own learning. As said above, the core elements of the programme implementation are active learning, cooperative work and continuous assessment.

There is a wide array of active learning techniques, but all of them are based on the same pillars: students' engagement in the learning process by performing meaningful learning activities that are also introduced into the classroom (Prince, 2004). Following the model by Johnson et al. (2006), active learning was adopted in combination with cooperative learning, where students pursue common goals working in small groups, and that differs from collaborative learning in the fact that it focuses on cooperation rather than in competition. Actually, cooperative teamwork is an essential ingredient in most didactic strategies in which students participate actively (Prince, 2004). It has been proven that it increases student achievement and creates positive relationships between students (Johnson et al., 2006). In fact, when students use small-group learning, they show more favourable attitudes toward learning, learn more, remember content for longer, develop superior reasoning and critical thinking skills, improve communication ability, and feel greater self-confidence and acceptance from others (Springer et al., 1999), abilities that students today will need in the future to survive in the rapidly changing world in which we live. Continuous assessment rounds out this constructive approach to learning, whose main features were summarized by Sánchez (1993) as follows: students should perceive it as a help to learn; it must be fully integrated into the learning process; it must indicate clearly to students their advances, difficulties and needs; assessment activities must deal with all aspects (conceptual, methodological and

attitudinal) in order to promote meaningful learning; it must include the teacher task, the classroom atmosphere and, in general, all aspects that influence the learning process. Thus, the design of appropriate learning and assessment activities around significant learning outcomes is an essential in this instructional practice.

In our celestial navigation course, the students are invited to participate in a project playing the role of the crew members of a commercial vessel on an ocean voyage. Distributed in small groups of 3 or 4 students, they role play the deck officer team of the ship in a power outage scenario in which they have to navigate the ship safely to the destination port using only conventional methods of navigation.

Taking this real problem of professional practice as a starting point, students work cooperatively in teams. Guided by the teacher, the working groups have to identify new knowledge, determining what they know and what they need to learn, in order to complete their assignment. This methodology promotes autonomous learning, and the team members will have to share the tasks to advance, assuming responsibility for the efficient work of the group as well as for the development of their individual learning.

A special classroom is used for face-to-face lessons: the Lower Bridge, equipped with Wi-Fi access, devices, instruments and other materials related to the subject, as well as with 5 large tables where groups can work in comfortable surroundings. It has, in addition, an exceptional location and access to a large terrace with a panoramic view over the port and the river.

Figure 1 shows a sample of the activities carried out by the working groups, which, following Johnson et al. (2006) have been designed taking into account some essential elements: positive interdependence, individual accountability, face-to-face promotive interaction, social skills, and group processing. An example of the learning and assessment activities designed to acquire the learning outcomes related to the correct use of sextants is provided in Appendix 2.

Figure 1 Teamwork in different activities, during face-to-face classes

The assessment of student learning must be consistent with the methodology used for its achievement. We agree with Garmendia et al. (2008) that gradual assimilation and that significant, more profound, and less superficial learning is needed for meaningful acquisition of course competences, for which purpose learning has to be on an ongoing basis throughout the term. Hence, active learning goes hand in hand with continuous assessment.

Since the academic year 2013/14, students of celestial navigation have formalized their engagement by signing a document, where they commit to cooperative work in groups, attending class and out-of-class meetings regularly, carrying out duties respecting the agreed deadlines for the preparation of assignments and their submission, etc.

The groups have to perform the proposed tasks and activities detailed in the corresponding teaching guides, in order to obtain all pieces of the puzzle, each of which is proportionally weighted in the final degree. As a check on individual attainment, students have to take only two written exams (at the end of puzzle pieces 2 and 8), with a total weight of 30% in the final grade.

Continuous evaluation is constant throughout the term, primarily of a formative nature, as students intermittently receive feedback on their assignments (deliverables) from the instructor, who provides information and appropriate guidance on competence acquisition levels and suggests improvements in their learning. In addition, evaluation of the learning process and individual achievement is done with continuous evaluation so that the final student grade can be given.

After completion of every puzzle piece, students are also asked to conduct self-evaluation of the learning outcomes that are acquired as well as to assess the designed activities, identifying strengths and areas for improvement.

### 3.2.3 *Student workload*

Achieving the learning outcomes needs time and effort on both sides of the teaching-learning pairing. In the active learning approach, on the one hand, teachers have to design the course and during the implementation they are expected to monitor the student coursework and to evaluate it continuously. On the other hand, a sustained effort in the fulfilment of tasks and activities is required from the groups of students.

