Peer review history for:

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Middle Stone Age social connectivity: Can stone tools indicate the transmission of cultural ideas? [peer review history]. S Afr J Sci. 2025;121(11/12), Art. #21619.
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The original manuscript for review is appended below.

Reviewer 1: Round 1
Date completed: 13 June 2025
Conflicts of interest: None

Recommendation: Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments
REVIEWER: Revisions required
Does the review fall within the scope of SAJS? Yes/No
REVIEWER: Yes
Is the review written in a style suitable for a non-specialist and is it of wider than only specialist interest? Yes/No
REVIEWER: No
Do the Title and Abstract clearly and accurately reflect the content of the manuscript? Yes/No
REVIEWER: Yes
Does the review provide a significantly novel perspective or significant recent advances in the field? Yes/No
REVIEWER: Yes
Is the objective of the review concisely stated? Yes/No
REVIEWER: Yes
Is appropriate and adequate reference made to other work in the field? Yes/No
REVIEWER: No
Do current debates and points of contention receive appropriate coverage? Yes/No/Not applicable
REVIEWER: Yes
Are gaps in the literature adequately identified? Yes/No/Not applicable
REVIEWER: Not applicable
Does the review provide direction for future research? Yes/No/Not applicable
REVIEWER: Yes
Are the methodology and statistical treatment appropriate? Not applicable/Yes/No/Partly/Not qualified to judge

REVIEWER: Not applicable
Are the interpretations and recommendations aligned with the objective? Yes/Partly/No
REVIEWER: Yes
Please rate the manuscript on overall contribution to the field Excellent/Good/Average/Below average/Poor
REVIEWER: Good
Please rate the manuscript on language, grammar and tone Excellent/Good/Average/Below average/Poor
REVIEWER: Good
Is the manuscript concise and free of repetition and redundancies? Yes/No
REVIEWER: Yes
Is the supplementary material relevant and separated appropriately from the main document? Yes/No/Not applicable
REVIEWER: Not applicable
Please rate the manuscript on overall quality Excellent/Good/Average/Below average/Poor
REVIEWER: Average
If accepted, would you recommend that the article receives priority publication? Yes/No
REVIEWER: No
Are you willing to review a revision of this manuscript? Yes/No
REVIEWER: Yes
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author. Yes/No
REVIEWER: Yes
Comments to the Author: The question of how human knowledge is transmitted is of interest to any thoughtful person, so comparisons of cultural transmission versus independent invention (called convergence in this manuscript) make for a thought-provoking paper. Such a topic is suited to the Journal's readership. However, in its present form, the paper is too specialised and relies too much on the language and terminology of lithic specialists to make it intelligible and of relevance to a general scientific audience. That does not mean that the paper cannot be moulded to suit the journal and its audience and I should be delighted if the author could adapt the paper in such a way. It will take quite a lot of rewriting, though. If the author is prepared to do this, I suggest reducing the number of examples and simplifying their description so that they demonstrate the methods of knowledge transmission without trying to explain the entire Middle Stone Age (MSA) sequence. In other words, pick a few lithic examples and use only those to demonstrate the concepts. In the case of cultural transmission, perhaps choose something like the levallois technique of core preparation. The general readership doesn't know what this is, so you need to define it carefully and simply and put in an illustration that shows both the core and the end product. Then show on a map where this technology occurs and give broad dates for the occurrence of the technology. Such an approach will make your point clearly and in an interesting way for non-archaeologists (of course you could choose any example of MSA technology and not necessarily levallois). A theoretical question that could be asked as part of your discussion is whether the two methods of learning are mutually exclusive (as seems to be implied in the paper). I am inclined to think that they are not mutually exclusive. Using lithic examples, as has been done in the paper, the presence of hollow-based points at Sibhudu and Umhlatuzana implies a regional tradition of knapping that may be related to the way that the points were hafted on to their shafts or handles. Such points have not yet been found in other

southern African MSA sites, but they do occur in the Upper Palaeolithic of Russia. This is a straightforward example of convergence. Notwithstanding the manufacture of hollow-based points as an example of convergence, other lithic strategies at Sibhudu and Umhlatuzana seem to imply cultural transmission of lithic technology, like the backed tools that are found at these sites and elsewhere in the late MSA of southern Africa. On line 149, the author says: Sites like Sibhudu and Umhlatuzana produced hollow-based points, while Rose Cottage and Sehonghong had high scraper frequencies, reflecting smaller, more isolated groups. References are needed and the author needs to explain the connection between these technologies and demography. It is not self-explanatory.

If the author decides not to rework this paper for SAJS, but rather to aim for a specialised archaeological journal, I have some suggestions that could improve the manuscript before resubmission. There are some sections of the manuscript where references are required, for example:

- Starting line 143 *During MIS 5, flaking techniques varied regionally, with flake production at Blombos irregular blade production at Cape St. Blaize, and non-standardized reduction strategies at Klasies River.*
- Starting line 145 *Pointed artifacts dominated summer rainfall regions, while denticulates were more common in winter rainfall areas, suggesting social fragmentation.* Apart from citing the data sources, this statement needs explanation. Why is social fragmentation implied by the technology and its distribution? I am not arguing against the idea; I'm simply asking for an explanation.
- *In contrast, MIS 4 and 2 show widespread transmission, notably in the Still Bay and Howiesons Poort industries, where bifacial point production and radial core reduction were consistent across sites like Blombos Cave, Hollow Rock Shelter, and Sibhudu. The movement of non-local fine-grained raw materials, as seen at Diepkloof, further suggests long-distance networks.* Please add the appropriate references.
- Starting line 186 *A comparative analysis of assemblages from Howiesons Poort Shelter, Sibhudu, Klasies River, Rose Cottage, Pinnacle Point 5–6, Klipdrift Shelter, and Diepkloof revealed a consistent production template across regions, reinforcing the role of cultural transmission in shaping lithic technology.*[17] The paper cited refers only to backed technology, so the statement is rather over-reaching.
- Starting line 198 *These consistencies—such as the use of locally available raw materials, core maintenance through débordants, and standardized blank production—suggest a shared technological tradition and ongoing knowledge transmission among MIS 5 groups in the region.* Explain the technical terms and then why they imply knowledge transmission.
- Starting line 226 *Additionally, minor variations in knapping techniques, independent of environmental or technological constraints, point to cultural drift.* This also needs some explanation.

