November 12, 2023

**Response to Reviewers**

*Manuscript RSOS-230650*

Editorial Office

Royal Society Publishing

Dear Editor,

Attached please find our revised manuscript, “Prestige bias in cultural evolutionary dynamics”. We have made several changes to the manuscript in response to the reviewers’ comments, which we believe improve the manuscript. Details of the changes appear below, with our responses in blue. In addition, we attach a version of the revised manuscript with colored changed (red for deletions, blue for additions).

We thank reviewers for their comments and hope you find our response satisfactory.

Sincerely,

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**Reviewer #1:**

This paper investigates the evolutionary dynamics of prestige bias by modeling it as an additive combination of “influence bias” and “success bias”. Both continuous and dichotomous cases are discussed. I like the gist of the paper, and I think rigorous, formal analysis of the evolutionary dynamics of prestige bias is urgently needed in the cultural evolution literature.

We are glad you liked our paper.

While I don’t feel competent enough to examine the mathematical details (the editor should therefore rely on other reviewers), I do have a few larger, conceptual comments that the authors may find helpful.

Major comments:

1) My first substantive comment concerns the definition of “prestige bias”. This is important because there’s quite a bit of confusion in the literature regarding how this term is used, which creates problems in not only how theories are constructed but also “prestige” itself gets operationalized and tested. Jimenez & Mesoudi (2019) provide some general comments on the current state of affairs (see Chellappoo (2021) for a philosophical critique of the concept of prestige itself), and I think these issues should be more explicitly acknowledged in the paper.

The authors make frequent reference to Boyd and Richerson 1988 book, which is fine, but notice that “prestige” was used rather casually and not explicitly formulated as a theoretical concept, To my knowledge “prestige” was first elevated to a “bias” status in Henrich & Gil-White (2001), and much subsequent scholarly discussion around “prestige bias” has been based on that 2001 paper. Given this reality, I really think it would make more sense to take Henrich & Gil-White’s 2001 paper as central. My suggestion is therefore to call “influence” (as defined by the authors) “prestige”, and G\_i,j in equation (10) would be the joint contribution of success and prestige as some proxy of copying probability. This formulation would have the advantage of defining prestige in a narrow yet clear manner, and make it easier to analyze the interaction of different biases in human decision-making. This change would not affect the model itself, only how it’s described and the discussions.

Thank you for the suggestion! We now center the definition of the biases around Henrich & Gil-White 2001. Thus, we have changed throughout the manuscript “influence” to “prestige” for the effect of number of copiers or clientele size, and “prestige” to “influence” for the joint contribution to the probability that an individual will be chosen as a model. We cite Henrich & Gil-White 2001, Henrich and Broesch 2011, Chudek et al 2012, and Jimenez & Mesoudi 2019 for these definitions, and refer to Chellappoo 2021 for criticism of the definition.

The main changes are in two paragraphs of the introduction: in line XXX,

“Jimenez and Mesoudi [1] also note that a way to acquire adaptive social information is by preferentially copying competent individuals within a valuable domain (which they also call success bias). However, they claim that competence within a domain is often difficult or impossible to directly asses, and therefore people tend to use indirect cues of success. Henrich and Broesch [26] have also suggested that direct assessment of success may be “noisy, unreliable or unavailable” and therefore copiers should also take into account indirect measures of perceived success (e.g., “great fishermen may be chosen as role-models for growing yams”.)”

and in line XXX,

“Henrich and Gil-White [28] noted that “the most skilled/knowledgeable role-models will, on average, end up with the biggest and most lavish clienteles, so the size and lavishness of a given model’s clientele size (the prestige) provides a convenient and reliable proxy for that person’s information quality”. Therefore, they predicted that skilled individuals have higher status, that people preferentially copy high-status individuals, and therefore that prestigious individuals may be influential even beyond their domain of expertise. They defined prestige as “freely conferred deference”, in contrast to dominance, and provided examples from the anthropological literature [28]. Similarly, the New Oxford American Dictionary defines prestige as the “widespread respect and admiration felt for someone or something on the basis of a perception of their achievements or quality”. Chudek et al. [32] have also defined prestige bias as “a tendency to learn from individuals to whom others have preferentially attended, learned or deferred” and demonstrated its occurrence in in 3-4 year old children. Henrich and Broesch [26] have further suggested that prestige bias can, over generations, lead to cultural adaptations, and that although prestige can lead to maladaptive traits spreading in the population, it can also accelerate the spread of adaptive traits.”

