Cultural Evolution Across Domains: Language, Technology and Art

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Abstract

The social and cognitive mechanisms of cultural evolution have been studied in detail for different domains: language, technology, the economy, art, etc. However, a model that incorporates the function of a cultural tradition and that is able to compare evolutionary dynamics across cultural domains has not been formulated. By exploring the dynamics of comparable linguistic, technological and artistic experimental tasks, we test the effect of domain-specific function on evolutionary mechanisms such as inheritance, innovation and selection. We find evidence that cultural domain shapes both the structure of the traditions and the way the cultural-evolutionary mechanisms operate. The simplifying effects of cultural transmission are noticeable in language and technology, but not in art; innovation is highest in art and lowest in language; and functional pressures lead to different morphological adaptations across domains. This speaks of a crucial role of function and domain in the evolution of culture.

Keywords: cultural evolution; language; technology; art; Lego; iterated learning; transmission chain; experiment

Introduction

Humans are distinct from all other species because of the scale and diversity of our culture. Our behaviour is strongly influenced by knowledge, beliefs, skills and values that are socially learned, as opposed to genetically inherited (Boyd & Richerson 1985, 2005). Cultural traditions such as languages, social habits, technologies, religion or art change over time, and this change has been characterized as an evolutionary process of descent with modification (Campbell, 1965; Durham, 1991; Whiten et al., 2011; Boyd & Richerson, 1985, 2005; Mesoudi, 2011). Traditions are often transmitted unchanged over the generations thanks to faithful imitation (Tomasello, 1996) and teaching (Csibra & Gergely, 2011). Mutated, or innovative, traits also appear in a cultural tradition due to copying error, intentional innovation or borrowing from other traditions. Cultural traits spread and wane in populations as a result of random, neutral evolutionary processes (Bentley et al., 2007) and of selection pressures (Rogers & Shoemaker, 1971; Boyd & Richerson, 1985, 2005; Rogers, 2003).

Cultural evolutionary processes have been described in detail for language (Croft, 2000; Ritt, 2004; Binder & Smith, 2013; Kirby, Dowman & Griffiths; Kirby, Griffiths & Smith, 2014), technology (Rogers, 2003; Fleming & Sorenson, 2001; Mesoudi et al., 2013), the economy (Nelson & Winters, 1982; Hodgson, 2004), social and political systems (Fukuyama, 2011; Gintis & van Shaik, 2013) and art (Haddon, 1914; Morris-Kay, 2012), among others. These and other studies indicate that culture is not a monolithic, homogeneous phenomenon and that the relevant cognitive mechanism --innovation to generate diversity and imitation to preserve the developments of past generations (Tomasello, 1996; Lewis & Laland 2012)-- interact in different ways with the functions prevalent in distinct cultural domains. A model comparing how cognitive biases interact the functions of culture has not been formulated. The present study represents the first attempt at understanding the diversity and complexity of human culture by comparing directly how cultural evolutionary processes unfold across domains. We investigate whether evolutionary mechanisms like inheritance, innovation and adaptation vary across three domains with very different cultural functions: language, technology and art.

Cultural evolutionary pressures derived from transmission

Culture evolves under two main pressures: one related to transmission, and one to usage. The first pressure requires cultural patterns to be learnable and reproducible so they can survive over generations. Under this pressure, patterns that are simple and compressible are selected for (Kirby, Cornish & Smith, 2008; Tamariz & Kirby, 2015). The second pressure requires cultural traditions to be useful for their relevant function. Under this pressure, traditions that are functional and useful --which may imply diversity or complexity or both-- are selected for (Regier, Kemp & Kay, 2015; Kirby et al., 2015).

An example of the kind of solution that evolve in the face of these two opposed forces is the systematic, regular structure of languages. Cross-linguistic studies have looked at the distribution of structure in lexical domains such as colour or kinship terms across world languages, and found that world languages simultaneously optimize simplicity and informativeness (Regier et al. 2015).