Figure 2: A Schematic illustration of cultural transmission and convergence. The caption needs more explanation because it isn't immediately obvious to an outsider what the figure is showing.

[See Appendix 1 for Reviewer 1's comments made directly on the manuscript]

Author response to Reviewer 1: Round 1

The question of how human knowledge is transmitted is of interest to any thoughtful person, so comparisons of cultural transmission versus independent invention (called convergence in this manuscript) make for a thought-provoking paper. Such a topic is suited to the Journal's readership. However, in its present form, the paper is too specialised and relies too much on the language and terminology of lithic specialists to make it intelligible and of relevance to a general scientific audience. That does not mean that the paper cannot be moulded to suit the journal and its audience, and I should be delighted if the author could adapt the paper in such a way. It will take quite a lot of rewriting, though. If the author is prepared to do this, I suggest reducing the number of examples and simplifying their description so that they demonstrate the methods of knowledge transmission without trying to explain the entire Middle Stone Age (MSA) sequence. In other words, pick a few lithic examples and use only those to demonstrate the concepts. In the case of cultural transmission, perhaps choose something like the Levallois technique of core preparation. The general readership doesn't know what this is, so you need to define it carefully and simply and put in an illustration that shows both the core and the end product. Then show on a map where this technology occurs and give broad dates for the occurrence of the technology. Such an approach will make your point clearly and in an interesting way for non-archaeologists (of course you could choose any example of MSA technology and not necessarily Levallois).

AUTHOR: We have revised the manuscript to make it more accessible to a general scientific audience for *SAJS*. Complex terms, such as the Levallois technique, are now clearly defined. Specialist terminology associated with lithic analysis (e.g., "lithic") has been replaced with more accessible terms such as "stone tool," and examples have been simplified by removing lengthy and detailed descriptions of tool types and the broader MSA sequence.

Regarding the suggestion to add a continental-scale diagram of Levallois, we feel this would distract readers from the main focus of the paper. Such a figure could unintentionally shift attention toward debates about the definition of Levallois or which sites should be classified as exhibiting Levallois technology, rather than on the central arguments about social networks that we wish to present. For this reason, we have chosen not to include it.

A theoretical question that could be asked as part of your discussion is whether the two methods of learning are mutually exclusive (as seems to be implied in the paper). I am inclined to think that they are not mutually exclusive. Using lithic examples, as has been done in the paper, the presence of hollow-based points at Sibhudu and Umhlatuzana implies a regional tradition of knapping that may be related to the way that the points were hafted on to their shafts or handles. Such points have not yet been found in other southern African MSA sites, but they do occur in the Upper Palaeolithic of Russia. This is a straightforward example of convergence. Notwithstanding the manufacture of hollow-based points as an example of convergence, other lithic strategies at Sibhudu and Umhlatuzana seem to imply cultural transmission of lithic technology, like the backed tools that are found at these sites and elsewhere in the late MSA of southern Africa. On line 149, the author says: Sites like Sibhudu and Umhlatuzana produced hollow-based points, while Rose Cottage and Sehonghong had high scraper frequencies, reflecting smaller, more isolated groups. References are needed and the author needs to explain the connection between these technologies and demography. It is not self-explanatory.

AUTHOR: We agree that convergent evolution and cultural transmission are not mutually exclusive, and the revised manuscript clarifies this distinction. In response to the reviewer's comment, we have explicitly highlighted that Hollow-based points at Sibhudu and Umhlatuzana can be seen as examples of convergent evolution, as they also appear in Paleolithic sites. We also emphasize that backed tools at these sites reflect cultural transmission, illustrating knowledge sharing both locally and across southern Africa. Furthermore, we clarified that high frequencies of scraping tools at Rose Cottage and Sehonghong may indicate smaller, more isolated groups; however, in the absence of demographic studies, we note, following Mackay (2014), that directly linking these patterns to population size is challenging due to multiple interacting variables.

If the author decides not to rework this paper for SAJS, but rather to aim for a specialised archaeological journal, I have some suggestions that could improve the manuscript before resubmission. There are some sections of the manuscript where references are required, for example: Starting line 143 *During MIS 5, flaking techniques varied regionally, with flake production at Blombos, irregular blade production at Cape St. Blaize, and non-standardized reduction strategies at Klasies River.*

AUTHOR: In the revised manuscript, we have consolidated and simplified the discussion of site-specific flaking techniques. For example, the original text detailing irregular blade production at Cape St. Blaize and non-standardized reduction strategies at Klasies River has been replaced with a more concise statement: *"During Marine Isotope Stage (MIS) 5, sites such as Blombos, Cape St. Blaize, and Klasies River show regional differences in toolmaking, reflecting local adaptation and limited interaction."*

This statement highlights the main patterns using a few key sites, rather than an exhaustive list of technical details, showing simplicity beyond detailed lithic studies. We have deliberately reduced the number of examples to improve clarity and readability for a broader audience. To support this summary without overloading the reference list, and in light of SAJS word limits, we cite Mackay et al., (2014), which synthesizes the relevant site-specific research in the context of coalescence and fragmentation.