as well as in the discussion, in line XXX:

“Some cultural traits or cultural role-models may be copied more often than others due to transmission biases. One such bias is success bias, in which copiers are more likely to copy a successful role-model. It has been suggested that because it is hard to estimate success, a more common bias is a bias towards role-models perceived to be successful. This perceived success can be determined by performance with respect to another trait, i.e., indirect success [7, 26], or by “the amount of voluntary deference and attention received by models” [1], i.e., prestige [28, 32] (but see Chellappoo [2] for a critical examination of the concept of prestige).”

2) My other comment is on better situating this work within the larger literature. Based on my first comment, if we treat the models in the paper as modeling the evolutionary dynamics of multiple learning biases, then it would make sense to reference how this has been done in previous work. Hong (2022), for example, models how conformist and payoff bias may be additively combined in influencing social learning. In reality, many different biases may collectively contribute to social learning and this may be done in different ways: in addition to the additive model, learning decisions can be determined in a step-wise manner (Enquist et al., 2007). The authors alluded to this in the discussion, but I think the relationship between the present modeling choices and previous approaches should be made more explicit and perhaps appear earlier in the paper.

We now include a paragraph in the discussion on previous studies that combine success-bias with different context-biases, including references to Hong 2022, Enquist et al., 2007, Denton et al. 2022, and Ammar et al. 2023 (line XXX):

“Others have analyzed models with interactions between different transmission biases. Hong [59] studied a model with both conformity and success bias (which he calls ‘payoff bias’). He showed that an intermediate level of conformity bias–not too little but not too much–can be adaptive and evolve to prevent invasion of low-success traits while allowing the invasion of high-success traits (for another example of adaptive filtering, see [60]). Similar to our model (eq. (10)), Hong [59] also additively combined the two transmission biases (his eq. 1). However, transmission biases can be combined in many ways. For example, Denton et al. [37] combined frequency-dependent bias and genetically determined content bias multiplicatively (their eq. 1). Ammar et al. [61] studied a model in which individuals have a repertoire of cultural variants to choose from, and both variant choice and transmission via social learning are success-biased. Moreover, they also included the possibility to ‘forget’ infrequently used variants; therefore, because usage is success-biased, memory is also success-biased. It remains to be seen how different assumptions on the mechanisms of learning and forgetting affect the evolutionary dynamics under different and interacting transmission biases.”

3) The adaptive success-bias weight is in my opinion the most interesting part of the paper, and in my opinion could benefit from a bit more clarification.

Sorry for the confusion. By “adaptive” we meant that each individual choses a success-bias weight that minimizes the difference between the optimal trait value A-hat and the expected chosen trait value. To avoid confusion, we now changed “adaptive success-bias weight” to “Optimal success-bias weight” in the relevant sub-section (line XXX) and in Figure 3.

First, equation (24) needs more explication. In evolution, “adaptive” typically means fitness maximizing, and the authors should specify how this argmin term relates to fitness in more detail.

Formally, in our model there is no natural selection and hence no “fitness” per se. Indeed, if the trait value would have been correlated with fitness, the optimal success-bias weight would increase fitness. We added a statement to clarify this line XXX:

“Indeed, if the trait value is correlated with fitness, the optimal success-bias weight would increase the fitness of individuals. However, here we ignore the effects of natural selection, focusing instead on selectively neutral traits.”

Second, my reading of Figure 3 is that both panel A and B shows change within one generation (and because of this I wouldn’t call such change evolutionary). I was expecting some analyses of evolutionary dynamics of this weight in the form of long-term (over many generations) evolutionary trajectories. I don’t how much extra coding this would require, but it certainly seems a worthwhile effort.

We agree that the kind of change within one generation shown in Fig. 3 cannot be called “evolutionary change”, and we made sure that we did not call it “evolutionary change”. We revised the caption of Fig. 3 to highlight this to prevent confusion:

“Both success-bias weight 𝛼 (A) and estimation error (B) decrease during the role-model choosing process (within a single generation), demonstrating that influence becomes more favored by copiers as more copiers have made their choice.”

