

# Another glass of failure? ☆

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## Abstract

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*Keywords:* Cultural Evolution, Roman Empire, amphorae production, social learning

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## 1. Introduction

xavi: Comentario general: por que cada frase la has puesto en un paragrafo distinto? Cada paragrafo deberia ser un tema y no una frase. Y deberias usar el concepto de topic sentence (la primera frase del paragrafo resume el paragrafo).

5 maria: si, claro, lo tengo que cambiar en el momento en el que incluya las imagenes. Lo deje asi porque era el primer draft :D

xavi: Esto va al JAS no? La primera frase deberia tener un tono mas arqueologico.

10 maria: he cambiado el parrafo para que parezca mas arqueologico :D

Material culture variability allows to understand a part of the mechanism of the human behaviour (Basalla, 1988; Schillinger et al., 2016a). Dynamic of

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<sup>1</sup>Since 1880.

changes on the material culture have been analyzed by the study of cultural  
15 pattern which varying over time and space (Eerkens, Jelmer and Lipo, Carl  
P., 2007; Lycett, 2015) The detection of those different patterns in artefact  
production in the archaeological records could also explain whether these change  
are produced by cultural reasons or not based on economical, political and social  
changes. maria: CITATION NEEDED

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As result, different information are shared by social learning generating an  
accumulation of knowledges which are transmitted from generation to genera-  
tions in different context and content conditions (Eerkens and Lipo, 2005; Neff,  
1992; Henrich and McElreath, 2003; Boyd et al., 2011). Likewise, the mode  
25 of learning transmission, along with several external conditions might affect  
directly or indirectly the pattern of manufacturing of the artefacts.

Within evolutionary perspective, social learning is analyzed to understand  
the human behaviour in archaeology. Thought material culture, we can observe  
cultural patterns which can explain how the culture evolve (Richerson and Boyd,  
30 2005).

However, different debates revolve around how individuals or groups ac-  
quired and transmitted techniques skills (Bowser and Patton, 2008; Mesoudi  
and O'Brien, 2008). In addition, this challenge is combined with the difficulty  
detecting the different modes of transmission in the archaeological record (Roux,  
35 2015). In the case of archaeology, several studies have analysed this process fo-  
cused on the production of handmade pottery (Steele, James et al., 2010) or  
stylistic variations (Neiman, 1995; Shennan and Wilkinson, 2001). Specifically  
our work pretend to know if those processes could be similar with a more stan-  
dardized and massive production (Gandon et al., 2014), focused on the case of  
40 pottery production in the Roman Empire.

xavi: Esta frase no dice realmente nada no? Debes ser mas concreta y concisa  
en lo que quieres transmitir. Dando la vuelta al tema, podrias estructurar el  
mismo contenido asi: 1. la cultural material que los arqueologos encuentran esta  
basada siempre en social learning, 2. la arqueologia evolutva analiza el proceso

45 para saber que tipo de social learning se esta usando, 3. la mayoria de estudios  
se centran en ceramica hecha a mano y variaciones estilisticas 4. creemos que  
este framework es aplicable a otros contextos y objetivos, como entender los  
procesos masivos de produccion de amforas en el imperio romano  
maria: cambiado

50

This paper explores the changes in the production processes during the Roman Empire. In particular, our study is focused on understanding the pottery-making techniques by analyzing large-scale amphorae production in a specific area. In this case, an evolutionary framework is used for studying the impli-  
55 cation and the impact that this production might involve on the evolution of social learning processes.

xavi: Este es el tema principal del paper; deberia ser explicitado antes y un poco mas detallado: 1. queremos entender los procesos productivos del imperio romano, 2. en concreto, la produccion en masa de anforas, 3. la aplicacion de  
60 un framework evolutivo nos permitira identificar que tipo de social learning esta envuelto.

maria: no se dnde ponerlo porque normalmente al final de la introduccion hay como un resumen de todo, donde deberia ponerlo?