Starting line 145 *Pointed artifacts dominated summer rainfall regions, while denticulates were more common in winter rainfall areas, suggesting social fragmentation.* Apart from citing the data sources, this statement needs explanation. Why is social fragmentation implied by the technology and its distribution? I am not arguing against the idea; I'm simply asking for an explanation.
AUTHOR: In the revised manuscript, the statement regarding the distribution of pointed artifacts and denticulates has been removed. This was done to simplify the discussion for a broader SAJS readership and to avoid overloading the text with technical lithic detail, while still retaining the key patterns and interpretations relevant to knowledge sharing and social networks.
In contrast, MIS 4 and 2 show widespread transmission, notably in the Still Bay and Howiesons Poort industries, where bifacial point production and radial core reduction were consistent across sites like Blombos Cave, Hollow Rock Shelter, and Sibhudu. The movement of non-local fine-grained raw materials, as seen at Diepkloof, further suggests long-distance networks. Please add the appropriate references.
AUTHOR: In the revised, consolidated manuscript, the detailed discussion of MIS 4 and 2 technologies, including Still Bay and Howiesons Poort bifacial point production, radial core reduction, and the movement of non-local raw materials, has been removed. This was done to simplify the text for a broader SAJS readership and to keep the manuscript within word and reference limits. Instead, we cite Mackay et al. (2014), which provides a comprehensive summary of these patterns, ensuring that key points about technological transmission are retained in a concise form.
Starting line 186 *A comparative analysis of assemblages from Howiesons Poort Shelter, Sibhudu, Klasies River, Rose Cottage, Pinnacle Point 5–6, Klipdrift Shelter, and Diepkloof revealed a consistent production template across regions, reinforcing the role of cultural transmission in shaping lithic technology.*[17] The paper cited refers only to backed technology, so the statement is rather over-reaching.
AUTHOR: We were referring to backed technology; hence, the cited paper Way et al. (2022) on backed tools. This has been corrected in the new, simplified version.
Starting line 198 *These consistencies—such as the use of locally available raw materials, core maintenance through débordants, and standardized blank production—suggest a shared technological tradition and ongoing knowledge transmission among MIS 5 groups in the region.* Explain the technical terms and then why they imply knowledge transmission. Starting line 226 *Additionally, minor variations in knapping techniques, independent of environmental or technological constraints, point to cultural drift.* This also needs some explanation.
AUTHOR: In the revised SAJS version, detailed references to specific technical practices, such as core maintenance through débordants, standardized blank production, and minor variations in knapping techniques, have been removed, along with phrases suggesting that these practices implied shared knowledge transmission and cultural drift, to improve accessibility for a broader readership and to remain within the journal's word limits.
Figure 2: A Schematic illustration of cultural transmission and convergence. The caption needs more explanation because it isn't immediately obvious to an outsider what the figure is showing.
AUTHOR: The caption for Figure 2 has been expanded to provide clearer explanation for a general audience.

Reviewer 2: Round 1 **Date completed:** 12 June 2025 **Conflicts of interest:** None
Recommendation: Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments
REVIEWER: Resubmit for review
Does the review fall within the scope of SAJS? Yes/No
REVIEWER: Yes
Is the review written in a style suitable for a non-specialist and is it of wider than only specialist interest? Yes/No

REVIEWER: Yes
Do the Title and Abstract clearly and accurately reflect the content of the manuscript? Yes/No
REVIEWER: Yes
Does the review provide a significantly novel perspective or significant recent advances in the field? Yes/No
REVIEWER: No
Is the objective of the review concisely stated? Yes/No
REVIEWER: Yes
Is appropriate and adequate reference made to other work in the field? Yes/No
REVIEWER: Yes
Do current debates and points of contention receive appropriate coverage? Yes/No/Not applicable
REVIEWER: Yes
Are gaps in the literature adequately identified? Yes/No/Not applicable
REVIEWER: No
Does the review provide direction for future research? Yes/No/Not applicable
REVIEWER: No
Are the methodology and statistical treatment appropriate? Not applicable/Yes/No/Partly/Not qualified to judge
REVIEWER: Not applicable
Are the interpretations and recommendations aligned with the objective? Yes/Partly/No
REVIEWER: Yes
Please rate the manuscript on overall contribution to the field Excellent/Good/Average/Below average/Poor
REVIEWER: Good
Please rate the manuscript on language, grammar and tone Excellent/Good/Average/Below average/Poor
REVIEWER: Excellent
Is the manuscript concise and free of repetition and redundancies? Yes/No
REVIEWER: No
Is the supplementary material relevant and separated appropriately from the main document? Yes/No/Not applicable
REVIEWER: Not applicable
Please rate the manuscript on overall quality Excellent/Good/Average/Below average/Poor
REVIEWER: Good
If accepted, would you recommend that the article receives priority publication? Yes/No
REVIEWER: No
Are you willing to review a revision of this manuscript? Yes/No
REVIEWER: Yes
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published

article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

REVIEWER: Yes

Comments to the Author:
This review article provides a general overview of the potential and pitfalls of using stone tools for tracing cultural transmission and social connectivity in the Middle Stone Age (MSA). Considering that this is the period of the emergence of Homo sapiens, that lithic artefacts constitute the most important and frequent archaeological evidence of this time, and that the South African MSA plays a key role in these debates, the article's topic and broad significance makes it in general a good fit for the South African Journal of Science.

The article is very well-written and easy to follow due to its good structure. I appreciated the figures and tables within this review article, which help summarise and visualise some of the main points. In general, the article is well-referenced except for a couple of more specific topics (see below). Regarding the review character of the article and the broad readership of SAJS, there is a good mix of generalising statements and concrete examples that necessarily gloss over some details. I also appreciated the introduction of novel ideas to social connectedness and the discussion of what drives it, which goes beyond mere environmental drivers.