Minor comments:

Line 402: “...includes both indirect success and influence biases, where the latter is a bias towards role-models with many copiers and hence is the same as conformity bias.” Influence bias as the authors define it is not the same as conformity bias. They are similar with important qualifications.

We are sorry for the confusion. We now removed “and hence is the same as conformity bias” (line XXX).

The paragraph that starts from line 459. This seems to me a casual use of the term “prestige” not to be confused with the more technical use here. Authors should at least point out that such use of “prestige” differs from how prestige is modelled in the paper.

You are correct. We decided to completely remove the paragraph.

Typo:  
Line 56: Heinrich and Broesch... Line 99: The copier than copies...

Fixed.

**Reviewer #2:**

Strategies concerning from whom to learn are termed “model biases” and include skill bias, success bias and prestige bias. The manuscript “Prestige bias in cultural evolutionary dynamics” uses a model that is a combination of within- and between- generation cultural dynamics to investigate the effect of prestige bias on cultural evolutionary dynamics. The authors derive mathematical frameworks and approximations for the evolutionary processes discussed here and use these approximations, together with simulation results to study probabilities and times to fixation for new traits entering the population.

Specifically, the authors define prestige bias as indirect success bias plus conformity bias,

Our model includes success bias plus prestige bias, not conformity bias. This misunderstanding might be due to our mistake in writing “and hence is the same as conformity bias” (line 401), which we now removed.

and through mathematical approximation they show that this model is approximately equivalent to a Wright Fisher model in which indirect success is captured through effective selection and influence bias is captured through effective population size. This means indirect success is analogous to constant natural selection and effective selection is analogous to genetic drift.

Main comments:

At a big picture level, the novelty and significance of the paper is hard to understand. Mostly because the authors use a variety of different models (constant or variable, constant or variable ‘environment’) and the differences and significance of each of these modeling choices is not discussed or really thoroughly compared to previous work.

For example, the authors introduce the concept of ‘influence’ bias, but then state, in line 405, that influence bias is equivalent to conformity bias - not sure if this is true. If this is indeed true, why introduce a whole other term/ concept which can only confuse the reader?

Thank you for pointing this out. We have removed the mistaken statement that “hence is the same as conformity bias” (line XXX), as conformity bias is not the same as prestige bias.

On line 440, the authors claim ‘their prestige is similar to our influence bias’, but really to me it seems that the paper defines prestige bias as a combination of indirect success and conformity bias. A thorough rewrite and clarity on the definitions (that the authors themselves use) of the biases discussed, as well as how they are all different from each other (for the purpose of this model) would greatly improve the paper. These contradictory claims make it difficult for the reader to ultimately understand the paper.

Thank you again for pointing out the confusion that our statements have caused. Following your comments and additional input from reviewer #1, we now center the definition of the biases around Henrich & Gil-White 2001. Thus, we have changed throughout the manuscript “influence” to “prestige” for the effect of number of copiers or clientele size, and “prestige” to “influence” for the joint contribution to the probability that an individual will be chosen as a model. The main changes are in two paragraphs of the introduction: in line XXX,

“Jimenez and Mesoudi [1] also note that a way to acquire adaptive social information is by preferentially copying competent individuals within a valuable domain (which they also call success bias). However, they claim that competence within a domain is often difficult or impossible to directly asses, and therefore people tend to use indirect cues of success. Henrich and Broesch [26] have also suggested that direct assessment of success may be “noisy, unreliable or unavailable” and therefore copiers should also take into account indirect measures of perceived success (e.g., “great fishermen may be chosen as role-models for growing yams”.)”

and in line XXX,

“Henrich and Gil-White [28] noted that “the most skilled/knowledgeable role-models will, on average, end up with the biggest and most lavish clienteles, so the size and lavishness of a given model’s clientele size (the prestige) provides a convenient and reliable proxy for that person’s information quality”. Therefore, they predicted that skilled individuals have higher status, that people preferentially copy high-status individuals, and therefore that prestigious individuals may be influential even beyond their domain of expertise. They defined prestige as “freely conferred deference”, in contrast to dominance, and provided examples from the anthropological literature [28]. Similarly, the New Oxford American Dictionary defines prestige as the “widespread respect and admiration felt for someone or something on the basis of a perception of their achievements or quality”. Chudek et al. [32] have also defined prestige bias as “a tendency to learn from individuals to whom others have preferentially attended, learned or deferred” and demonstrated its occurrence in in 3-4 year old children. Henrich and Broesch [26] have further suggested that prestige bias can, over generations, lead to cultural adaptations, and that although prestige can lead to maladaptive traits spreading in the population, it can also accelerate the spread of adaptive traits.”