65 Specifically, the aim of this study is understanding if pottery-making techniques were transmitted through vertical or horizontal social learning. Our main hypothesis concerns the transmission of the techniques by vertical transmission and how vertical transmission is spreading in time and space. These technological knowledges could have been transmitted from master to disciple  
70 and thus continuously. If vertical transmission predominates in this process over horizontal transmission then amphorae made in nearby workshops might share more similar traits than amphorae made from farthest workshop. Otherwise whether horizontal transmission is the main transmission in this process the social learning would be transmitted by workers. Then there would not  
75 be differences among workshops on the production. The artefact variation can

be related to the geographical distance (Björklund et al., 2010; Shennan et al., 2015; Van Strien et al., 2015). In material culture, artefact variation might be affected by geographical distance where material culture is more similar in close population who interacted each other. In other case, the correlation between  
80 both seems not visible due to different factors (Hart, 2012). In our case, we can detect measurable differences among this type of amphorae correlated with the geographical distance.

In this work we have explored the social learning processes associated with amphorae production through a combination of empirical analysis and multi-  
85 variate methods. The paper is structured as follows. The next section introduces the case study and existing hypotheses, the third section will illustrate about the methods that we have applied to analyze our case study, the next section will deal about the results; and finally we highlight with a discussion about our results.

90 xavi: by observing que? Por otra parte, el ultimo parrafo de la intro siempre resume el contenido del paper (next section will define the case study and existing hypotheses, the third one will deal with the methods...blablabla  
maria: cambiado

## 95 2. The amphoric production in Roman Baetica

maria: he quitado las subsection y he anadido el título provisional como me comentaste

Our case study examines the variation of the amphorae production located  
100 in *Baetica* (currently Andalusia, south Spain). During the Roman Empire, this ancient province became an important support for the production and distribution of olive oil to the rest of the Empire from Ist to IIIrd centuries Chic (2005); Berni (1998); Remesal (1998)

For this reason, a large-scale infrastructure of amphorae production was

105 developed around this area to supply the provinces of the Roman Empire with  
a huge impact during the supplying of the roman legions in places such as  
Britania (Funari, 2005; Carreras Monfort, 1998) or Germania (Remesal, 1986)  
maria: he cambiado campanas militares por legiones romanas :)

110 *Baetica* had also a strong connection thought rivers that allowed developing  
an important trade network mostly around the Mediterranean (García Vargas,  
2010). maria: he dejado solo mediterraneo pero he puesto mostly :P

As result of this increase, more than 90 pottery workshops were currently  
115 located along the Guadalquivir river and its tributaries. The majority of am-  
phorae produced in this area belong to *Dressel 20* divided into different typolo-  
gies (Berni Millet, 2008; Martin-Kilcher, 1994). This amphora type was used  
mostly to transport olive oil for around 300 years in order to satisfy the demand  
within Roman Empire (Remesal, 1977). In particular, olive oil was a significant  
120 product frequently related in different aspect of the roman daily life such as  
consumption, lighting and hygiene (Mattingly, D.J., 1988).

The importance of this commerce is also showed by the fact that Dressel 20  
amphorae production were identified with different marks about its provenance  
although the meaning of the actors in this process seems not clear maria: (CI-  
125 TATION NEEDED, podria anadir aqui el paper de Antiquity?)  
. In any case, our main question will be related to understand how the amphorae  
workshops were organized in *Baetica* area and whether it is possible to iden-  
tify amphorae made in different workshops. Thus, this amphorae production  
was a particular example of production strategy that experimented few changes  
130 around three centuries.

xavi: faltaria acabar esta seccion con una discusion del problema que quieres  
resolver, incluyendo la pregunta de como se organizaban los talleres, que hipote-  
sis hay y como liga esto con lo que has explicado de social learning.

135 maria: done. No he incluido las hiptesis de partida porque ya hablo de ellas

en la introduccion, tendria que incluirlas aqui tambien?

### 3. Material and methods

xavi: Es mejor si empiezas con el metodo aqui; si no, el lector no entiende  
140 de lo que estas hablando.

maria: cambiado

We analyse a dataset of 470 amphorae collected from 5 different workshops  
excavated. The workshops were located in Malpica (Palma del Río, Córdoba),  
145 Cerro del Belén (Palma del Río, Córdoba) (Díaz Trujillo, 1992), Parlamento  
(Sevilla) (García Vargas, 2000), Villaseca (Córdoba)(García Vargas and Morena,  
fourthcoming) and Las Delicias (Écija, Sevilla) (Fernández et al., 2001; Mauné  
et al., 2014) 1.

