Fostering Critical and Computational Thinking in the Field of Primary and Secondary Education in non-STEM Subjects by Using Data Sets and Applications

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***Abstract* – Critical and computational thinking in primary and secondary education in recent years shows growing importance in methodical approaches used in the classroom. Although many examples exist for using critical and computational thinking in STEM educational area, the social sciences i.e., non-STEM areas were somehow left out due to the relatively more difficult design of such content, especially in the part of the development of computational thinking. In that context, in this paper we present one way of using critical and computational thinking in non-STEM education, more specifically on the example of historical data sources, through the use of programming in Python. As an example, we use historical data for Trans-Atlantic Slave Trade routes, that were the largest long-distance coerced movement of people in history up to the mid-nineteenth century, for connecting concepts of databases, Data Science and programming for development of critical and computational thinking in context of history science. This way of using modern approaches in classroom should give teachers and pupils a broader picture of importance of interdisciplinary education for critical and computational thinking development through STEM and non-STEM classes that give pupils novel skills needed for future labor market.**

Keywords – Critical Thinking; Computational Thinking; STEM, non-STEM; Data Science; programming; Python; history, Trans-Atlantic Slave Trade routes

I. INTRODUCTION

In this paper we analyze prerequisites for substantiation of critical thinking and present one possible approach to foster critical and computational thinking in non-STEM courses by using historical data sources by programming in Python. The idea is to develop new approach and present one possible model to promote STEM in non-STEM courses as an upgrade of gamification method in the early stage of education (primary) with an aim to introduce STEM basics to wider number of students thus creating an opportunity for new learning and skills. Starting from the very beginning it's extremely important to persist in finding a way to encourage critical thinking at an early age of life, especially in primary education. This mode of thinking represents the skill that improves intellectual values by processing information and experiences due to observing and analyzing all factors throughout the process of synthesizing, reasoning, and conceptualizing. We could name many arguments why critical thinking is important in the life of an individual. One of the most important among others is boosting-up the research skills, enhancing the problem-solving ability, improving decision making, stimulating creativity and curiosity. Siburian et. al [1] published the findings confirming significant correlation between critical and creative thinking skills on cognitive learning with 72.80% contribution of critical thinking skills and creative thinking skills simultaneously to cognitive learning results. On the other hand, Amanda Hiner [2] argues that critical thinking is often not effectively or intentionally taught in college classrooms, resulting in disappointing learning outcomes for students and that educators should be trained on how to teach critical thinking and should integrate focused instruction in critical thinking into their classrooms in order for students to make significant, positive gains in their critical or analytical abilities. Hence, the teacher's role is invaluable in this process.

Student critical thinking skills can be improved through adjusting curriculum to encourage these skills [3]. Bailin and Battersby [4] suggest that critical thinking requires a careful critical examination of the subject issue. They provide an example of the questions for the inquiry process e.g.:

- What is the issue?
- What kinds of claims or judgments are at issue?
- What are the relevant reasons and arguments on various sides of the issue?
- What is the context of the issue?
- How strong is each of the arguments?
- Weighing and balancing the evaluated arguments, what judgment should we come to?

In order to even begin to inquire, students need to be clear about the issue which is to be impetus for the inquiry [5]. This requires that they understand the criteria for a well-formed and appropriate issue for inquiry. To foster critical thinking in elementary school some authors [6] suggest applying a 3 Step Method. The 1st element of this method is setting a cognitive challenge, something that is not easily answered and, in the case of philosophical inquiry, probably has no definite answer. Having a problem set, the 2nd thing is how to approach it, what method to use to move towards a solution (e.g.,

collaborative process inside the group) and the 3rd one is social construction – using the kind of dialogue described earlier to investigate the problem.

II. TECHNOLOGY AND APPLICATIONS IN NON-STEM COURSES

One of the possible approaches to foster creativity in education we see in acquiring STEM knowledge and skills. The data suggests that more students prefer non-STEM courses, hence, the idea was to develop a method of using STEM knowledge in a problem-solving exercise based on a critical thinking in the history course (primary and secondary school).