as well as in the discussion, in line XXX:

“Some cultural traits or cultural role-models may be copied more often than others due to transmission biases. One such bias is success bias, in which copiers are more likely to copy a successful role-model. It has been suggested that because it is hard to estimate success, a more common bias is a bias towards role-models perceived to be successful. This perceived success can be determined by performance with respect to another trait, i.e., indirect success [7, 26], or by “the amount of voluntary deference and attention received by models” [1], i.e., prestige [28, 32] (but see Chellappoo [2] for a critical examination of the concept of prestige).”

It would be worthwhile to give a summary of the 3 different models used (in the introduction section maybe)

We now summarize the models in the first paragraph of the Models section (line XXX):

“We begin with a continuous-trait model with indirect success bias, previously suggested by Boyd and Richerson [7]. Note that the indirect success bias is due to an indirect evaluation, in which a certain phenotype is used to evaluate the success of potential role-models. We extend this model to include prestige bias and then develop a version of the model with a dichotomous trait to facilitate mathematical analysis.”

We have also made some smaller changes to be more explicit about the different models; in the Results (line XXX):

“After finding these approximations for the role-model choice process, we focus on the dichotomous-trait model, in which mathematical analysis is simpler, and studied the fixation probability and time in both a constant and a cyclic changing environment.”

and in the Discussion:

“We developed two cultural-evolutionary models, one with continuous and one with dichotomous trait values.” (line XXX)

“Analyzing the dichotomous-trait model using the the DMD approximation…” (line XXX)

“We also analyzed the dichotomous-trait model in a cyclic changing environment…” (line XXX)

and thoroughly discuss how the modeling choices differ from previous approaches: constant/changing environment (which, side note, is not mentioned at all until the middle of Results section, not even in the Model description sections), constant and variable alpha. What is the purpose of each, how do you compare and contrast them and what is the significance of the results presented?

Separately, currently, the discussion section, for the most part, argues for the existence of prestige bias in experimental settings and discusses previous papers, but doesn’t really discuss the results observed here. The choice to choose role models one by one versus all at the same time is also not thoroughly discussed.

We have added further discussion of our results….

Ultimately, the authors should use the Introduction section to argue for the importance to study these biases and the Discussion section to actually discuss their observed results and place them in context of previous work, as well as highlight the novel dynamics observed.

We decided to keep paragraphs that discuss previous papers on prestige (“Chudek et al. [32] report…”, “According to Henrich and Broesch [26], natural selection has favored…“, “Dunbar [31] hypothesized that larger, more complex brains…”) in the discussion rather than the introduction, as we feel they are not part of the background to understand our motivation and the models we developed, but are still interesting in a general discussion on prestige.

Moreover, the figures and the results need a point of comparison, such that the novelty and significance of the paper can be understood by the reader. What dynamics do you observe that are different from previous models? What is the specific change or mechanism that is driving these differences in the dynamics?

I found the results on lines 436 (fig 3) potentially interesting and worth more exploration, but are only studied superficially. What drives these lower values? Also, the fact that the value seems to stabilize rather quickly after a sharp decrease is not mentioned or discussed, but seems important for understanding of what might cause the observed dynamics.

The manuscript already has many results without those on the optimal success-bias weight, but we decided to add just these limited results because they were interesting (as the reviewer also suggests) and they suggest further directions to study models in which two biases interact. We think that what drives these lower values is the fact that relying on available information in the choices of others can help reduce estimation error. This is mentioned in the discussion (line xxx): “The rationale, then, is that the more information a copier has, e.g., by using others as information sources, the more informative and effective his choice can be.”

As suggested by the reviewer, we revised the text to highlight the quick decrease and stabilization of the optimal success-bias weight (line XXX):

“We find that when copiers choose their success-bias weight according to eq. (24), it quickly decreases with the number of copiers that have already chosen a role-model and then stays at what appears to be an equilibrium (Figure 3).”

Specific comments, typos, etc:

Equation 11 is wrong: Numerator needs K\_i-1.