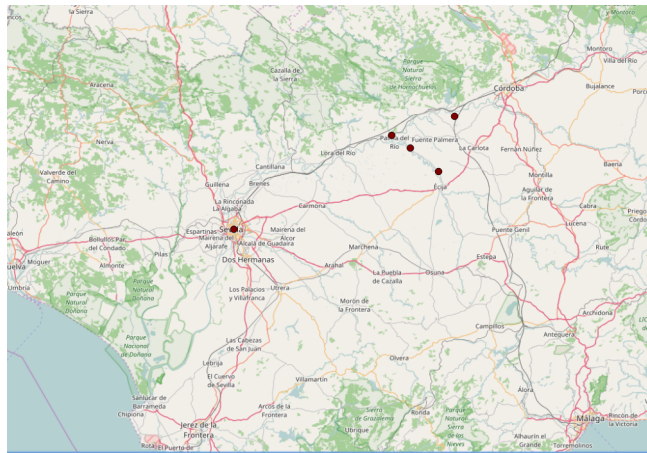


Figure 1: Dressel 20 workshops distribution along the rivers Guadalquivir and Genil

maria: la imagen es provisional que ando aprendiendo con qgis. Faltarían  
150 los nombres :)

We created a dataset where were selected 80-100 samples of each pottery

workshops. The choice of these workshops corresponded to several reasons. Firstly, the workshops were selected from different spaces in order to analyse the production patterns depending on the distance of each workshop. Secondly, the extended chronology of these workshops serves as proxy to examine changes on the variation shape. In our case, the type Dressel 20 did not experimented especially visible changes on the production pattern during three centuries. Finally, the workshops selected were open excavated and provided a large number of materials.

maria: he incluido esta subsection antigua field method dentro de esta

Eight different measurements were taken for each amphorae sample of the 5 workshops studied. The measurements were done using different tools: caliber, square and bevel to take the measurements and profile gauge to draw the pottery shapes. xavi: no necesitas especificar esto...yo quitaria la ultima frase  
maria: y así? o la quito?

The measurements were focused on the rim sherds whose fragments were the most preserved on the archaeological sample. In the case of pottery attributes, rim sherds and the curvature of handles work as an useful indicators of variability (Berni Millet, 2008). maria: especificado en la pagina 25, explain why

Moreover, the measurements were divided into exterior diameter, inside diameter, rim height, rim width, shape width, rim inside height, other rim width and protruding. rim maria: deberia incluir una imagen explicando cada medida?

. The method requires a large sample size and for this reason we focused on rim sherds. Other significative parts such as handles and bases are found in lesser quantities thus compromising the applicability of the method due to small sample size.

In our study, we have selected five variants according with three centuries (Dressel B: I; Dressel C: I-II; Dressel D: II; Dressel E: III, Dressel F: III. Without important variations in three centuries, the chronology respond to a relative dating obtained by the classification identified on shapes in different studies defined by defined by P. Berni (Berni Millet, 2008) and Martin Kilcher (Martin-

Kilcher, 1994). All of these variants selected were found in excavations from the  
185 proper workshops studied in order to avoid some material which can contaminate  
the sample. For the proposal of this study, the rest of variants were not taken  
into account from our study by not having enough material for the analysis.

### 3.1. Principal Component Analysis

The sample selected were tested using statistical method such as Princi-  
190 pal Component Analysis and Discriminant Analysis to explore these metrical  
differences on the rim sherds.

xavi: Es mas correcto hablar de "reducir la dimensionalidad" en lugar del  
numero de variables. Por otra parte, no se si hace falta detallar tanto PCA...mira  
otros papers similares usando PCA y veras que es tan comun que no hace falta  
195 definir mucho (quizas solo especifica la primera frase, y que es comun en arqueo  
como las obras citadas abajo).

maria: es curioso porque en los papers que he visto sobre arqueometria ni se  
paran con esto pero en los de arqueologia si, por eso lo hice, debera reducirlo  
mas ahora?

200

We used Principal Component Analysis (PCA) to reduce the dimensionality  
of our dataset. This method allows to create a reduced number of *new variables*  
which contain all the relevant information of the previous variables without  
losing relevance. The firsts principal components are expressed as the result of  
205 the most variance of the all information from the original variables. Moreover  
the information is expressed as the result of most variation retained in the first  
principal components (Jolliffe, 2002; Shennan, 2008). This method is commonly  
used in archaeology for the study of the variation of material culture (Li et al.,  
2014; Schillinger et al., 2016b) In our study, this method allows to transform  
210 our measurements into PCs and take the firsts PCA with more variability in  
the dataset.