Iterated learning experiments and computer models help understand the social and cognitive mechanisms that may

have led to this distribution. Using miniature artificial languages made up of words associated to objects, Kirby et al. (2008, 2015) modeled the effects of transmission and of usage. In transmission experiments, a participant is trained on a language, and then she is tested on it. Her output is used to train the next participant, forming a transmission chain. After several generations, the languages have very few distinct words left: they have become highly compressible, and therefore easy to learn. But they cannot name all the meanings (Kirby et al., 2008). Kirby et al. (2015) ran a communication condition in which two participants are trained on a language and then use it to play communication games with each other; after many interactions, the languages stay expressive: they maintain a distinct word for each object. They also ran a condition that included both transmission and communication: a pair learns a language and then play communicative games with it; the words they produce at the end of the game are used to train the next pair in a transmission chain. Here, under pressure for transmission and for utility, the languages developed regular systematicity over generations to become simultaneously easy to learn, and also fully expressive, with a distinct word for each object.

The conclusions of the studies reviewed above lead us to predict an increase in compressibility, or simplicity, in response to cultural transmission in the three domains. In the language domain, we should also expect a pressure for expressivity arising from communicative function, which puts a limit to how simple linguistic patterns can get. This raises the question whether other domains have similar breaks on simplicity. The following section explores this question and justifies our predictions for the effects of function in each of our cultural domains.

Domain-related predictions

Art is produced for the purposes of self-expression and evaluated by criteria like beauty or artistic value, making it a highly subjective domain of culture. Each individual may have his or her own expressive biases and ideas about artistic value. The functional pressures guiding the evolution of art may thus vary across individuals, and the artistic tradition, therefore, might not show the signature of directional selection for specific features over several generations. Additionally, we might expect innovation to have some functional benefit in art. We therefore predict low transmission accuracy and also a reduction in the evolution of simplicity in this domain.
The goals of technology are usually objective and clearly defined, which leads us to predict high transmission accuracy of adaptive traits which contribute to achieving the goal at hand, combined with the predicted pressure for simplicity.
Unlike technological solutions, which are strongly constrained by the structure of the problem they have to solve, linguistic signals are not constrained by the structure of their referents. Most signals in human languages are arbitrary, that is, they do not resemble or are caused by their

referent meaning (de Saussure, 1983 [1916]). In order to be communicatively functional, however, signals must be shared conventionally by the interlocutors. An innovation in the signal has the potential to disrupt a convention, as the listener might not be able to recognize it. For these reasons, and also based on the studies reviewed above, we predict low innovation of signals, in addition to the predicted selection for simplicity caused by transmission.

Experimental Testing of the Effects of Cultural Domain on Evolutionary Dynamics

In order to test these predictions we compare the evolution of cultural traditions pertaining to the three domains in a transmission chain experiment where participants use similar materials in a similar task (making Lego constructions), but with different functions, corresponding to each of the domains.

Methods

Participants. Ninety-nine participants (66 were female; ages ranged from 18 to 35, mean = 21.2, SD=3.54), took part in this study. The results from three of them were excluded because of non-adherence to the instructions. They were recruited through the University of Edinburgh employment service and also in the Psychology building. The experiment lasted 6 to 7 minutes in total, for which each participant could choose to be rewarded with between £1 or a snack (a can drink and a chocolate bar).

