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Bioinformatics, a Befitting Tool for *e*-Learning: Potential and Constrains according Teachers' Perceptions

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Abstract. Bioinformatics tools are suitable didactic instruments to combine updated knowledge with spotlight teaching strategies, e.g., *e*-learning. This study depicts the status of computational resources at schools pinpointed by teachers. Frequently, computers are obsolete, with outdated software, not connected to internet, their number is limited and often placed in areas not primarily aimed for teaching (schools' libraries and/or classrooms for professional/technical programs). These are key limitations preventing the implementation of digital-based activities in classrooms. This reality calls for the need to provide schools with updated informatics resources and fast internet connection to scaffold top-notch learning.

Keywords. Bioinformatics, *e*-Learning, Informatics at School, Teacher Professional Development.

1. Introduction

Computational resources and biological research are strongly connected [1-3]. Nowadays, every biology laboratory has computers with robust internet access to perform bioinformatics analysis [4-5]. In this regard and trying to adequate modern teaching practices to the new developments in biological research, several initiatives have been implemented to integrate bioinformatics-based approaches as an educational strategy [6-9]. In this scope, a portfolio of bioinformatics activities is available for the educational community to approach scientific issues such as antibiotic resistance, genetics, food preservation or evolution [10-13].

Recognizing the key role of teachers in this process, research institutions, universities, policy makers and teachers training programs, need to focus their interventions in helping teachers to implement bioinformatics in their classes [14-17].

Several studies were carried out to diagnose teachers' perceptions about bioinformatics integration in middle and high school curricula [17-20]. Teachers revealed to be interested in bioinformatics and recognized the importance of its incorporation in the curricula. However, from these studies was not clear the impact of the availability of computational resources at schools, namely computers and internet access. This study is a diagnostic of in-service teachers' perceptions about the accessibility of computational resources at schools to promote digital-based teaching and learning approaches in general, and to implement bioinformatics activities in particular.

1.1 Study Context

In a previous study, we diagnose teachers' perceptions about bioinformatics and identify the constrains for bioinformatics integration in middle and high schools [20]. In fact, Martins *et al.* [20] showed that teachers were interested in bioinformatics as a scientific area and as a didactic resource. Teachers revealed to be acquainted with bioinformatics definition, well-aware that computer and consistent internet access is required for data mining of biological datasets to retrieve meaningful information. Alongside with teachers' need of further training to boost their confidence to carry out bioinformatics-based interventions [20], it is urgent to revise middle and high school curricula to fuel an effective integration of bioinformatics in teaching practices, which is in line with other studies [6-7,16-19].

When in-service teachers were asked about the informatics readiness of their schools to promote bioinformatics-based approaches in their teaching practices, the majority admitted that their schools have the necessary conditions to implement bioinformatics-based approaches. Despite this, participants pointed out as one of the main constrains the poor internet connection and lack of computers [20].

The importance of clarifying these testimonials was reinforced particularly taking into account the recent need to rapidly implement *e*-learning strategies as a

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consequence of the compulsory containment due to COVID-19 pandemic [21-23]. To fully investigate the reason why teachers acknowledge that although schools have the resources (i.e. computers and internet) these are unsuitable to implement bioinformatics activities, we carried out an inquire to 37 Biology teachers who attended a bioinformatics workshop for science teachers [24].

To tackle this, two research questions were raised:

- How well are Portuguese middle and high schools prepared to implement bioinformatics in the classroom?
- Is the informatics equipment available at schools, updated and accessible for all teachers and at any time, *i.e.*, do schools have the equipment available to teachers and ready to be used in the classroom?

2. Methods

2.1. Participants

This research focus on a group of teachers who attended a training workshop in bioinformatics "*From DNA to Genes and to Comparative Genomics: Bioinformatics in the Classroom*". This four-hours workshop occurred in Lisboa in the context of an annual international meeting for teachers [24]. This group consisted of 37 Biology teachers from 28 schools (26 public and 2 private) from 8 different regions, mainly urban areas, being 78.40% of the participants teaching at schools in Lisboa and Setúbal which are built-up areas with a high population density.

Eight of the 37 teachers hold a MSc degree. One teacher holds a PhD degree. Participants have an average of 25.44 ± 7.75 years of teaching experience. At the moment of the workshop, 12 teachers taught at middle school level (students between 12-15 years old), 12 taught at high school level (students between 16-18 years old) and 12 taught both middle and high school levels. One participant did not fill in this information.