Fixed.

Wright-Fisher mean change equation in line 307 we computed should read sx(1-x), unclear why the extra term, please double check.

Fixed, it is now sx(1-x)+o(s).

Equation 19: plugging s and Ne into the exact equation cited (eq 8 in ref 19) gives an extra factor of 2, please double check

In ref 19, Kimura assumes Ne = 2N due to “randomly mating population of size N”, and therefore there is an extra factor of 2 in Eq 8. Thus, our eq 19 remains unchanged. Note that the reference just above result 4 said “Kimura and Ohta”, this was a mistake and corrected now to “Kimura”.

Figure 1: Why does the probability of fixation increase with alpha in Fig1 but the opposite trend can be observed in Fig2? This comment falls in the general trend that the results of the model and the mechanisms driving them, their significance, implications are not discussed.

Figure 1: caption states A/A\_hat varies between 0.01 and 0.99, but x axes in C and D don't show this, very unclear how the numbers would match.

Are both Fig 2C and Fig 2D needed? 2D does not contain new information.

We have now removed panel D.

In addition, the paper contains many typos, omissions as well as confusing statements or sentences that are hard to parse. A thorough rewrite is necessary. We write a subset of the typos encountered here:

Thank you, we have gone over your subset and hopefully also fixed additional typos.

Line 98, than to then

Fixed.

Line 100 transmission models are

Fixed.

Line 124: say that you’ll describe this new distribution in what follows.

We added “We formulate this assumption in the following.”

Remove comma line 151.

Fixed.

Line 152: a simplified version of what? Of your previous model?

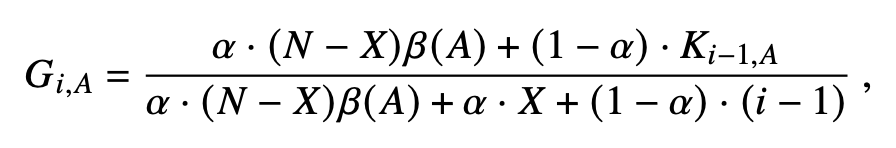
We meant a simplified version of the previous model—instead of a continuous trait, we focus on a dichotomous trait. We revised the text to “We introduce a simplified version of the above model where the trait has only two phenotypes”.

The paper keeps switching between individual-based alphas and constant alpha and it’s hard to keep track of how all the assumptions change as the various results are presented. Moreover, even though it’s introduced in line 156, alpha is technically never formally defined. See also line 174, confusing, since these don’t appear in eq 11.

Thank you for this comment. We revised the manuscript to be less confusing. The success-bias weight 𝛼 is introduced for the first time in eq. 10 (not in eq. 11), following which it is formally defined (line XXX):

“Here, the success-bias weight 𝛼𝑖,𝑗 determines the relative weighting of success and prestige bias. It is a characteristic of the interaction of role-model 𝑗 with copier 𝑖 that determines the relative significance of direct success vs. prestige in the role-model’s overall influence in the eyes of the copier. Different individuals may evaluate the importance of success and prestige differently. Additionally, we assume each role-model displays its prestige and success individually.”

Eq. 11 of the original submission used 𝛼’ instead of 𝛼. We have changed eq. 11 to use 𝛼 to avoid confusion and rearranged it to be more similar to eq. 10:



We now list the assumptions on the success-bias weight in the manuscript and the places in which those assumptions are explicitly stated:

* In the continuous model we define the success-bias weight a characteristic of the interaction of role-model j and copier i (as mentioned in line XXX).
* In the simplified dichotomous model, we assume the success-bias weight is constant and homogeneous (line XXX).
* Result 1 (which applies to both the continuous and the dichotomous models) assumes that: “the success-bias weight only depends on the role-model and not the copier, i.e., 𝛼𝑖,𝑗 = 𝛼𝑗“ (line XXX) – this was missing and is now added to the result.
* Result 2 assumes that “both the trait estimation error and the success-bias weight are constant in the population, 𝑒𝑖 =𝑒 for all 𝑖=1,...,𝑁 and 𝛼𝑖,𝑗 =𝛼 for all 𝑖,𝑗=1,...,𝑁.” (line XXX) – this was incorrect in the submitted version as it wrongly stated “𝛼𝑖,𝑗 =𝛼j”.
* The fixation probability and time section used the dichotomous-trait model, which assumes constant success-bias weight; this is now made explicit: “For simplicity, we use the dichotomous-trait model, which also assumes a constant success-bias weight 𝛼𝑖,𝑗 = 𝛼” (line XXX).
* The section of an optimal success-bias weight is now revised to be more clear and more explicit, including adding a subscript i to the sign of the optimal success-bias weight 𝛼\*ito make it more clear that it is a trait of copier i. The text that begins the section also now clearly states (line XXX):