Materials. Participants come into the lab to find on the table 45 identical 2x4 orange loose Lego bricks, a number of objects (see next section for details) and a Lego construction standing next to each object (see e.g. Fig. 1). The objects were a tennis ball, a flower made of fabric and plastic, a £1 coin, a wooden spoon and a mesh bag containing pebbles.
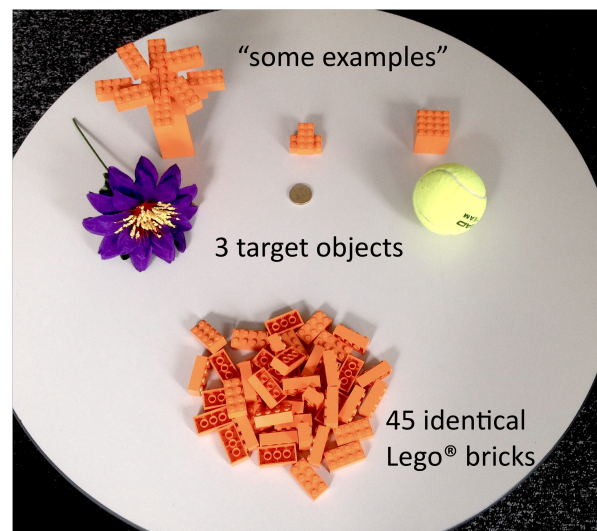

Figure 1: Experimental setup in one of the trials in the Art condition.

Procedure. After signing a consent form, participants were instructed to make one construction for each of the objects using the Lego bricks. In the Art condition three objects were present (the ball, the flower and the coin) and the participants were told to use the loose bricks to produce 'original' works of art that would be 'judged for their artistic value'. In the Technology condition, the same three objects were present and the participants were asked to make a stand out of Lego to support each of them so that the sum of heights measured from the table to the top of each objects was maximized. In the Language condition, all five objects were present, as was an interlocutor (another participant), sitting across the table. Participants had to make signals with the Lego bricks to communicate the objects to the interlocutor during a series of naming games: the experimenter showed a photograph of one of the objects to the participant, he made a Lego signal in view of the interlocutor, who had to guess which of the five objects the signal referred to. They were both told they scored a point for each correct answer, and their goal was to score as many points as possible in the time available. The experimenter showed pictures of the objects in random order, and told the interlocutor and noted down whether each response was correct. In all domain conditions, the maximum time allocated for the task was 5 minutes. Each participant was tested on only one condition.

Transmission chains. Participants were organized in transmission chains, so that the 'example' Lego constructions seen by one participant (or pair of participants in the Language condition) were the constructions produced by the participant in the previous generation in the chain. The first participant in each chain, therefore, saw no examples. They were not told what to do with the examples; they could copy them, draw inspiration from them or ignore them.

Data analysis. The 216 Lego constructions related to the three objects common to all conditions (the ball, the flower and the coin) were manually coded: we recorded the number of pieces, overall height, width and depth, volume (of the smallest cuboid box that could contain the construction), and area of the faces that were external or visible (long sides, short sides, top and bottom). Using these data, we estimated complexity using a 3D version of perimetric complexity, equal to the squared total external and any internal areas in mm^2 divided by the volume contained within those areas in mm^3 (yielding units mm^{-1}). This measure is an extension of standard 2D perimetric complexity, equal to the squared length of the inside plus outside perimeters of a drawing divided by the ink area contained within those perimeters, and known to be a good estimate of processing effort for a graphic (Pelli et al. 2006).

In order to estimate the level of innovation during transmission, each pair of constructions for the same object in consecutive generations (e.g. the construction inspired by the ball in the art condition, chain 1, produced at generations

1 and 2) was rated for difference (a proxy of innovation) on a scale of 0 to 9 points (0 if they were identical, 9 if they were completely different) by three independent coders. The inter-coder agreement was very high (Pearson's r values ranged between 0.821 and 0.831, N=180, p<0.001).

We measured functional success in two of the domains. In technology, the height in cm from the table to the top of the object. In Language, the number of successful communicative interactions in five minutes.

We used R (R Core Team, 2012) and *lme4* (Bates, Maechler & Bolker, 2012) to perform linear mixed effects analyses of the effects of Lego figure innovation and morphological features (complexity, width, length and heigh) on cultural domain. As fixed effects, we entered Domain (Art, Tech and Language), Object (Ball, Flower, Coin) and Generation (1–6 for Complexity, 1-5 for Innovation) (without interaction term) into the model. As random effects, we had an intercept for Chain (1-12), as well as by-Chain random slope for the effect of Domain, Object and Generation. *Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality*. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question (Winter, 2013).