2.2. Materials

2.2.1. The Workshop

The workshop "*From DNA to Genes and to Comparative Genomics: Bioinformatics in the Classroom*" was designed and implemented for the first time in 2018 under the scope of the V International meeting for teachers of Casa das Ciências [25]. This workshop is aimed to explore with teachers the potential of bioinformatics as a didactic resource. Following specifically designed guidelines [11], teachers are guided to explore four bioinformatics tools in order to data mining a DNA sequence focusing on identifying genes and determine the putative functions of their products. Additionally, using bioinformatics resources of comparative genomics, the presence of certain genes in different taxonomic groups is also analysed in order to infer evolutionary relationships. This holistic approach contributes to understand basic notions of genomics, genes, genomes and proteins and, adding to this, introduces genomics-related key concepts such as Open Reading Frame (ORF), Basic Local Alignment Tool (BLAST) or synteny [26].

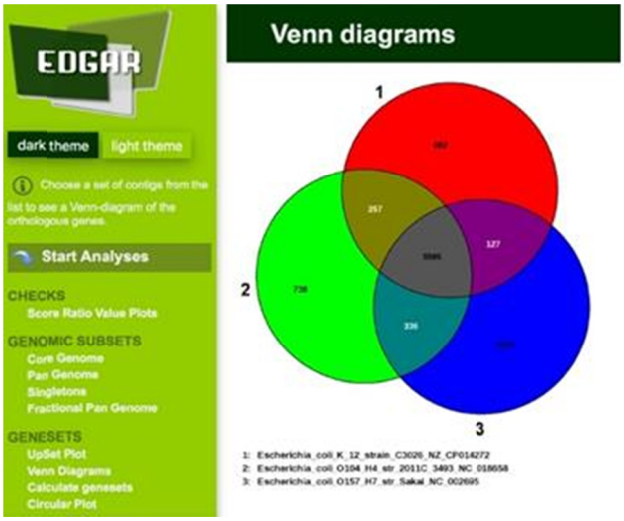

Figure 1. Genome comparison between three strains of *Escherichia coli* using a Venn Diagram to identify the core genome, pan genome and accessory genome

In 2019, a reedition of the workshop was considered and performed during the VI International meeting for teachers of Casa das Ciências [24]. The workshop was updated to include further resources. Efficient Database framework for comparative Genome Analyses using BLAST score Ratios (EDGAR) platform was added in the workflow of the workshop to run genome comparisons [27].

The activity was intended to identify, among up to five bacterial strains, the set of homologous and specific genes of each strain

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using the Venn Diagram functionality of EDGAR (Fig. 1). Based on the results obtained, notions of core genome, pan genome and accessory genome are discussed. Circular Plots and the Nucleotide Identity Average matrix (ANI) (Fig. 2) are analysed from a comparative genomics perspective. EDGAR functionality for the creation of phylogenetic trees is also explored.

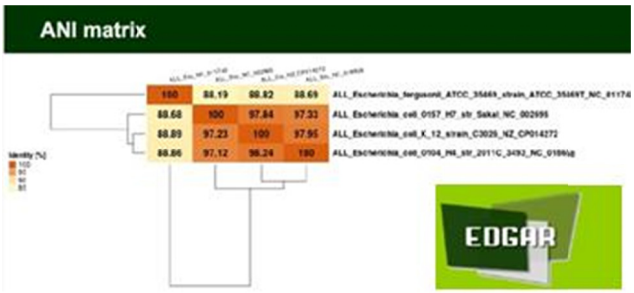

Figure 2. Genome comparison between a set of three strains of *Escherichia coli* and one strain of *Escherichia fergusonii* using an ANI matrix to identify genomes that belong to the same bacteria species (>95% according to [28])

All the exercises proposed in the workshop privileged simple, intuitive and user-friendly tools. Adding to this, the graphic interface of the outputs obtained at EDGAR are appealing and empower analytical skills of data interpretation through graphs and/or tables.

2.2.2. The Questionnaire

The questionnaire (Fig. 3), developed in our previous study [20], was clustered in two dimensions: teachers perceived knowledge on bioinformatics (Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q9, Q12, Q13, Q14, Q15, Q16) and in-service teachers' perceptions about the computational and internet resources available at their schools to implement bioinformatics-based activities (Q8, Q10, Q11).