“In results 2-6, we assumed that 𝛼 is homogeneous in the population and constant, that is, it does not depend on any specific context. Next, we examined what happens in the continuous-trait model if the 𝑖-th copier evaluates its own optimal success-bias weight, 𝛼\*𝑖”.

Line 160: Without loss of generality: not sure this is true, especially when just two phenotypes, error rates could very well change the dynamics significantly here.

We removed the remark “without loss of generality”

Line 162: which rest of the details?

We removed the remark about the rest of the details.

Line 186: confusing to say order of copiers doesn’t matter when it’s baked into the model.

We removed the remark about the order of copiers.

Line 274: The sentence that starts with that has no verb? Unclear what the meaning is.

Right, we now revised the sentence to say “We find that the number of simulations needed to sufficiently approximate our model with the DM approximation is roughly 1,000” (line XXX)

Line 302: why is this surprising?

We changed “surprising” to “interesting”.

Result 6 needs citation. Why?

The line before Result 6 does indeed give a citation to Ram et al 2018 (ref 21). It says: “Using the drift and diffusion terms and following [21], we can approximate the fixation probability in a changing environment.”

Caption Fig1: “bounded by blue”. There is no blue line in this figure.

Changed from “blue” to “dashed line”.

Overall the captions sometimes lack all the parameters necessary to understand the results:

For example Fig 2A, B: what is k, l?

We have added the values for k,l in these sub figures: “k=20, l=80 (panels A and B)” (caption of Figure 2)

That figure also needs more runs of the simulation.

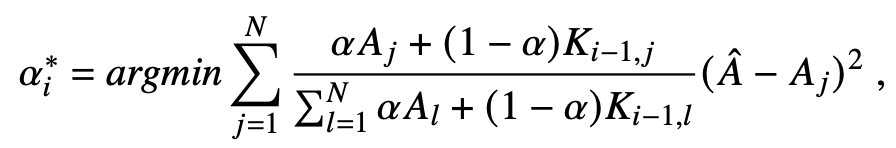
Figure S3 shows that the variance of simulation results does not decrease when using over 4,000 simulations, and we performed 10,000 in Figure 2 to be on the safe side.

Figure 3: what does copier mean on x axis? Number of copiers?

In our model, each copier chooses a role model in their “turn”. Thus, “Copier” in the x axis of Figure 3 refers to the order of copiers. We now revised the x label to be “Copier i" and the y label to be “Optimal success-bias weight, 𝛼∗i".

We also changed equation 24 to make this more clear by changing 𝛼\* to 𝛼\*i and Kj to Ki-1,j and revised the relevant paragraph (line XXX):

“In results 2-6, we assumed that 𝛼 is homogeneous in the population and constant, that is, it does not depend on any specific context. Next, we examined what happens in the continuous-trait model if the 𝑖-th copier evaluates its own optimal success-bias weight, 𝛼∗i, which minimizes the expected squared error between the chosen trait value and the optimal trait value 𝐴ˆ,



where 𝐴𝑗 is the trait of role-model 𝑗 and 𝐾𝑖−1,𝑗 is the number of copiers that already chose role-model 𝑗 by the time the 𝑖-the copier chooses a role-model. Simply put, each copier i estimates what success-bias weight 𝛼∗i will result in copying a trait that is most similar to the ideal trait value 𝐴ˆ…. We find that when copiers choose their success-bias weight according to eq. (24), it decreases with the number of copiers that have already chosen a role-model (Figure 3).”

Line 404: typo, the these

Fixed.

Line 456: what is ‘it’ here?

Changed to (line XXX): “They show that the social networks representing copier--role-model relationships are centralized, suggesting that it which is consistent with the prediction that people substantially share notions about who is a good cultural model”.

Also I would reword ‘they’ studied: The researchers studied. The authors studied…

Done.