Results

Cultural domain had a significant effect on complexity (χ^2(2)=13.39, p=.0012). The least complex constructions were produced in the language domain (average 2.50mm^{-1} ± 0.68 S.E.); in the technology domain, complexity increased by 3.37mm^{-1} ± 0.74 S.E. and in the art domain, by 2.94mm^{-1} ± 0.74 S.E. (Fig. 2).
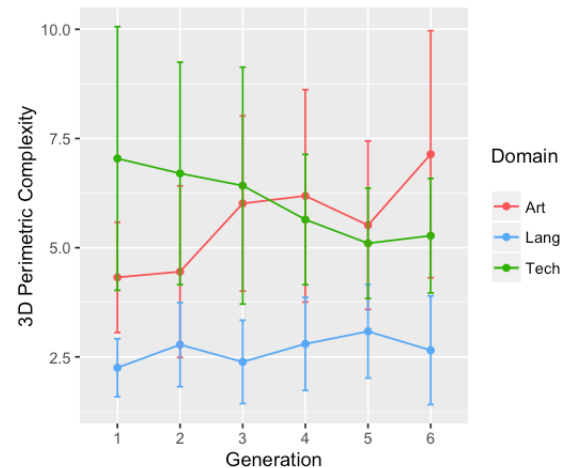

Figure 2: Complexity in the three domains over generations (95% C.I. shown throughout).

There was an interaction between domain and generation (χ^2(10)=18.573, p=0.046) due to the complexity of in the art domain increasing and in the technology domain condition decreasing over generations (Fig. 2).

Object also affected complexity (χ^2(2)=52.83, p=3.4x10^{-12}). Here, the least complex constructions were associated

with the coin (average $0.61\text{mm}^{-1} \pm 0.68$ S.E.); for the flower, complexity increased by $3.16\text{mm}^{-1} \pm 0.40$ S.E. and for the ball, by $1.68\text{mm}^{-1} \pm 0.40$ S.E.
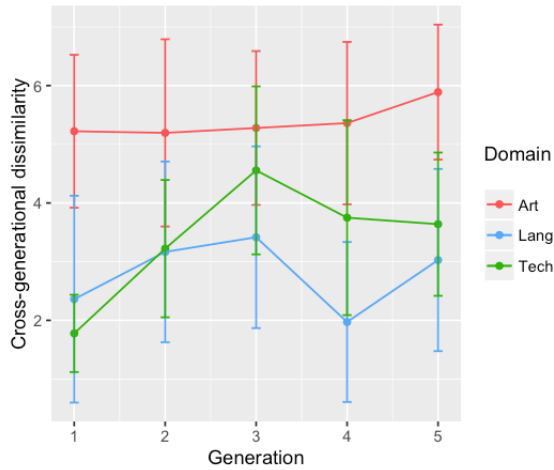

Figure 3: Innovation in the three domains over generations.

Regarding innovation, there was a significant effect of Domain ($\chi^2(2)=11.65$, $p=0.003$). Innovation was greatest in the art domain (average 5.11 points $\pm$ 0.57 S.E.), with a drop of 2.60 points $\pm$ 0.61 S.E. in the language domain and a drop of 2.00 points $\pm$ 0.61 S.E. in the technology domain (Fig. 3).