These two dimensions aimed to know if the participants are acquainted with the definition and scope of bioinformatics, and to collect data on their perceptions of school readiness to implement bioinformatics as a didactic tool.

The questionnaire also included an initial section for demographic characterization of the group and three additional items to assess teachers' opinions about the questionnaire itself.

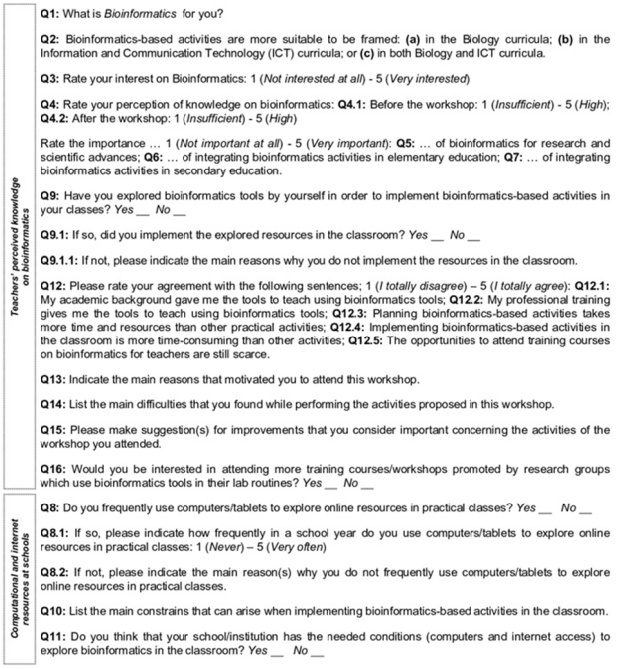

Figure 3. Questionnaire used in the study

2.3. Data Collection

Teachers voluntarily enrolled in the workshop which included a theoretical part and a practice component during which teachers co-worked in teams of two or three participants.

After the workshop all the participants were informed about the main aim of this study and, with their consent, the questionnaire (Fig. 3) was applied.

2.4. Data Analyses

Descriptive and inferential statistical analysis were performed for quantitative data [29]. For qualitative data, a thematic content analysis of the participants' responses to open-ended questions was carried out [30-31].

3. Results and Discussion

3.1. Teachers' perceived knowledge on bioinformatics

The participant teachers of this study revealed to be aware of the main scope of bioinformatics field (Q1). The majority (54.29%) of the participants defined bioinformatics according to the etymology of the word, which is a one-dimensional definition referring to the application of information technology to biology. However, data analysis and data storage were also mentioned. In this regard, it can be considered that participants knew what

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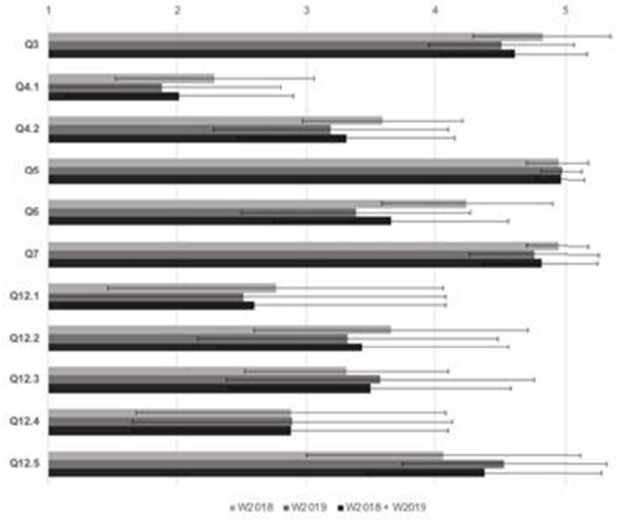
bioinformatics is, recognized its importance for scientific research (Q5) and revealed to be highly interested in this scientific topic (Q3) (Fig. 4).



**Statistically significant differences between groups.*
***Statistically significant differences before and after the workshop*

Figure 4. Answers given by participants according to a Likert Scale (Range 1 to 5). Bars represent the mean value and the error bars refer to the standard deviation

Participants (51.35%) agreed that bioinformatics can be framed in Biology classes and understand its potential as a teaching and learning topic (Q2). Interestingly, teachers added that bioinformatics could also be explored both in Biology classes and Information and Communications Technology (ICT) classes. The reasoning is that bioinformatics can be framed in the Biology curricula, but it can also be used to promote interdisciplinary based pedagogies. These approaches are strongly encouraged according to up-to-date science teaching standards, such as the Next Generation Science Standards [32], especially in the Science, Technology, Engineering and Mathematics (STEM) field [33-36]. This result reveals that participants of the study were aware of the adequacy of bioinformatics for Biology classes, but also went further and showed to understand the follow-up potentialities of this integration for other curricular areas. It is important to emphasize that participants were science teachers and consequently do not teach Information and Communications Technology (ICT) classes.