Regarding the idea, Nurzengky et. al [7] have already developed one possible model of student critical thinking skills in history education. Their survey study was empirically tested on N:124 junior high school students in South Jakarta and even though they imply that model should be slightly modified, results confirmed that student interpretations, inference, evaluation, explanation, and monitoring have been positively associated with student critical thinking skills in history education. Machotka & Papapetrou [8] have presented project output, the conceptual frame and exploratory workshop to probe the field and to build a constructive interdisciplinary dialogue between two research areas: Data Science and Art History with conclusion that Data Science can enrich art studies while analysis of visual data can have a positive impact on Data Science. In their paper the authors present examples of future research directions from the Data Science perspective of Digital Art History that include (a) the development of new dimensionality reduction methods and feature-extraction mechanisms from complex Digital Art History data (e.g. digitized manuscripts and images), (b) the construction of novel neural network architectures based on CNNs and LSTMs with attention mechanisms to address the time and space variables, (c) the design of user-interactive tools with advanced machine learning and data management capabilities that can be deployed in real-time scenarios, such as museum navigation, and (d) explicitly maintaining the users and human experts to provide interactive feedback to the learning process via techniques such as reinforcement learning or active learning [8].

Looking towards the data sets and by analyzing its content we have followed the discussion of Damerow & Wintergrün [9] regarding challenges of the initial data collection process and how it fits into the overall research data life cycle. They suggest creating a data corpus much more explicit to contextualize data considering that decision on what particular data set, method, or technology we use has a great impact on the results of an analysis.

In recent years a huge amount of data has been collected for scientific and educational purposes. A huge amount of data has become an integral element of contemporary society [10]. For educational purposes a vast number of data set emerged that can be used as additional tools in classroom to improve learning such as data sets from given links:

- https://data.world/datasets/education
- https://libguides.css.edu/EDU6190/DataSets
- https://dataschools.education/resource/useful-datasets-for-data-education-in-schools/

although, most of them are applicable to higher education. Available data sets, if prepared for non-STEM teachers, could be used for critical and computational thinking in schools as an example of Slave Voyages show.

In this paper in the Introduction, we provide the main challenges of critical thinking to be introduced in the classroom. Next, the Technology and applications in non-STEM courses section give overview of relevant examples of using STEM knowledge of problem-solving principles in non-STEM courses. The Conceptualizing data sets for history courses section shows an example of Slave Voyages data set based on collected historical data where we describe the process of preparing and analyzing the example data set for research questions for which we developed program in Python programming language. In Results and discussion, we show ways in which the program can be used for development of critical thinking. In Conclusion we emphasize the potential future applications and further development of this approach for applications in the curriculum of primary and secondary schools, on the basis of which students and professors will be able to develop computational and critical thinking.

III. CONCEPTUALIZING DATA SETS FOR HISTORY COURSES

A. History and Methodology of Slave Voyages data set collection and preparation

After collapse of the Amerindian population, the New World has experienced a shortage of labor at plantations (sugar, tobacco, other agricultural goods) and at gold exploitation in 16th century. As a result, Europeans and Euro-Americans made a slave trade routes with Africans in order to maintain the supply chain with new tropical goods and gold to the old world through slavery [11]. It was this slavery that has driven the growth of the economy of America and other countries (empires) involved in the slave trade and has triggered changes on the political global stage with an impact on society and culture and other aspects of the daily lives of the stakeholders involved.

Data collected in Voyages Database contains data about voyages that occurred from 16th to mid-19th century from which almost all are published and archival information. As noted by the authors of the database, there are records of more than 36000 voyages documented through one or more history sources from which one sixth are based on at least one record, while ~60% of the voyages have three or more separate sources each. List of the sources are given at the link Trans-Atlantic Slave Trade - Understanding the Database (slavevoyages.org). Collected slave trade data gives a broader picture of history causes and consequences through examining cultural, demographic, economic and

technological changes, although through examining newly discovered history sources, new evidence and new records are occurring in database. Currently data set shows that 12520000 captives were sent to America from Africa in period of 16th to mid-19ht century in around 41190 voyages from which 10.7 million are disembarked mostly in America. The validity of this data set was also confirmed with genetic research shown in paper [12].