There was also a significant effect of object on innovation ($\chi^2(2)=19.80$, $p=5\text{x}10^{-5}$). Innovation was greatest for the flower (average 5.42 points $\pm$ 0.57 S.E.),, with a drop of 0.32 points $\pm$ 0.36 S.E. for the ball and a drop of 1.56 points $\pm$ 0.36 S.E. for the coin.
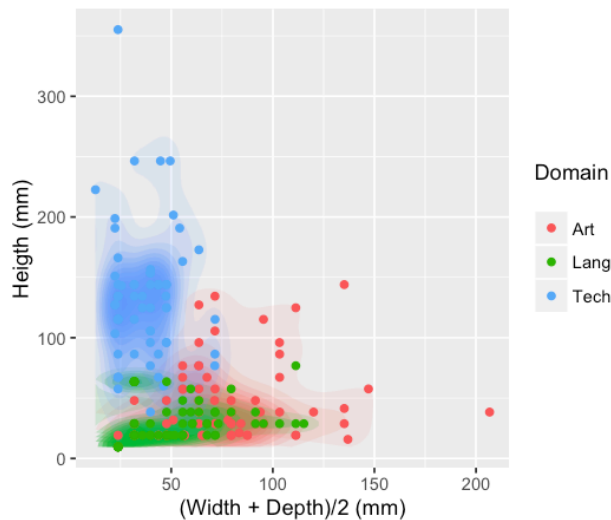

Figure 4: Height of the Lego constructions in the different domains against horizontal dimensions

As far as the morphological features are concerned there was an effect domain on Lego construction height ($\chi^2(2)=30.161$, $p=2.8\text{x}10^{-7}$), with the towers in the

Technology condition were significantly taller (on average $123.06\text{mm} \pm 9.14$ S.E.) than the artworks ($80.72\text{mm} \pm 8.78$ S.E. shorter) and the linguistic signals ($95.3\text{mm} \pm 8.78$ S.E. shorter). Fig. 4 shows height versus horizontal dimensions width and depth in the three domains.

The number of Lego pieces and the volume also showed an effect of domain. For number of pieces, $\chi^2(2)=34.46$, $p=3.3\text{x}10^{-8}$; technology had the most pieces, with 15.35 ± 1.44 S.E. pieces, with a drop of 2.66 ± 0.88 S.E. pieces in art and a drop of 9.59 ± 0.88 S.E. in language. For volume, $\chi^2(2)=17.84$, $p=1.3\text{x}10^{-4}$; here, art had the largest volume, 226cm^3, with a drop of 109 $\text{cm}^3 \pm 40$ S.E. pieces in technology and a drop of 195 $\text{cm}^3 \pm 40$ S.E. in language.

Functional success in the language and technology domains did not change significantly over generations: there was no effect of generation on height of tower plus object in the technology domain constructions ($\chi^2(1)=0.012$, p=0.91). The effect of generation on communicative success in the language domain was not significant either ($\chi^2(1)=3.021$, p=0.082), although success in the last four generations visibly increases with respect to the first two (Fig. 5).
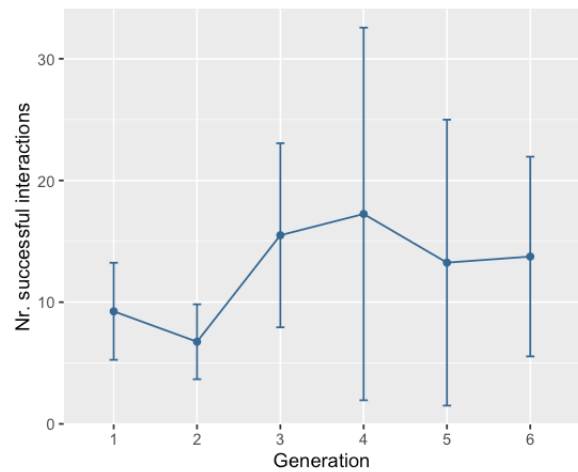

Figure 5: Success over generations in the language domain.

Discussion

Summary of results. First, for language, we predicted simplifications (or reduction in complexity) over generations and low levels of innovation. We found no evidence for the first prediction: Lego figures in the linguistic task are significantly simpler than in the other two domains (Fig. 2), but complexity does not change over generations. The second prediction is reflected in the results: out of the three domains, language shows the lowest innovation levels (Fig. 3). Second, for art, our predicted absence of simplification is clear from the results: we actually saw an increase in complexity over generations for art (Fig. 2); we also predicted high levels of innovation, which, again, are found in the results (Fig. 3). Thirdly, for technology, we found evidence for the predicted simplification of constructions (Fig. 2) and for selection of traits related to the function: Lego constructions in this

domain are clearly taller and narrower than those in art or language (Fig. 4).