There was a general agreement among participants that bioinformatics-based activities are adequate for high school level (Q7) (Fig. 4). However, teachers inquired in this study, showed concerns about the importance of integrating bioinformatics-approaches in middle school level (Q6) (Fig. 4). This result is lower and statistically significant ($p<0.01$) when compared to the results obtained among the teachers who participated in the workshop edition of 2018 that more confidently agree on the importance of integrating bioinformatics in middle school [20]. This difference can be due to the exercises explored in workshop edition of 2019 that broaden the range of platforms explored when compared with the first edition of the workshop. This could have contributed to teachers better understand how they integrate bioinformatics in high school classes and, at the same time, feel that all bioinformatics tools are too complex for middle school level. When designing a new workshop other platforms can be explored such as Pathogen Modeling Program (PMP) [37] or Combined Database for Predictive Microbiology – ComBase [38-39] that showed to be compatible with middle school level to explore, for example, food preservation techniques [12,40].

Not surprising, and consolidating the data obtained in the first study [20], the majority (70.27%) of participants admitted that they have never explored bioinformatics tools by themselves (Q9) and most of them (72.73%) revealed to have actually implemented the bioinformatics tools in their classes (Q9.1). Teachers confirmed the perception that bioinformatics-based strategies are more time consuming and requires more resources than other type of practical classes (Q12.3) (Fig. 4).

Furthermore, they feel that their academic background and professional training is not sufficient for them to confidently explore bioinformatics tools within a didactic context (Q9.1.1; Q12.1; Q12.2) (Fig. 4).

Concerning the perceived background of teachers on bioinformatics, there is a statistically significant difference between teachers' answers ($p<0.01$) before and after the workshop (Q4.1; Q4.2) (Fig. 4). Teachers clearly agree that the workshop contributed to deeper their background on bioinformatics. In fact, workshop participants admitted that their background on bioinformatics improved after the workshop, boosting their confidence to explore bioinformatics in the classroom. Interestingly, the reason that motivated around

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half (48.65%) of the teachers to participate in the workshop (Q13) was to gain further training, corroborating the previous study [20].

These results were also obtained in the assessment of other training interventions on bioinformatics for teachers and corroborate the need of teachers update on this field (Q12.5.; Q16) [6-7,16,18-20] (Fig. 4).

Regarding the workshop itself (Q14, Q15), most of the participants did not mention any improvements on the bioinformatics-based activities explored at the session. The ones who did, claimed for a longer workshop (more than 4 hours) or a 25 hours training course to broaden their perspectives on the potential of bioinformatics-based tools adapted to different school levels. Adding to this, informally teachers express their will to access scientific counselling to implement bioinformatics in their classes all over the school year.

3.2. Teachers' perceptions about the computational and internet resources available at schools to implement bioinformatics-based activities

According to the first dimension of questions, regarding teachers' perceived knowledge on bioinformatics, it is legitim to assume that participants were aware of the main aim of bioinformatics, of its potential as an educational resource, and that teachers were interested and motivated to learn more about this scientific field.

These participants were also conscious of what is needed in order to implement bioinformatics in their classes. Accordingly, they are able to have a critical and a helpful perception about the possibilities and the constrains to integrate bioinformatics in their different school realities.

The second dimension of questions aimed to diagnose in-service teachers' perceptions about the computational and internet resources available at their schools for bioinformatics-based activities.

More than 90% of the participants admitted using computers/tablets to explore digital resources in their classes (Q8) which indicates that teachers are used to take advantage of technologies in their classes (Q8.1).

When asked specifically about the readiness of their institutions to develop bioinformatics activities, the majority (62.16%) of the participants assumed that the school/institutions where they were teaching did not have the necessary conditions to integrate bioinformatics-based strategies (Q11). Although this data may apparently contradict what teachers mentioned in the first edition of the workshop [20], the evidence gathered in the current study suggests that teachers understood that the existence of computers and internet does not ensure by itself the possibility to carry out bioinformatics exercises.