There are some points of criticism, however, that I'd like to see the authors engage with that could further improve the article. Only few of them are major points that have to be clarified before the paper can be published, with more minor comments that the authors may or may not wish to follow (also depending on other considerations such as word length or how specific the information in a review article for SAJS ought to be from editorial side as well). I'd be happy to review a revised version of the manuscript again.

Major points

- The authors rightfully discuss that similarities in stone tools can not only arise through social transmission but also by independent innovation (convergence). I really appreciate the critical discussion between these two processes in the article and only have minor points to add to this (see below). That being said, there are actually three processes that can lead to similarities in stone tools across time and space: diffusion, convergence and migration/dispersal. The omission of dispersals is interesting as many recent papers on stone tools and convergence have hinged on some kind of dispersal paradigm (e.g. Nubian cores and out of Africa expansions). But it is relevant since, once we can identify the transmission of information of cultural ideas, the question arises whether this stems from diffusion (which the authors would likely put under social connectivity) or migration. While both diffusion and migration entail information transmission, they are not exactly the same process, with one operating as sharing of knowledge between groups (and so leading to the spread of certain stone tools), whereas the other involves a physical relocation of groups that transmit knowledge of making such stone tools among them. On top, diffusion often involves product copying and thus the adoption of simpler assemblage elements, whereas migrations entail more process copying with high-fidelity transmission of more complex and multi-step systems (e.g. core reduction methods as part of information transmission within the migrating population (e.g. Eren et al. 2011; Nigst 2012; Tostevin 2012). These may sound like nuances, but for a review paper tackling a "big topic" this should be clarified. Also, this can add to the discussion on how we identify "social connectivity" (which would be some kind of diffusion process). The cited paper by Will & Mackay (2020) has a detailed recent discussion about it, but there are also plenty of other references on it.
- Social connectivity. Somehow, the article never gets around to a more detailed definition of this term and what it entails. It is an umbrella term for all kinds of underlying processes with more or less the same meaning - but a fancier, recent name - than diffusion (my reading of the situation, not what the authors insinuate). The nature and duration of connections between groups of hunter-gatherers can be quite varied, from exchange, trade, warfare etc. Again, some of the similarities seen in the record of the MSA of (southern) Africa might have less to do with social connectivity but with mobile hunter-gatherer bands moving around the landscapes. In sum, fleshing out this concept a little bit – and adding the diffusion/migration discussions from above to this – will go a long way toward

demystifying the use of “social connectivity” here. There are also some great papers on showing social connectivity based on ostrich eggshell beads in South Africa (but also eastern Africa) that should be mentioned in this context (Stewart et al. 2020; Miller & Wang 2022). As it stands, the paper reads as if “social connectivity = cultural transmission” e.g. lines 52-54), and while this may not be intended, it is too simple and not correct.

- For a review paper, I was missing some new ideas and impetus for future research/methods into the topics of cultural transmission and social connectivity. The article does an excellent job of reviewing current methods and approaches, but does not really show (new) ways on how we will do better, particularly for differentiating between transmission and convergence. In a similar vein, the paper is great in listing important dimensions of driving social connectedness in humans, but does not say how we would use the archaeological record to study these various dimensions. Papers like the one by Stewart et al. (2020) or Miller & Wang (2022) might be worth to look at here. The “Synthesis and Discussion” & Conclusion could be compressed and merged – there is quite some repetition with the foregoing sections – and such “new methods/avenues of research” introduced and briefly discussed.

<u>Minor points</u>

- The paper is generally well referenced for the archaeology part, but not so for the cultural transmission/learning part. The authors are likely aware that there is a heavy debate at the moment in the field on how to identify (various) learning mechanisms and when they first appear in the archaeological record. The (critical) work by Claudio Tennie comes to mind (see e.g. Tennie et al. 2017), but also others. Throwaway sentences such as “Some of the earliest stone tools indicate that the ability to pass down knowledge through imitation has deep evolutionary roots dating back to the Plio-Pleistocene” (line 36-37) have been contradicted by some research (e.g. Snyder et al. 2022). In addition, the discussion on “biases” of cultural transmission (lines 68-71) could benefit from at least adding some of the vast recent expert literature on the topic and some expansion of this whole paragraph (there are more biases and learning processes than mentioned here).
- There is a great recent study on different modes of cultural transmission throughout the Paleolithic and Stone Age by Colage & d’Errico (a couple of days ago, so the authors couldn’t have known about it) that just came out and is highly relevant to this paper. I suggest the authors incorporate their insights into cultural transmission and results as they relate to the Middle Stone (Colage & d’Errico 2025).
- Tostevin’s BACT method is well-described and probably still the gold standard for lithic analysis that tries to identify cultural transmission, although it is not without its faults. The authors describe the experimental and low-level theory of this approach well. What I was missing in the description of the method, however, was the innovative theoretical frame (e.g., taskscape visibility and social intimacy etc.) which provides the “high-theory” part of it (Tostevin 2012, pages 23-93) and what makes this middle-range theory truly convincing as it builds bridges from both sides. They only mention this as “theoretical cultural frameworks” (lines 86-87), but some more detail on how this is exactly done and what is meant by this is relevant in the scope of this article.
- Lines 116-117: Funny enough, the origins of the Levallois method are now seen as a classic example of a case of convergence when viewed from a global scale. How does this fit with Levallois being a classic example of cultural transmission here? Can it be both? (I guess so, but depending on analytical scale!).
- Line 149: There is a more recent study on hollow-based points in the final MSA and how it relates to groups/social transmission that could be checked and cited (Bader et al. 2022).
- Lines 231-237: I found these “examples” for cultural transmission not convincing at all. Is it reasonable to assume 140,000 years of stable cultural transmission within this region? Might it not rather be that we lack a continuous record here? Independent innovation of similar technologies in similar environments over very large time-scales (>100000 years) is the much more likely option. In general, here and with the previous examples of potential cultural transmission, there is a bit of a lack of critical engagement with the published results of the studies. Some are more convincing than others to show cultural transmission, and this should be reflected in a (critical) review!
- How to identify convergence. The paper generally does a good job of describing some of the