The study of a subject may be influenced by several factors (Kolari et al., 2006). However, student learning is very often predominantly influenced by the evaluation strategy that the instructor adopts. In fact, research by Garmendia et al. (2008) demonstrated the decisive influence of the evaluation criteria. They not only observed a strict parallelism between the percentage for each aspect in the mark and the percentage of time dedicated to its study, but also that the distribution of student workloads during the year is closely related to the evaluation system that is used in each subject. Thus, for example, when the traditional evaluation system -where the final mark corresponds to the final exam- is applied, students concentrate their study time into the weeks leading up to taking the final exam.

In the celestial navigation course, group activities are weighed in the final grade according to the estimated time required for their performance and are monitored and evaluated throughout the term with the aim of improving learning.

When planning the course according to the ECTS system, one of the most complicated issues teachers face is to estimate the students' workload and thus to balance the course demands with the credit units that are gained. As mentioned above, the 6 ECTS credits assigned to the celestial navigation course correspond to 60 hours of face-to-face activity and to 90 hours of independent work. So, the total dedication of an average student to the subject must be 150 hours. It has to be taken into account that individual students do not learn alone in cooperative learning. Although they have to perform tasks individually, they are part of a team. All members of the group must acquire the learning objectives that are marked, regardless of the individual progress of any one. So, the groups formed by 3 students add a total of 450 hours to achieve the objectives of the course; and the groups of 4 students add a total of 600 hours.

Table 3 shows the estimated dedication of individual students to every piece of the puzzle. In Figure 2, the weekly distribution of this estimation is presented in comparison with the dedication reported by students over the past 4 academic years. Students were asked to keep a personal control sheet on a voluntary basis every day. The information they reported was considered reliable as students were informed that the reward came from filling out the form and there was no need to exaggerate the figures. In fact, the maximum absolute deviation from the teacher's estimation was 18.4 hours, and the global average deviation 3.3 hours. More importantly, Figure 2 shows that, as expected, the students sustained their activity, distributing their effort throughout the term, fulfilling the pattern that the teacher had estimated.

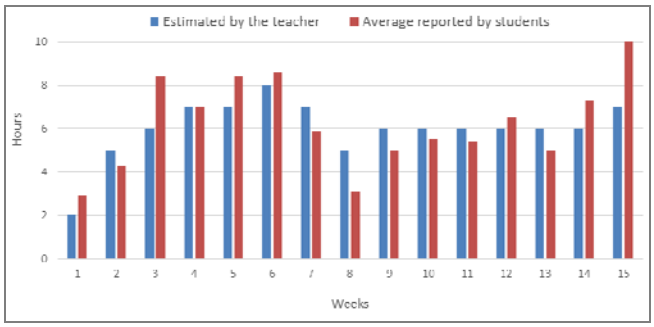


Figure 2. Weekly distribution of time devoted to the subject by students, outside the classroom. Years 2013/14 to 2016/17

## 4 RESULTS AND DISCUSSION

To measure the effectiveness of the new methodology implemented in the celestial navigation course, the results obtained over the past 5 years of traditional teaching (2006/07 to 2010/11) were compared with the past 5 years in which the active methodologies were applied (2012/13 to 2016/17).

Students enrolled in the celestial navigation course compose the observed population, as shown in Table 2 disaggregated by gender and academic year. However, it was not considered worth to disaggregate the results as no significant gender-specific outcomes were observed. Due to the repercussion that it may have on the interpretation of some results, it is also important to explain that the uneven distribution of students in this period basically obeys to two causes: first, the celestial navigation course was formerly allocated in the second year and now in the third year, and the natural tendency is to a progressive decrease in the number of students; second, in the traditional methodology there was a higher percentage of students who did not pass so their number was gradually growing.

It has also to be pointed out that throughout the whole period the same lecturer was the unique teacher of the subject, so that instructional effectiveness is not affected by varying teaching staff performances.

Objective metrics and other indicators of student perceptions were used to measure the effectiveness of the new teaching method implemented in the celestial navigation course. The results are discussed below. This situation will, in turn, facilitate the decision-making process, in order to continually improve the course planning, detecting factors that prevent good results.