Other constrains pointed out by teachers impairing the implementation of bioinformatics activities in the classroom (Q10) are related with: logistic constrains (75%); training needs (8.33%); literacy (perceived knowledge and skills) (13.89%); and student's performance (2.78%).

Regarding the logistics constrains, teachers mainly mentioned that computers at school are obsolete, not easy to access and internet connection is often poor (Fig. 5). Around 10% of teachers reported informatics-based resources understood as computers and internet limitations.

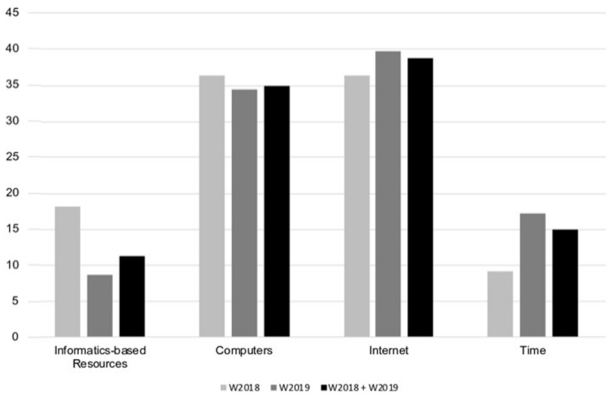

Figure 5. Main logistics constrains to implement bioinformatics in the classroom from an in-service teacher perspective (Q10)

Participant teachers who referred not to use technological equipment in their classrooms (Q8.2) mentioned reasons such as: "*Lack of computers and time-consuming administrative procedures to get access to a classroom equipped with computers*"; "*Difficulties to*

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access the internet" and "*Lack of computers in the schools and so teachers have to ask students to bring their personal computers*". These statements suggest that school computers are not really available for teaching, being frequently allocated to no teaching activities (school libraries and/or classrooms for professional/technical programs).

Furthermore, it is important to highlight that these results are likely biased since the inquired teachers serve in central schools located in large urban areas, in which is expected that informatics resources (i.e. computers and internet connection) are more likely accessible comparatively with non-urban schools. This suggests an inequity between urban and non-urban schools regarding the integration of bioinformatics in learning activities.

A possibility to overcome the lack of computers at school or to avoid using obsolete computers is inviting students to use their own. However, between 2009 and 2012, the percentage of students who reported having a least one computer or more at home in Portugal is lower than OECD average [41]. This reality become recently obvious with the *e*-learning strategies implemented due to COVID-19 pandemic [42-43].

Computers are now a key tool for teaching and learning and more than ever their role as a didactic instrument, that can connect students and teachers, is highlighted [44-46]. In this regard, governments should develop programs and create funding opportunities in order to make possible for each student to have a computer at home.

Alternatively, personal smartphones may be used to perform simple and accessible tasks that do not require a computer as for instance to introduce Phyton to answer biological questions [47], or explore biodiversity using deep-learning platforms such as the iNaturalist® [48-49].

Regarding limitations related with internet access, teachers stated: "*It is present at school, but it is not working in an efficient way*". In fact, among the schools sampled, although internet connection is available, its efficiency can only provide basic tasks, such as email or to access digital resources for teachers, thus not suitable for bioinformatics analysis. In public schools, the internet network is provided by the ministry of education and it has a limited access (both concerning speed and number of computers connected with). This means that even if the students bring their personal computers, a request for access a robust wireless connection has to be made to execute bioinformatics exercises. In this context, improving internet access to both teachers and students within the schools needs to be urgently considered by educational stakeholders.

Finally, it is worthy mention that technical support is important to ensure that informatics equipment is set to operate normally. Although this aspect was not mentioned by teachers, it was inferred from informal discussions at the workshop "*From DNA to Genes and to Comparative Genomics: Bioinformatics in the Classroom*" (2019). Furthermore, interdisciplinarity and collaboration between Biology teachers and ICT teachers during the activities could help to address problems related with computers and internet connection.

4. Conclusion

Generally, teachers acknowledged that their schools are equipped with computers and internet connection [20]. This may suggest that resources would be available to integrate bioinformatics in teaching practices. However, in the present study teachers admitted that often computers are obsolete with outdated software, poor internet connection and inaccessible for teaching.

Focusing on these considerations the active use of educational web-based resources, in which bioinformatics can have a key role, calls for a digital reform of schools as encouraged by Next Generation Science Standards (NGSS) [32].

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