Simplification. Our results clearly show that cultural domain has an effect on simplification. The absence of the expected simplification in language could be explained by the fact that the initial items were already at floor in terms of complexity. In the other domains, we see an interaction between simplicity and domain over generations. A bias in favour of innovation may have been sufficient to drive an increase in complexity in the art domain, whereas in the technology domain, we observe some evidence for the decrease in complexity predicted by previous work.

The floor effect in the language domain may be explained by the details of experimental design. In previous iterated learning experiments, the first participant in each chain was trained on random items. In our chains, in contrast, the first participant of each chain improvised signals in the absence of examples. These chain-initial signals already had very low levels of complexity.

Innovation. Cultural domain also modulates the rate of innovation (mutation) that takes place during transmission (Fig. 3). The high innovation level in the art condition may be explained by the perception that originality increases artistic value; selection for novelty thus affects the transmission accuracy. Low innovation in language may respond to the fact that conventional signals, which we share with our interlocutors, are more likely to be effective in the short term than innovative signals, even if these have other desirable properties.

The effects of selective pressures on fundamental evolutionary mechanisms like inheritance of or mutation are specific characteristics of cultural evolution that have no equivalent in the paradigmatic case of evolution, biology, where selection affects traits, not the mechanisms of inheritance or mutation. Our results show that the mechanisms of inheritance and mutation in culture can *adapt* to the functional domain of a tradition.

Adaptation. Domain also seems to pose selective pressures on the morphological traits of the Lego constructions. Significant increases in functional success (number of successful communicative interactions, tower height and artistic value) would have constituted evidence for adaptation: traits that increase functionality are more likely to be copied by the next generation, resulting in increased performance. We have not found such cumulative effect over time, but nevertheless there are clear differences in size and shape between the constructions across domains to indicate adaptation of the constructions to the domain-specific task. In the technology condition, the vertical dimension of the Lego stands is significantly larger in the works of art or linguistic signals (Fig. 4), a clear fit to the task of maximizing height. The art constructions are the largest in volume (even with fewer pieces than the technology ones), which we may interpret as an adaptation to creativity. As for the linguistic signals, they have the least pieces, volume, as well as horizontal and vertical dimensions. Communicative success showed a marginally significant upward trend over generations (p=0.08, Fig. 5), indicating selection for traits that adapted to the communicative task.

Object. The reported effect of object (flower, ball, coin) is also relevant to our question, because each object poses functional constraints on the Lego constructions in addition to those posed by cultural domain. Across conditions, the constructions associated with the coin had lowest complexity and innovation, those with the flower, highest complexity and innovation, with those for the ball in between in both measures. This can be explained by iconicity and size: the constructions mirrored the object size: fewest Lego bricks for coin and most for flower; the number of bricks may constrain possible innovations, with more bricks affording more changes. The analysis returned no significant interactions between object and domain for either complexity or innovation, indicating that the objects behaved similarly across domains.

Conclusion

The study reported here represents the first direct comparison of cultural evolution across cultural domains. We have found that the affordances and constraints of a linguistic, a technological and an artistic task have significant effects on the evolution of the cultural traditions, and also on key evolutionary mechanisms such as transmission fidelity and innovation. The mechanisms and pressures that operate in cultural evolution unfold differently across domain: the simplification driven by transmission is visible in the linguistic, but not in the artistic domain; and the rate of innovation is greater in art than in technology or language. This is an important step towards understanding the huge diversity of traditions found in culture. Furthermore, our study pioneers exciting possibilities of using lab techniques to test hypotheses regarding the mechanisms of cultural evolution across domains.

Acknowledgments

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