Data set used for Trans-Atlantic Slave Trade is published on the web page of Slave Voyages project (https://www.slavevoyages.org/) whose purpose is to collect archival data on slave-trading voyages from unpublished and published history sources and create dataset for further scientific research. The whole data set is available at link https://www.slavevoyages.org/voyage/database. Variables used in this database are divided into eight groups: 1) Ship, nation, owners – 14 variables, 2) Voyage Outcome – 5 variables, 3) Voyage Itinerary – 11 variables, 4) Voyage Dates – 9 variables, 5) Captain and Crew – 4 variables, 6) Slave (numbers) – 12 variables, 7) Slave (characteristics) – 9 variables, 8) Source – 1 variable, making total of 55 variables. The complete description of variables (fields) can be found on the link https://www.slavevoyages.org/voyage/about#variable-list/2/en/. Due to the large number of used variables in the database, when creating customized data tables (data sets) based on specific research question suitable for use in classes, records should be cleaned and prepared according to the methods and concepts used in Data Science. We must emphasize the importance of knowing the description of the variables when interpreting the data used, i.e., we must be aware of the way they are collected and the methods used especially when working with historical sources where estimated and calculated values are also used.

B. Application of ready-made program solutions in Python for history class - Slave trade routes example

For developing critical thinking and computational thinking outside of traditional STEM classes we build small program based on Python programming language ((version 3.7.9) in Spyder scientific environment) for connecting basic concepts in Data Science (preparing and cleaning data, libraries used for Big Data analysis in Python) with history data of slave trade routes through selected research questions suitable for K-12 students.

1) What research questions can be conducted based on historical sources about slave trade routes?

As we already mentioned, this data set has 55 variables and from those variables a vast number of research questions can be asked in context of history of Trans-Atlantic Slave Trade Routes and critical thinking. For this paper we choose to present a few:

1. For specific selected range of years of arrival at port of disembarkation (in overall period of 16th to 19th century) and country, discuss ratio of total embarked and total disembarked slaves in Middle passage (voyage of enslaved Africans across the Atlantic Ocean to the New World) for every individual voyage?
2. For specific selected range of years of arrival at port of disembarkation (in period of 16th to 19th century) and selected country discuss ratio of total embarked and total disembarked slaves in Middle passage grouped by specific year?
3. What does comparison of those numbers for different countries tell you about the role of individual countries in the slave trade voyages for that selected period range?

To give an answer to these questions, we prepared custom data set that include fields with the variables Year of arrival at port of disembarkation, Total embarked, Total disembarked, Flag (imputed). From initially 36073 records and after cleaning the data (in this case of cleaning the data we think about discarding those records that don't have data for one of the variables in individual record) we got for our customized data set 34444 records, of which 2209 records have unknown assigned country. Also, we sorted data by year and country (Flag (imputed) variable) because of practical usage for educational purposes, although this step is not mandatory (part of the data table is shown on Fig. 1).

Year of arrival at port of disembarkation	Total embarked	Total disembarked	Flag (imputed)
1606	90	77	Denmark / Baltic
1641	150	130	Denmark / Baltic
1646	347	269	Denmark / Baltic
1646	260	212	Denmark / Baltic
1647	392	320	Denmark / Baltic
1647	251	174	Denmark / Baltic
1657	325	259	Denmark / Baltic
1660	328	285	Denmark / Baltic
1679	290	245	Denmark / Baltic
1683	334	254	Denmark / Baltic
1686	250	200	Denmark / Baltic

Figure 1. Example of prepared and cleaned customize data set according to research questions and Data Science principles.