difficulties in differentiating transmission vs. convergence and its factors. Overall, it is clear that this is not an easy task and is definitely scale-dependent. Some factors make it more likely, though not all are cited in the manuscript and might be added: lithics that (i) are less complex; (ii) are similar across fewer dimensions; (iii) are found further apart in space and time; (iv) derive from historically similar technological systems and ecological contexts; and, (v) occur in assemblages with few other similar objects.

- The classic example to cite in the cultural transmission versus convergence section for a paper dealing with the (Southern) African MSA would be Nubian cores (instead of blades). The papers by Hallinan & Shaw (2020; plus more recent work by Hallinan on the topic) and Will et al. (2015) provide clear and straightforward examples.
- The "Synthesis and discussion" section misses references in some paragraphs (e.g. lines 360-364; lines 366-371, lines 391-398)
- Lines 373-379: This part felt odd and misplaced in the current paper. It is also a caricature regarding defined technocomplexes: Obviously, the Howiesons Poort is defined by similarities in many domains of lithic techno-typology and is likely to stem from cultural transmission within and between groups (as the paper says itself). This is what cultural-historical units (stripped of the ethnical baggage from the early 20th century) are used for: heuristic devices of abstraction and classification to bundle together different assemblages in one entity. Sure, one loses detail and variability, but this is the nature of abstraction and classification that is also required for communication in scientific disciplines (the authors themselves use these classificatory units, such as the Howiesons Poort in the paper). Calling this outdated without proper engagement of what these units ought to do (and what not) is too simple an argument for this otherwise well-argued review. Interestingly enough, in theoretical circles, the convergence between more recent ideas of cultural transmission theory and culture-historical archaeology has been mentioned and discussed in a much more positive and constructive way by people like Ian Hodder and others (this goes beyond the scope of the paper, though). Either engage more seriously and constructively with the topic of technocomplexes and their (mis)uses (there is also some "positive" recent literature on the topic that is not cited here), or remove this part and focus on other topics that are closer to the central topic of this article.
- Line 380: How should the complexity of artefacts be assessed? There are many competing measurements (techno-units, procedural units, Petri nets) etc. If the authors think we should go in this way, then please also spell out the methodical details.
- Line 393: I agree with the authors here, but other factors such as demography and the characteristics of the artefacts themselves should be added here.

<u>References</u>

- Bader, G. D., Sommer, C., Conard, N. J., & Wadley, L. (2022). The final MSA of eastern South Africa: a comparative study between Umbeli Belli and Sibhudu. Azania: Archaeological Research in Africa, 57(2), 197-238.
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- Stewart, B. A., Zhao, Y., Mitchell, P. J., Dewar, G., Gleason, J. D., & Blum, J. D. (2020). Ostrich eggshell bead strontium isotopes reveal persistent macroscale social networking across late Quaternary southern Africa. Proceedings of the National Academy of Sciences, 117(12), 6453-6462.
- Tennie, C., Premo, L. S., Braun, D. R., & McPherron, S. P. (2017). Early stone tools and cultural

transmission: Resetting the null hypothesis. Current Anthropology, 58(5), 652-672.

- Will, M., Mackay, A., & Phillips, N. (2015). Implications of Nubian-like core reduction systems in southern Africa for the identification of early modern human dispersals. PLoS One, 10(6), e0131824.

Author response to Reviewer 2: Round 1

The authors rightfully discuss that similarities in stone tools cannot only arise through social transmission but also by independent innovation (convergence). I really appreciate the critical discussion between these two processes in the article and only have minor points to add to this (see below). That being said, there are actually three processes that can lead to similarities in stone tools across time and space: diffusion, convergence and migration/dispersal. The omission of dispersals is interesting as many recent papers on stone tools and convergence have hinged on some kind of dispersal paradigm (e.g. Nubian cores and out of Africa expansions). But it is relevant since, once we can identify the transmission of information of cultural ideas, the question arises whether this stems from diffusion (which the authors would likely put under social connectivity) or migration. While both diffusion and migration entail information transmission, they are not exactly the same process, with one operating as sharing of knowledge between groups (and so leading to the spread of certain stone tools), whereas the other involves a physical relocation of groups that transmit knowledge of making such stone tools among them. On top, diffusion often involves product copying and thus the adoption of simpler assemblage elements, whereas migrations entail more process copying with high-fidelity transmission of more complex and multi-step systems (e.g. core reduction methods as part of information transmission within the migrating population (e.g. Eren et al. 2011; Nigst 2012; Tostevin 2012). These may sound like nuances, but for a review paper tackling a "big topic" this should be clarified. Also, this can add to the discussion on how we identify "social connectivity" (which would be some kind of diffusion process). The cited paper by Will & Mackay (2020) has a detailed recent discussion about it, but there are also plenty of other references on it.

AUTHOR: In the revised manuscript, we have added a brief description of all three processes in the Introduction and a more detailed discussion in the Stone Tools and Convergence section, including how each can lead to similarities in stone tools. We have also incorporated the references suggested by the reviewer. Due to journal word limits, we could not include additional references beyond those, but we believe the discussion now clearly addresses the distinctions between diffusion, migration, and convergence.