### 4.1 *Course outcomes*

The standard indicators selected to measure the course outcomes have been introduced in section 2. They were calculated using the following formulas:

Success Rate:

$$SR = \frac{Num.\ students\ gaining\ satisfactory\ marks}{Num.\ students\ in\ attendance} \times 100 \quad (1)$$

Efficiency Rate:

$$ER = \frac{Num.\ students\ gaining\ satisfactory\ marks}{Num.\ enrolled\ students} \times 100 \quad (2)$$

Attrition Rate:

$$ATTR = \frac{Num.\ students\ not\ enrolled\ or\ not\ attending\ years\ X{+}1\ and\ X{+}2}{Num.\ students\ enrolled\ in\ year\ X} \times 100 \quad (3)$$

Attendance Rate:

$$AR = \frac{Num.\ students\ missing\ less\ than\ 10\%\ of\ classes}{Num.\ enrolled\ Students} \times 100 \quad (4)$$

Figure 3 shows the relationship between the first two indicators (SR and ER), and Figure 4 between the last two (AR and ATTR). It can be observed that correlations between each pair of performance indicators are statistically significant and of considerable magnitude.

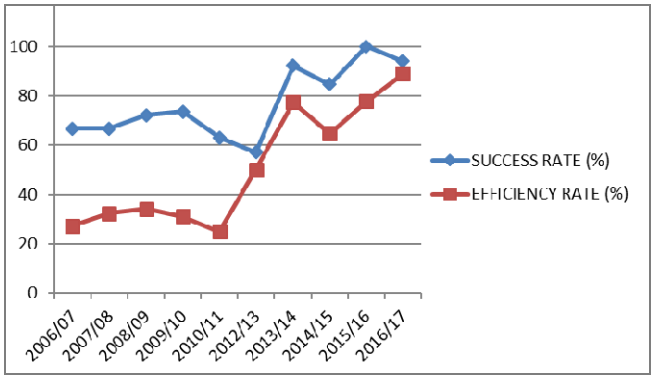


Figure 3. Success Rate and Efficiency Rate in the celestial navigation course, years 2006/07 to 2016/17

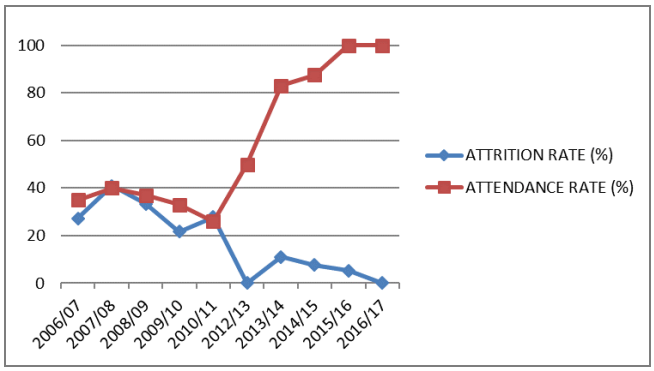


Figure 4. Attrition Rate and Attendance Rate in the celestial navigation course, years 2006/07 to 2016/17

In the first place, the evolution of the indicators proves a completely different behaviour depending on the teaching-learning methodology in use. Since the first implementation of active learning, it can be seen that both the Success Rate and the Efficiency Rate have both been growing significantly and moving closer in line with the Attendance Rate, the behaviour of the latter quite unlike the Attrition Rate.

In our view, students receiving the traditional curriculum were not used to devoting sustained effort to the subject and neither received continuous feedback nor marks on their progress. As a consequence, as the course went ahead, as soon as they felt they had no possibility of easily passing the subject, they gave up studying and stopped attendance well before the end of the course. The new programme, nonetheless, entails a sustained workload for students who receive feedback on their progress and score points that will make up their final grade. As the course progresses, they feel their continuous efforts are worthwhile, sensing that final approval of the subject is within their reach. Were it otherwise, the work done throughout the course would be to no avail.

In addition, the good progression that the success rate showed was surely favoured by the fact that when students take the celestial navigation course, they are already familiar with the methodology as well as with the teacher's style, as it is also applied in the basic navigation course that the same teacher delivers in the second year.

Observed gaps between success and efficiency rates in the last period can be explained through the analysis of every individual dropout. Course enrolment takes place in September, whereas it is delivered along the second semester, starting by the end of January. In the interim, in the majority of the dropout cases, students' personal circumstances had changed: either they had unexpectedly failed in basic subjects, or they had to deal with further family/job responsibilities, thus they could not afford devoting the required effort into this course.