For this customized data set and research questions proposed, we write a Python program shown below in Fig. 2.

```
#import of libraries for Data Science
import pandas as pd
import matplotlib.pyplot as plt

#import of dataset
df = pd.read_csv("Questions_dataset.csv",sep="\t")
#printing dataset (all columns are not shown)
pd.set_option('display.max_columns', None)
print(df)
#printing dataset (all columns are shown)
pd.set_option('display.max_columns', None)
print(df)
#List of counties
Countries={"1":"Denmark / Baltic","2":"France","3":"Great Britain",\
           "4":"Netherlands","5":"Portugal / Brazil","6":"Spain / Uruguay",\
           "7":"U.S.A.","8":"Unknown"}
#Insert range of years (1500-1870)
Start_period=int(input("Please enter a start year:\n"))
End_period=int(input("Please enter a end year:\n"))

print(Countries)

country= input("Select country:")

#Criteria for filtering data by Years and selected country for bar plot
years = df.loc[(df["Year of arrival at port of disembarkation"]>=Start_period)\
               &(df["Year of arrival at port of disembarkation"]<=End_period)\
               &(df['Flag (imputed)']==Countries.get(country))]
#print(years)
#print(years.sum(axis=0))


#creating bar plot with filtered data for every record in data
ax =years.plot.bar(x="Year of arrival at port of disembarkation",y="Total embarked",\
                   color="red", label="Total embarked",figsize=(12,5))
years.plot.bar(x="Year of arrival at port of disembarkation",y="Total disembarked",\
               color="blue", label="Total disembarked",ax=ax)
ax.set_xlabel("Year of arrival at port of disembarkation")
ax.set_ylabel("Total embarked/Total disembarked")
plt.title('Slave trade routes')
plt.show()
```

```
#creating bar plot for filtered data with group by function
gy = years.groupby('Year of arrival at port of disembarkation')
GroupedYears=gy.sum()
print(GroupedYears)
ax =GroupedYears.plot.bar( figsize=(14,5))
ax.set_xlabel("Year of arrival at port of disembarkation")
ax.set_ylabel("Total embarked/Total disembarked")
#labels of years on bar plot
for container in ax.containers:
    ax.bar_label(container)

plt.title('Slave trade routes')
plt.show()

years2 = df.loc[(df["Year of arrival at port of disembarkation"]\
                >=Start_period)
                &(df["Year of arrival at port of disembarkation"]\
                <=End_period)]


#creating graph for countries in selected year range
gf=years2.groupby("Flag (imputed)")
GroupedFlag=gf.sum()
print(GroupedFlag[["Total embarked","Total disembarked"]])

ax =GroupedFlag[["Total embarked","Total disembarked"]].plot.barh(figsize=(12,5))
ax.set_xlabel("Year of arrival at port of disembarkation")
ax.set_ylabel("Total embarked/Total disembarked")
for container in ax.containers:
    ax.bar_label(container)
plt.title('Slave trade routes')
plt.show()
```

Figure 2. Custom made code for investigating research questions.

In summary, this program as input data takes our custom data set in csv format. For user selected options for available records of countries that were included in slave market, we select a range of years (for example for option 6-Spain /Uruguay, we select range of years from the year 1800 to the year 1805) and with this input parameters we plot three bar plots. First of the plots describe individual voyages, second bar plot shows grouped data for those criteria for range of years and third bar plot shows for selected years number of embarked and disembarked captives for involved countries in Trans-Atlantic slave trade routes. For working with data set, we use pandas and matplotlib libraries, one of the most common libraries used in Data Science field. On the Fig. 2 in code in front of each bar plot code is comment that separates parts of the program according to proposed questions so users could change arguments as needed.

IV. Results and Discussion

In order to give an answer to questions proposed, after running the program, we select period from the year 1800 to the year 1805, and for country option, option 6-Spain /Uruguay. As a result of running the code we got bar plots shown on Fig. 3-5.