### 3.2. Discriminant Linear Analysis

The performed results with PCA were analysed with Linear Discriminant Analyse (LDA). LDA was used to find significant differences among workshops by the combination among variables obtained for the first principal components. Unlike the PCA, LDA identifies which variables allow to distinguish or discriminate each group and how many variables are necessary to achieve the best combination as possible. In our case, this method allowed to demonstrate the correlation between spatial distance and distance among workshops. LDA was used to explore a better separate training set from the results of the most relevant principal components. LDA can classify the PCs result of the measurements into different groups. We also generate a Confusion Matrix (CM) to able of quantifying the degree of confusion and compare the index of similarity among workshops. CM calculated the probability of success and error of the results. It generates a matrix where higher value are the results of an incorrect classification. The distance generated with the results of DA will be compared with the spatial distance to see if it exists a correlation between morphometric distance and spatial distance.

As example, this method has been commonly used to detect differences in artifact production (Charlton et al., 2012; Thorpe et al., 1984), and particularly for a similar study about the production pottery in *Tarraconense* (Aguilera, 1998)

## 4. Results

Several multivariate methods such as PCA and LDA were used to quantify the technical differences on the pattern production among workshops. maria: he dejado esta frase a modo introductorio y he quitado las subsection

The analysis of PCA produces a set of values for each variable observed. Variables show how much variability exist in the dataset grouped by each principal components. The results, indicated in the Fig 2, show most variability in

the firsts principal components than the rest. The most differences were focused on the protruding rim and rim width. maria: debería incluir una tabla con las diferencias?

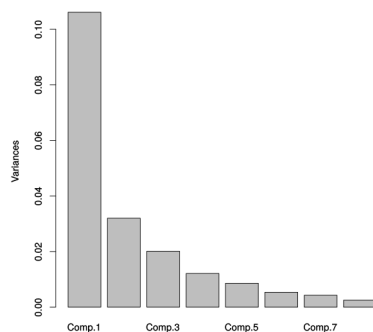


Figure 2: PCA results

245 The patterns observed in the first 2 Principal Components were plotted to visualize the degree of variation by isolation among workshops. The results, shown in Fig. 3, suggested than amphorae from closer workshops tend to be more similar than amphorae made in furthest workshops. In particular, the Fig illustrates how the four closest workshops show variation on PC1 (i.e. Belén, 250 Delicias, Villaseca and Malpica) while Parlamento displays a distinctive pattern than the rest of workshops on PC2 values. xavi: que pattern? esto es parte resultados parte discussion, así que quizás deberias unir las 2 secciones

maria: las diferencias que se muestran entre todos y Parlamento en especial por eso puse pattern porque parece que no se asimila a ninguno. Lo de los 255 resultados discussion no lo entendi :(

Discriminant Analysis was used to analyze the results obtained from PCA. The results of CM showed than workshops with more troubles to be distinguished such Malpica and Belén shared a minor spatial distance than the rest 260 (see Table 1). Therefore, similar amphorae making techniques processes were strongly correlated with the spatial distance. xavi: distance matrix?

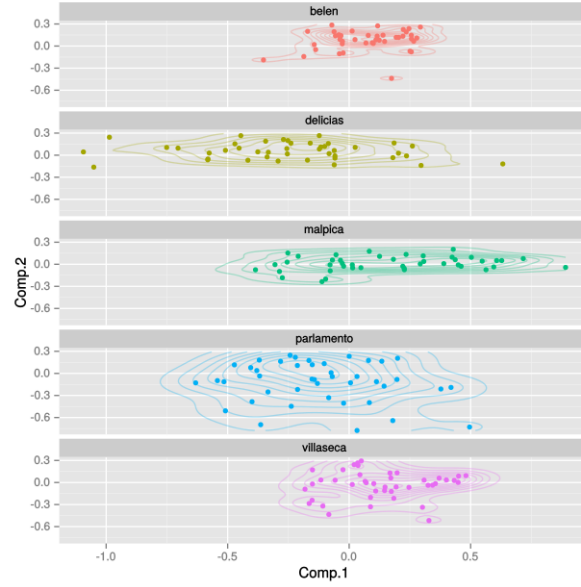


Figure 3: First and Second Principal Components for the analyzed sample

maria: no entiendo lo de distance matrix

	belen	delicias	malpica	parlamento	villaseca
belen	31	8	14	9	9
delicias	0	22	6	11	1
malpica	5	2	11	2	10
parlamento	4	5	6	15	5
villaseca	3	6	6	6	18

Table 1: Confusion Matrix. Accuracy 45.12 %. P.Value <0.01.