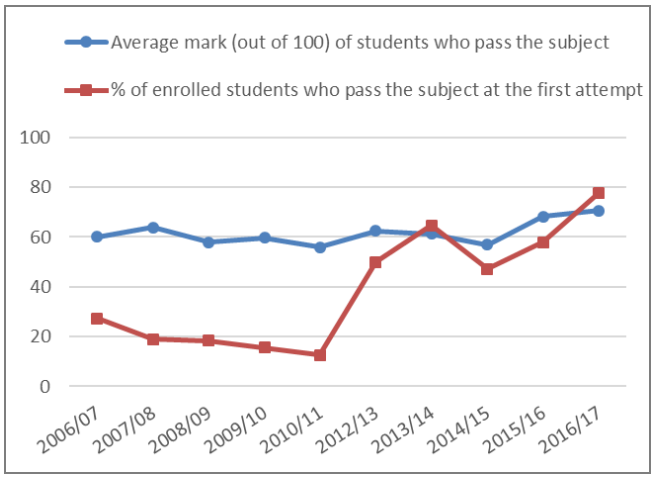


Figure 5. Percentage of enrolled students who pass the subject in the first year and average marks obtained by students who pass the subject, years 2006/07 to 2016/17

Finally, active learning has been consistently associated with more favourable student results (Prince, 2004; Freeman et al., 2014). Our experiences confirm this fact, as not only is there a higher percentage of students who follow the new celestial navigation curriculum and pass it, compared to students following the old curriculum, but there is also an increased percentage passing at the first attempt. However, we have not noticed a clear increase in the average mark obtained by students who pass, until the last two academic years when it was closer and surpassed the 70 points (out of 100) barrier (see Figure 5).

### 4.2 *Student perceptions*

As stated in section 2, students' perceptions of their educational experiences, although intrinsically subjective, are of the outmost importance as they influence academic performance. That is why they should be taken into consideration in the process of designing a course programme.

In our case, the concerns and opinions of students were gathered from the opinion survey on individual teachers administered to students at the end of each year (SET: Student Evaluation of Teaching), from their reflections collected in the course portfolio and also from informal meetings. Additionally, their suggestions for improvement have proved to be an indispensable tool for the management of course quality.

In spite of its shortcomings, SET results have been reviewed in combination with the reflections, comments and suggestions that students voiced in their portfolios. This feedback has shown to be an important tool for the improvement of our subsequent teaching.

In the first place, it should be pointed out that the percentage of enrolled students who responded to the SET questionnaire was much higher in recent years as attendance rates in the final weeks have greatly increased. However, any direct comparison may be skewed, because the responses were more likely to come from students with better learning attitudes while the traditional methodology was applied, although most students have responded well since the implementation of the new teaching-learning approach.

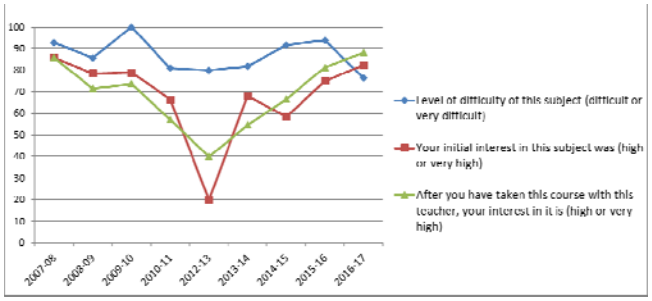


Figure 6. Perception of the level of difficulty and initial and final interest in the subject. Percentage of students, years 2007/08 to 2016/17

Regardless of the teaching methodology in use, students perceived the subject matter of celestial navigation as difficult or very difficult. However, this perception lessened (the percentage has fallen below 80%) over the last academic year, so the trend will have to be monitored in the future, as it may be related to different learning styles. The comparison may also be seen in Figure 6 between the initial and the final interest that the students said they felt towards the subject. The final interest was always lower than the initial interest before the new curriculum was implemented and since that time, this tendency is chiefly the opposite. Thus, it can be concluded that the use of innovative learning methods has a clear impact on student engagement as their attitudes towards the subject improved.

Table 4 shows the average set of scores in the 5 main areas of teacher performance rated by the students attending the celestial navigation course. There was a marked decrease in the figures during the transition, especially the 2013/14 academic year, which neatly express student dissatisfaction with the new learning strategies.