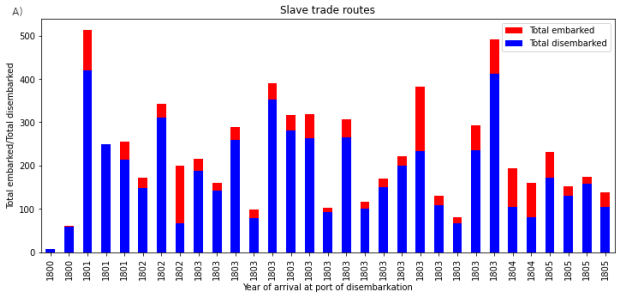

Figure 3. Bar plots obtained with python programming language for year range 1800-1805 and county Spain/Uruguay. A) Individual voyages in selected year range and county.

According to Fig. 3, for purpose of interpreting obtained bar plots, students could argue and conclude, that individual voyages have small amount of embarked and disembarked slaves, that for some voyages the difference between embarked and disembarked slaves is large so interpretation of this data should use critical

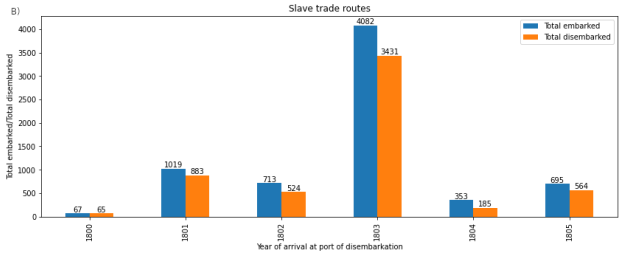

Figure 4. Bar plots obtained with python programming language for year range 1800-1805 and county Spain/Uruguay. B) Grouped data by year for selected year range and country.

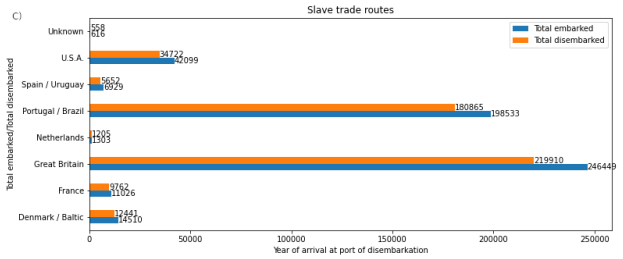

Figure 5. Bar plots obtained with python programming language for year range 1800-1805 and county Spain/Uruguay. C) Horizontal bar plot for countries in data set for selected range of years.

thinking in order to connect those results with historical circumstances (storms, rebellion, diseases, pirates as an example) for conducting the realistic interpretation based on historical data. Also, students could discuss which year had the highest frequency of voyages under a certain flag, which in this case had been the year 1803, as is seen from the selected parameters.

In Fig.4 for a selected country, students can track data grouped by specific year in a selected range of years and discuss the historical circumstances that led to an increase in the global slave trade for a given year, but also and circumstances that led to decrease in it. For our case of selected years that was also the year 1803 when traffic had been almost four times greater than for other years for selected country (Spain/Uruguay).

We investigate for answering the third question from list of countries that were included in Trans-Atlantic slave trade routes (Denmark / Baltic, France, Great Britain, Netherlands, Portugal / Brazil, Spain / Uruguay U.S.A., Unknown), which one of them had the highest traffic in that specific year range. From the year 1800 to the year 1805, the highest number of embarked and disembarked slaves in Middle passage had Great Britain with 246449 embarked and 219910 disembarked slaves. If we compare this short-selected range of years with the total number of captives embarked and landed from the year 1500 to the year 1870 for Great Britain, the traffic in that selected short range of years accounts for 8% of total slaves embarked and 8.47% of slaves landed. If we compare that short time span for Great Britain with the slave trade of each listed country from the 16th to the mid-19th century, for which data exists, it accounts for 2.32% of all embarkations and 2.39% of all slave landings. Overall numbers for each country can be obtained by using this program for input values from the year 1500 to the year 1870. This program, except for bar plots, also

prints and summary table for selected range of years as Table 1 shows. It is interesting that the highest traffic had Portugal/Brazil so analyzing historical context using critical thinking could be discussed through themes of economy, society, politics and technology for involved countries.