We compared morphometric and spatial distance by performing peer-to-peer analysis between all workshops. We calculated the geographical distance between each site and the distance among pottery measures, calculated using the previous results. (FIG) shows that the pottery distance is strongly correlated with the spatial distance of workshops.

xavi: Como decia yo quitaria las subsection. Y si hablas de correlacion  
270 deberias cuantificarla (lo miramos cuando este el paper en un segundo draft)  
maria: no lo he tocado porque no se como hacerlo lo de distance matrix

Thus, the results suggest a variability on the making-techniques processes might depend on the spatial distance.

## 275 5. Discussion and Conclusion

Differences on the making techniques processes among workshops show a variability correlated with spatial distance. The analysed morphometric traits suggest that the similarity between amphorae decrease with the spatial distance between the workshops where they were produced. As result, amphorae made in  
280 nearby workshops with a minor spatial distance share more traits than amphorae made in pottery workshops furthest. In other words, the variability on the making techniques processes between closer workshops was difficult to differentiate. In our case, Malpica and Belén workshops where the geographical proximity are the closest shared more traits in comparison with other workshops (Parlamento  
285 and Las Delicias). Thus the probability of interaction between workshops is increasing when the proximity is closest while this likelihood decreases when the possibility of interaction is low.

We have observed than rivers courses could have affected in the transmission factors. In the case of the commerce, rivers and its tributaries played an  
290 important role for the transport of goods. The huge demand within Roman Empire and the good conditions for the loading and unloading of products maria: busqueda citation needed

might have influenced the mode of transmission due to the continuous contact between workshops. xavi: no entiendo esta frase aqui. que quieres decir?  
295 maria: quiero decir que el Guadalquivir ofrecia buenas condiciones para el intercambio de materiales o productos

The results suggest also that vertical transmission could be the main cultural mechanism to explain the variability between workshops. The different morphological traits among workshops seem proper of a low contact between potters from others workshops. The evidenced confirms therefore that these techniques traits were transmitted with high fidelity and only with few changes during three centuries. It would mean that the disciples could have remained the making techniques processes in the workshops where they were trained.

By contrast, horizontal transmission doesn't seem to be the most probable process. The continuous contact between potters from different places had generated a more homogeneity in the technical practises. Workshops were sharing the same production techniques. As result, it would generate a social network where potters with the same social learning level worked in different workshops at the same time. Our result suggest a progressive contact with closer workshop instead. Moreover, the fact that isolation by distance is detected suggests a limited displacement between distant workshops. Thus, vertical transmission would be explained with this observed process. However, the diversity of social learning processes are clearly complex. In other words, the transmission of knowledges between master and disciple did not discard that horizontal transmission played an important role in this process as well. It can be a process where this vertical transmission dominated at first in the same workshops but consequently this transmission would be affected by workers who exchanged ideas or workers moving to other workshops.

The combination of empirical analysis with the statistical methods have provided a strong baseline for a better understanding of the amphorae production in the Roman Empirexavi: Esto es el JAS, no hace falta que vendas los metodos cuantitativos :-)

maria: si, pero es un caso particular que yo no he visto en JAS :p o como podria ponerlo?

These methods offer also an strong complement to other methods as archaeometry for the characterization of production sites and places of consumption.

We have identified measurable differences in the techniques by observing and

we have tested these particularities using multivariate methods. Our analysis  
330 provides an useful baseline for the exploration of the social learning processes  
related with amphora production in the Roman Empire. Hence, the results  
have lightened to understand the link between social learning and archaeological  
evidence in a diversity of scenarios.

## 6. Acknowledgments

335 Data were collected and performed and analysed in R version 3.2.4. statis-  
tical language and implemented with the package MASS. [maria: incluir la url  
con los datos y el cdigo and citation needed](#)

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