Table 4. Average student ratings on a 1-5 Likert scale of teaching planning (TP), teaching methodology (TM), teaching development (TD), teacher interaction with students (IS) and learning assessment (LA)

| | 07/08 | 08/09 | 09/10 | 10/11 | 12/13 | 13/14 | 14/15 | 15/16 | 16/17 |
|---|---|---|---|---|---|---|---|---|---|
| TP | 4,6 | 4,5 | 4,4 | 4,4 | 4,4 | 3,8 | 4,2 | 4,1 | 4,3 |
| TM | 4,5 | 4,3 | 4 | 4,2 | 3,4 | 3,7 | 3,8 | 4 | 4,2 |
| TD | 4,5 | 4,3 | 4 | 4,2 | 4 | 3,7 | 4 | 4,1 | 4,2 |
| IS | 4,6 | 4,3 | 4 | 4,4 | 4,2 | 3,6 | 3,9 | 4,1 | 4,2 |
| LA | 4,4 | 4,1 | 3,8 | 4,2 | 4 | 3,8 | 3,8 | 3,9 | 4,1 |

The reflections students wrote that year in their portfolios were vital to understanding the causes of their discontent with the new learning proposal. We read, for instance: "The time dedicated to obtain the necessary learning is much greater using this methodology, than with the traditional one. It is not worth it"; "I would remove homework. There is too much".

There were also positive remarks: "Continuous evaluation requires a daily work so that if you fulfil your compromise you arrive at the end with much work done and concepts well settled"; "I am always aware of the acquired learning and of my progress. The methodology has assisted me little by little".

These kinds of considerations helped us to identify the critical factors on which to focus our efforts. In the subsequent years we made some improvements, mainly by means of reducing the number of deliverables, reinforcing the teamwork, and highlighting the good outcomes that the innovative approach produced. As a consequence, the student ratings openly recovered, displaying a higher satisfaction with their perceived learning experience. As some students of the 2016/17 cohort summarized: "Teamwork has been real. We have demonstrated extraordinary communication skills. I feel that all team members collaborated in getting everyone to achieve the learning objectives. As a result, we have not only improved our personal relationship, but our satisfaction seeing the good results has also served as motivation and we have gained confidence in our work as a team"; "I found myself very comfortable in class and with my teammates. With this methodology we work in a group with instruments and materials related to the subject, we solve practical cases, etc., which makes the stay in class much more productive and enjoyable".

Yet, if we listen to other voices, we see that there is still room for improvement: "Generally speaking, I liked the methodology adopted in this subject. However, it is a subject that requires a lot of personal and collective work, which can be very tiring. In my case, I believe that if it were not for the work done along the semester it would have been impossible for me to pass it just by working all at once at the end of the course".

In fact, research on SET scores has concluded that students dislike expending effort, an attitude that is reflected in their evaluations (Braga et al., 2014). However, in these cases, student performance tends to be better, because the instructor has required students to expend significant effort in order to achieve better grades.

## 5 CONCLUSIONS

The availability of new, reliable and precise satellite navigation systems has relegated traditional celestial navigation to serve as a mere back-up method for positioning at sea during oceanic passage. These changes have entailed the need to completely update the curricular programme and the associated teaching methodology. They have been introduced with institutional support at the Nautical College of the University of the Basque Country, making the most of the opportunity provided by the construction of the EHEA. In this paper, the impact of the new pedagogical approach on students' performance and

perceptions has been evaluated. The results have been compared with those obtained in previous years when traditional methodology was used.

Objective indicators of students' performance show that higher achievement is clearly related to the use of innovative teaching strategies. In our view, the key element for the spectacular growth that has been experienced is the sustained work that the groups of students perform throughout the course.

The use of cooperative work and innovative teaching-learning methods also has other positive effects. On the one hand, in addition to specific competences, students develop key skills in areas such as communication, working with others or autonomous learning. On the other hand, the engagement and commitment of students who now show a better attitude towards celestial navigation has improved and is being consolidated over the past few years.

However, despite students reporting their awareness of the advantages derived from the methodology in use, they are not completely satisfied with their learning experience as the required amount of sustained work is considerably time-consuming. At first, this had a negative impact on the student evaluation of teaching, but SET scores have increased lately as a consequence of having adopted progressive measures.

We are conscious that this study has some limitations, the main of which are, firstly, that the overall course effectiveness has been measured by using standard indicators of academic performance; and, secondly, that the course structure and learning strategies have been tailored to our instructional needs, circumstances, curriculum and students, and its implementation is heavily dependent on instructor`s motivation, commitment and ability to facilitate the teaching-learning process. Hence, further research would be required to measure the course effectiveness regarding the achievement of other relevant learning outcomes that active learning methods promote, such as critical thinking, problem solving, social skills, cooperative teamwork, etc.; and some others closely related to maritime navigation, such as the navigators' situational awareness and situation assessment, their ability to respond to a critical situation, etc.