TABLE 1. SUMMARY NUMBERS OF EMBARKED AND DISEMBARKED SLAVES THROUGH 16TH TO MID-19TH CENTURY.

Flag (imputed)	Total embarked	Total disembarked
Denmark / Baltic	104273	86648
France	1307821	1113711
Great Britain	3082495	2596168
Netherlands	594375	510009
Other	3686	3176
Portugal / Brazil	3883856	3471023
Spain / Uruguay	569126	497734
Sweden	191	176
U.S.A.	377764	313401
Unknown	718580	594350
Sum	**10642167**	**9186396**

As an example of usage of this program for critical thinking and computational thinking development we recommend to compare for different countries how slave trade took place over the span of twenty years and discuss which of the country were dominant from 16th to mid-19th century in slave trade and put it in history circumstances relevant for domains of technology, economy, society and politics. An example of using program in this way for grouped data are shown in Fig. 6 to Fig. 12 for the period from the year 1650 to the year 1670 and countries Denmark / Baltic, France, Great Britain, Netherlands, Portugal / Brazil, Spain / Uruguay and U.S.A.

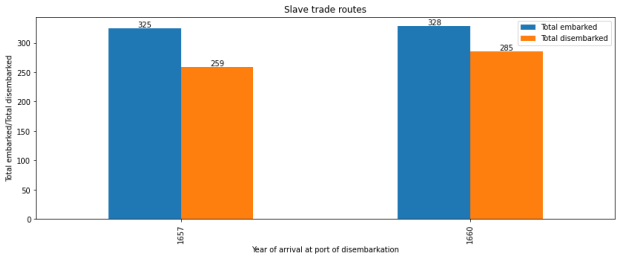

Figure 6. Denmark / Baltic (1650-1670)

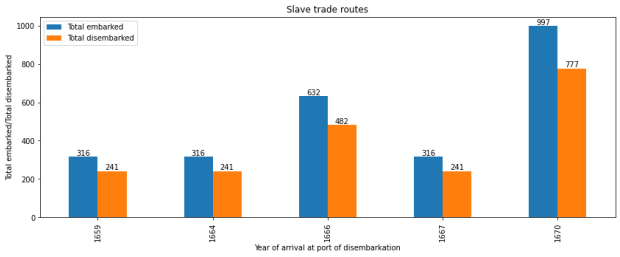

Figure 7. France (1650-1670)

By comparing bar plots for this period, we can conclude that for given data set the smallest traffic with captives were under flags of U.S.A. and Denmark/ Baltic and the highest occurred in that period for Netherlands (66999 embarked slaves, and 53993 disembarked slaves) as Table 2. shows, that is realistic conclusion specifically because US gained their independence a century later.

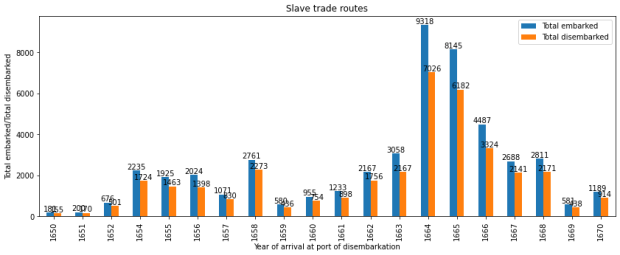

Figure 8. Great Britain (1650-1670)

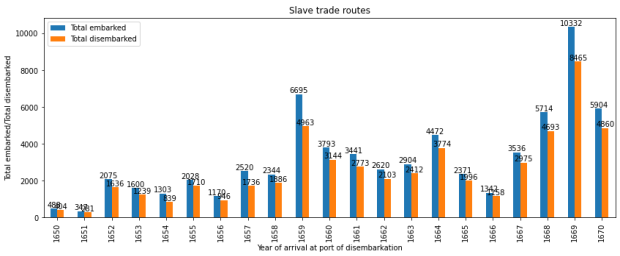

Figure 9. Netherlands (1650-1670)