Social connectivity. Somehow, the article never gets around to a more detailed definition of this term and what it entails. It is an umbrella term for all kinds of underlying processes with more or less the same meaning - but a fancier, recent name - than diffusion (my reading of the situation, not what the authors insinuate). The nature and duration of connections between groups of hunter-gatherers can be quite varied, from exchange, trade, warfare etc. Again, some of the similarities seen in the record of the MSA of (southern) Africa might have less to do with social connectivity but with mobile hunter-gatherer bands moving around the landscapes. In sum, fleshing out this concept a little bit – and adding the diffusion/migration discussions from above to this – will go a long way toward demystifying the use of "social connectivity" here. There are also some great papers on showing social connectivity based on ostrich eggshell beads in South Africa (but also eastern Africa) that should be mentioned in this context (Stewart et al. 2020; Miller & Wang 2022). As it stands, the paper reads as if "social connectivity = cultural transmission" e.g. lines 52-54), and while this may not be intended, it is too simple and not correct.

AUTHOR: In the first paragraph, the text was rewritten in line with Reviewer One's suggestion to simplify the manuscript for a broader audience beyond lithic studies and archaeology. This paragraph includes a section where social connections and networks are clearly defined and referenced. The suggested references on social networks have been added.

For a review paper, I was missing some new ideas and impetus for future research/methods into the topics of cultural transmission and social connectivity. The article does an excellent job of reviewing current methods and approaches but does not really show (new) ways on how we will do better, particularly for differentiating between transmission and convergence. In a similar vein, the paper is great in listing important dimensions of driving social connectedness in humans but does not say how we would use the archaeological record to study these various dimensions. Papers like the one by Stewart et al. (2020) or

Miller & Wang (2022) might be worth to look at here. The “Synthesis and Discussion” & Conclusion could be compressed and merged – there is quite some repetition with the foregoing sections – and such “new methods/avenues of research” introduced and briefly discussed.
AUTHOR: The discussion section has been rewritten to introduce new avenues for research, including methods to differentiate cultural transmission from convergence, using the archaeological record beyond lithic artefacts, and integrating experimental approaches. In addition, also incorporating direct evidence of symbolic and social exchange, such as beads and ornaments, to investigate different drivers of connectivity. Redundancy has been reduced, and the suggested references have been added.
The paper is generally well referenced for the archaeology part, but not so for the cultural transmission/learning part. The authors are likely aware that there is a heavy debate at the moment in the field on how to identify (various) learning mechanisms and when they first appear in the archaeological record. The (critical) work by Claudio Tennie comes to mind (see e.g. Tennie et al. 2017), but also others. Throwaway sentences such as “Some of the earliest stone tools indicate that the ability to pass down knowledge through imitation has deep evolutionary roots dating back to the Plio-Pleistocene” (line 36-37) have been contradicted by some research (e.g. Snyder et al. 2022). In addition, the discussion on “biases” of cultural transmission (lines 68-71) could benefit from at least adding some of the vast recent expert literature on the topic and some expansion of this whole paragraph (there are more biases and learning processes than mentioned here).
AUTHOR: We thank the reviewer for the additional recent references, which have been incorporated along with the debates surrounding how to identify various learning mechanisms and when they first appear. Together with the references already included in the manuscript, such as Cavalli-Sforza’s work, this provides a more balanced coverage of cultural transmission. Sentences such as “Some of the earliest stone tools indicate that the ability to pass down knowledge through imitation has deep evolutionary roots dating back to the Plio-Pleistocene” have been removed to account for these debates. The main changes were made in the Introduction and the Stone Tools and Cultural Transmission sections, where the discussion on biases has been briefly expanded. Although we were unable to make substantial additions due to the journal’s word limit, all the key points highlighted by the reviewer have been addressed.
There is a great recent study on different modes of cultural transmission throughout the Paleolithic and Stone Age by Colage & d’Errico (a couple of days ago, so the authors couldn’t have known about it) that just came out and is highly relevant to this paper. I suggest the authors incorporate their insights into cultural transmission and results as they relate to the Middle Stone Age (Colage & d’Errico 2025).
AUTHOR: The reference has been cited and its discussion incorporated in the Introduction section.
Tostevin’s BACT method is well-described and probably still the gold standard for lithic analysis that tries to identify cultural transmission, although it is not without its faults. The authors describe the experimental and low-level theory of this approach well. What I was missing in the description of the method, however, was the innovative theoretical frame (e.g., taskscape visibility and social intimacy etc.) which provides the “high-theory” part of it (Tostevin 2012, pages 23-93) and what makes this middle-range theory truly convincing as it builds bridges from both sides. They only mention this as “theoretical cultural frameworks” (lines 86-87), but some more detail on how this is exactly done and what is meant by this is relevant in the scope of this article.
AUTHOR: We have incorporated a brief discussion of taskscape visibility and social intimacy into the paragraph, clarifying how BACT bridges experimental data and middle-range theory to track cultural transmission.
Lines 116-117: Funny enough, the origins of the Levallois method are now seen as a classic example of a case of convergence when viewed from a global scale. How does this fit with Levallois being a classic example of cultural transmission here? Can it be both? (I guess so but depending on analytical scale!).
AUTHOR: We have engaged with both bodies of literature, citing studies that interpret Levallois as evidence of cultural transmission as well as those that view it as a case of convergence. We highlight that analytical scale matters and emphasize the need for further methodological refinement, as no consensus currently exists on whether the Levallois technique reflects convergence or transmission.
Line 149: There is a more recent study on hollow-based points in the final MSA and how it relates to groups/social transmission that could be checked and cited (Bader et al. 2022).
AUTHOR: The reference (Bader et al. 2022) has been added and cited in the manuscript.