Further work could also be carried out, in cooperation with teaching staff from other Maritime Education and Training (MET) Institutions, in order to design a specific IMO Model Course and/or to develop new training materials, aiming to assist teachers in organising and delivering the celestial navigation course.

Last but not least, in addition to adjustments in teaching planning to new times, celestial navigation teachers face the challenge of teaching a subject conceived as difficult and even as obsolete. In our view, the proposed approach is well suited to this purpose, as it contributes to heightened interest among students and notably improves their academic performance. However, once students finish their training period, they will most likely abandon the sight reduction practice to fix the ships' position, as it is not standard practice on board a vessel.

We do not know for how long celestial navigation will be a requirement for deck officers. In the meantime, in order to guarantee that their continued mastery of this competence while performing their professional duties, specific institutional support is required. In this sense, it has to be taken into account that the educational and the professional fields are alike, and the same principle applies: the way in which they are assessed/inspected determines what and how they study/perform their duties.

We forward some ideas in this respect to open the discussion: 1) Given that Vetting and Port State Control inspections affect the preparation of deck officers, they could pay attention to officer proficiency in nautical astronomy; 2) The IMO should also consider making the validity of a pass in celestial navigation certified by an approved MET Institution dependent on refresher courses after a few years from its date of issue. This could be done by establishing a special endorsement or certificate of proficiency in celestial navigation for all officers in charge of the watch on board vessels engaged in oceanic voyages.

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## APPENDIX 1. CELESTIAL NAVIGATION: COMPETENCES AND LEARNING OUTCOMES.

| |
|---|
| Competence 1. Determine position and the accuracy of resultant position fix by celestial observations |
| Learning outcomes: |
| 1.1. Thorough knowledge of the astronomical geographic coordinate system. |
| 1.2. Understanding of the general problem solved by celestial navigation. |
| 1.3. Adequate knowledge and practical mastery of the elements of navigational astronomy (navigational heavenly bodies, Earth movements, celestial coordinate systems, PZX triangle, apparent daily motion of stars, time, etc.) as required to support the next learning outcomes. |
| 1.4. Practical knowledge and proficiency in the operation of the necessary instruments (sextant, chronometer) and publications (nautical almanac, Pub. No. 249). |
| 1.5. Solution of PZX triangle for altitude and azimuth, and for declination and local hour angle. |
| 1.6. Identification of observed heavenly bodies. |
| 1.7. Measurement of observer's latitude by observed altitude of *Polaris* and sights taken for the meridian passage of the Sun. |
| 1.8. Understanding and plotting of astronomical position lines. |
| 1.9. Planning, taking and reduction of altitude sights. |
| 1.10. Ability to determine the ship's position using astronomical position lines both during the day and in the twilights. |
| 1.11. Securing that the fix obtained by celestial observations is within accepted accuracy levels. |
| Competence 2. Calibrate the compass error using celestial bodies. |
| Learning outcomes: |
| 2.1. Ability to determine errors of the magnetic and gyro-compasses using celestial means, and to allow for such errors. |
| 2.2. Ability to take Sunrise / Sunset compass checks. |
| 2.3. Ability to check for compass error by observing a compass bearing of *Polaris.* |

APPENDIX 2. Learning and assessment activities related to the technical mastery of sextants (an excerpt from the teaching guide).

SEXTANT


Do I know when and how to take a sight and to determine the observed altitude of a celestial body?

Learning outcomes:

1.4. Practical knowledge and proficiency in the operation of the necessary instruments (sextant, chronometer) and publications (nautical almanac, Pub. No. 249).

LEARNING ACTIVITIES

Objectives:

Correctly adjust sextant for adjustable errors.
Determine corrected reading of the sextant altitude of celestial bodies.
Properly perform the observation procedure.

Materials:

18 sextants
2 panels (day and twilight)
Terrace
Planetarium

| Activity | Duration |
|---|---|
| Sextant adjustment | 0.5 h |
| Sextant reading | 0.5 h |
| Observation procedure | 1 h |

ASSESSMENT ACTIVITIES

| | Evidence | | Evaluation | |
|---|---|---|---|---|
| | Group | Individual | Group | Individual |
| Portfolio | x | | x | |
| Video | | x | x | x |
| Self-evaluation | | x | | x |