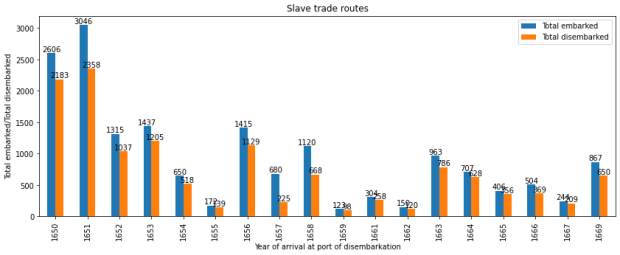

Figure 10. Portugal / Brazil (1650-1670)

Figure 11. Spain / Uruguay (1650-1670)

Figure 12. U.S.A(1650-1670)

TABLE 2. SUMMARY NUMBERS OF EMBARKED AND DISEMBARKED SLAVES THROUGH THE YEAR 1650 TO THE YEAR 1870.

Flag (imputed)	Total embarked	Total disembarked
Denmark / Baltic	653	544
France	2577	1982
Great Britain	48285	36721
Netherlands	66999	53993
Portugal / Brazil	16709	12936
Spain / Uruguay	6493	5305
U.S.A.	181	155
Unknown	2466	1804
Sum	**144363**	**113440**

For this data - in selected range of years, students can comment the trends in traffic for individual country (for example Portugal/Brazil had the highest traffic of slaves at the beginning of that period (1650) but at the end of that period was much lower and in decline (1670), while in contrast, Netherlands had at the beginning of that period the lowest traffic but till the end of the period the traffic grew). This comparison of traffic with slaves could also be a theme for discussion in classroom with including the history context of that period - what history circumstances in economy, society, politics, technology happened in each country for that specific period that had led to increase or decrease in slave trade traffic.

V. CONCLUSION

Connecting interdisciplinary research areas and their concepts in primary and secondary education and beyond give students and teachers a broader opportunity for knowledge-based learning using modern approaches. Teachers can use research methods to give students tasks from real world problems to develop a critical thinking that will prepare them for their professional future. As the world moves towards the digital age, students and teachers should adapt to the changes by using critical and computational thinking for their future jobs. One way of adapting can be done by introducing in educational curriculum such interdisciplinary content, as we show in this paper on the history example of Trans-Atlantic trade slave routes, a real history data set that is used for exploring history by introducing research questions that can lead to critical and computational thinking development. To increase the level of critical and computational thinking, more variables from this data set can be used in a particular research question in order to see increasingly complex historical facts through critical thinking, while respecting the limitations that historical sources (data sets and variables) and Data Science methods may have. For example, we could use in data set a variable for type of the ship that was carrying slaves to see if there is some correlation between died slaves or we can use the same logic for making conclusions about correlation between length of the voyage and died slaves.

With introducing more variables in data set related to research questions, because of null values in records in some fields (due to lack of history record details), the number of overall number of records could be reduced in which case we have to discuss validity of our data interpretation using critical and computational thinking. In this paper we propose a way of fostering critical and computational thinking in the field of primary and secondary education in non-STEM subjects by using data sets and their possible applications as a starting point. Although for this specific example of Slave trade routes, one could comment that maybe the better options would be usage of different kind of visualization tools in non-STEM classes, but the aim of this example is that teacher and student should gain knowledge of Data Science concepts such as cleaning and preparation of the data sets and building customized data sets that could be used in ready-made Python scripts on all educational levels even if they at the beginning don't have appropriate digital skills. Also, according to Digital Education Action Plan (2021-2027, https://education.ec.europa.eu/focus-topics/digital-education/action-plan), 39% of teachers don't use digitalized contents in classroom because of lack of digital skills so with prepared and detailed instructions, they should advance their digital skills in classroom by adjusting examples and expanding the given ones. Our future work will include expanding examples and data sets and Python scripts for history and for other non-STEM subjects, so modern and advanced primary and secondary curricula could implement them in future education.

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