Lines 231-237: I found these "examples" for cultural transmission not convincing at all. Is it reasonable to assume 140,000 years of stable cultural transmission within this region? Might it not rather be that we lack a continuous record here? Independent innovation of similar technologies in similar environments over very large time-scales (>100000 years) is the much more likely option. In general, here and with the previous examples of potential cultural transmission, there is a bit of a lack of critical engagement with the published results of the studies. Some are more convincing than others to show cultural transmission, and this should be reflected in a (critical) review!
AUTHOR: This section has been largely rewritten in response to Reviewer One's major comment to simplify the manuscript for a journal audience beyond lithic studies and archaeology. Many of the previous examples, including this one, have been removed to reduce technical detail, while the remaining examples have been critically engaged.
How to identify convergence. The paper generally does a good job of describing some of the difficulties in differentiating transmission vs. convergence and its factors. Overall, it is clear that this is not an easy task and is definitely scale-dependent. Some factors make it more likely, though not all are cited in the manuscript and might be added: lithics that (i) are less complex; (ii) are similar across fewer dimensions; (iii) are found further apart in space and time; (iv) derive from historically similar technological systems and ecological contexts; and, (v) occur in assemblages with few other similar objects.
AUTHOR: All the factors mentioned for identifying convergence are already captured in Table 2, except for the point on low-frequency or isolated occurrences of similar tools, which we have now added. To avoid redundancy and respect word limits, we have not repeated the table content in the form of a paragraph.
The classic example to cite in the cultural transmission versus convergence section for a paper dealing with the (Southern) African MSA would be Nubian cores (instead of blades). The papers by Hallinan & Shaw (2020; plus, more recent work by Hallinan on the topic) and Will et al. (2015) provide clear and straightforward examples.
AUTHOR: The references have been cited, and their discussion has been incorporated into the convergence section.
The "Synthesis and discussion" section misses references in some paragraphs (e.g. lines 360-364; lines 366-371, lines 391-398)
AUTHOR: The discussion section has been rewritten and well referenced.
Lines 373-379: This part felt odd and misplaced in the current paper. It is also a caricature regarding defined technocomplexes: Obviously, the Howiesons Poort is defined by similarities in many domains of lithic techno-typology and is likely to stem from cultural transmission within and between groups (as the paper says itself). This is what cultural-historical units (stripped of the ethnical baggage from the early 20th century) are used for: heuristic devices of abstraction and classification to bundle together different assemblages in one entity. Sure, one loses detail and variability, but this is the nature of abstraction and classification that is also required for communication in scientific disciplines (the authors themselves use these classificatory units, such as the Howiesons Poort in the paper). Calling this outdated without proper engagement of what these units ought to do (and what not) is too simple an argument for this otherwise well-argued review. Interestingly enough, in theoretical circles, the convergence between more recent ideas of cultural transmission theory and culture-historical archaeology has been mentioned and discussed in a much more positive and constructive way by people like Ian Hodder and others (this goes beyond the scope of the paper, though). Either engage more seriously and constructively with the topic of technocomplexes and their (mis)uses (there is also some "positive" recent literature on the topic that is not cited here), or remove this part and focus on other topics that are closer to the central topic of this article.
AUTHOR: We have removed these lines to maintain focus on the central topics of the paper.
Line 380: How should the complexity of artefacts be assessed? There are many competing measurements (techno-units, procedural units, Petri nets) etc. If the authors think we should go in this way, then please also spell out the methodical details.
AUTHOR: The paragraph was removed considering the above comment by the reviewer.
Line 393: I agree with the authors here, but other factors such as demography and the characteristics of the artefacts themselves should be added here.
AUTHOR: This has been factored into the revised paragraph.

Reviewer 1: Round 2
Date completed: 11 September 2025
Conflicts of interest: None

Recommendation: Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments
REVIEWER: Accept
Does the review fall within the scope of SAJS? Yes/No
REVIEWER: Yes
Is the review written in a style suitable for a non-specialist and is it of wider than only specialist interest? Yes/No
REVIEWER: Yes
Do the Title and Abstract clearly and accurately reflect the content of the manuscript? Yes/No
REVIEWER: Yes
Does the review provide a significantly novel perspective or significant recent advances in the field? Yes/No
REVIEWER: Yes
Is the objective of the review concisely stated? Yes/No
REVIEWER: Yes
Is appropriate and adequate reference made to other work in the field? Yes/No
REVIEWER: Yes
Do current debates and points of contention receive appropriate coverage? Yes/No/Not applicable
REVIEWER: Yes
Are gaps in the literature adequately identified? Yes/No/Not applicable
REVIEWER: Not applicable
Does the review provide direction for future research? Yes/No/Not applicable
REVIEWER: Yes
Are the methodology and statistical treatment appropriate? Not applicable/Yes/No/Partly/Not qualified to judge
REVIEWER: Not applicable
Are the interpretations and recommendations aligned with the objective? Yes/Partly/No
REVIEWER: Yes
Please rate the manuscript on overall contribution to the field Excellent/Good/Average/Below average/Poor
REVIEWER: Good
Please rate the manuscript on language, grammar and tone Excellent/Good/Average/Below average/Poor
REVIEWER: Excellent
Is the manuscript concise and free of repetition and redundancies? Yes/No
REVIEWER: Yes
Is the supplementary material relevant and separated appropriately from the main document? Yes/No/Not applicable

REVIEWER: Not applicable

Please rate the manuscript on overall quality
Excellent/Good/Average/Below average/Poor

REVIEWER: Good

If accepted, would you recommend that the article receives priority publication?
Yes/No

REVIEWER: No

Are you willing to review a revision of this manuscript?
Yes/No

REVIEWER: Yes

With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

REVIEWER: Yes

Comments to the Author:
In this revised paper, the author has made a genuine effort to engage with the original critique. I applaud the author for recognising that the review was intended to be constructive and that it was designed to help produce a better product. The paper is now more accessible to a general readership and is therefore suitable for publication in SAJS. In the process of the revision, the structure and writing have become 'tighter' and the paper is greatly improved.

I recommend publication of the paper.

Reviewer 2: Round 2
Date completed: 18 September 2025
Conflicts of interest: None

Recommendation:
Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments

REVIEWER: Accept

Does the review fall within the scope of SAJS?
Yes/No

REVIEWER: Yes

Is the review written in a style suitable for a non-specialist and is it of wider than only specialist interest?
Yes/No

REVIEWER: Yes

Do the Title and Abstract clearly and accurately reflect the content of the manuscript?
Yes/No

REVIEWER: Yes

Does the review provide a significantly novel perspective or significant recent advances in the field?
Yes/No

REVIEWER: Yes

Is the objective of the review concisely stated?
Yes/No

REVIEWER: Yes

Is appropriate and adequate reference made to other work in the field?
Yes/No

REVIEWER: Yes

Do current debates and points of contention receive appropriate coverage?
Yes/No/Not applicable

REVIEWER: Yes
Are gaps in the literature adequately identified? Yes/No/Not applicable
REVIEWER: Yes
Does the review provide direction for future research? Yes/No/Not applicable
REVIEWER: Yes
Are the methodology and statistical treatment appropriate? Not applicable/Yes/No/Partly/Not qualified to judge
REVIEWER: Not applicable
Are the interpretations and recommendations aligned with the objective? Yes/Partly/No
REVIEWER: Yes
Please rate the manuscript on overall contribution to the field Excellent/Good/Average/Below average/Poor
REVIEWER: Excellent
Please rate the manuscript on language, grammar and tone Excellent/Good/Average/Below average/Poor
REVIEWER: Excellent
Is the manuscript concise and free of repetition and redundancies? Yes/No
REVIEWER: Yes
Is the supplementary material relevant and separated appropriately from the main document? Yes/No/Not applicable
REVIEWER: Yes
Please rate the manuscript on overall quality Excellent/Good/Average/Below average/Poor
REVIEWER: Excellent
If accepted, would you recommend that the article receives priority publication? Yes/No
REVIEWER: Yes
Are you willing to review a revision of this manuscript? Yes/No
REVIEWER: Yes
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author. Yes/No
REVIEWER: Yes
Comments to the Author: Having been a reviewer for the original submission of this article, I commend the authors for taking the comments from me and the other referee seriously and making a big effort to modify their manuscript. The substantially revised manuscript is a big improvement, and all my previous comments were incorporated. I support acceptance of the article in its current form and congratulate the authors to a great article!

Middle Stone Age social connectivity: Can stone tools indicate the transmission of cultural ideas?

Abstract

The emergence of social ties among early humans becomes particularly prominent during the Middle Stone Age in Africa, a period characterized by increasingly complex human behaviors. Archaeologists rely on various proxies to infer social connectivity, with lithic artifacts playing a central role. However, the extent to which stone tools reliably reflect cultural transmission and learning remains a subject of debate. While some researchers interpret similarities in lithic production as indicative of knowledge exchange, others argue that such patterns may arise from independent innovation or convergent evolution rather than direct transmission. Nevertheless, growing research, particularly in southern Africa and beyond, suggests that patterns in lithic technology provide strong evidence of cultural transmission and interaction in some cases. While both cultural transmission and convergence shape technological patterns, emerging research using middle-range theories and contextual data is improving our ability to distinguish them. By refining these methods, we can better assess the role of cultural transmission in early human societies and move beyond simplistic assumptions about knowledge exchange.

Significance

The extent to which lithic artifacts can be used to infer cultural transmission remains contested, with some attributing similarities to independent innovation. Emerging evidence from Africa links them to social learning. This review evaluates their validity as markers of cultural transmission in the Middle Stone Age, shedding light on early human social dynamics.

Keywords: Evolutionary archaeology, lithic technology, cultural transmission, convergence.

Introduction

One of the defining characteristics of humans is the capacity to share knowledge through cultural transmission, allowing skills and information to pass across generations.[1,2] Evidence suggests that by at least 3.3 million years ago, early hominins were crafting and utilizing stone tools to assist in obtaining resources.[3,4] Since the manufacture of stone tools produces substantial amounts of debris, these artifacts often provide enduring traces of past human behaviors.[5] As a result, lithic technology serves as a crucial window for archaeologists to explore the evolution of cultural transmission.[6–9] Some of the earliest stone tools indicate that the ability to pass down knowledge through imitation has deep evolutionary roots, dating back to the Plio-Pleistocene.[10] This capacity for cultural transmission became even more pronounced during the Middle Stone Age (MSA; 300,000 to 30,000 years ago), with the development of increasingly complex technologies and behaviors linked to the emergence of *Homo sapiens*.[11–14] Among these behaviors was the formation of structured social ties, which facilitated the transmission of cultural knowledge, skills, and innovations.[13]

Researchers employ various archaeological proxies to investigate cultural transmission in the past, with lithic artifacts being one of them.[7,8,13,15,16] Similar patterns in tool production, tool form, and long-distance raw material transfer during the MSA are often used to infer the presence and extent of knowledge exchange.[7–9,13,17,18] However, the extent to which lithic artifacts reliably indicate cultural transmission remains contested, with some scholars arguing that such similarities may result from independent innovation rather than direct social learning, complicating interpretations.[19–23] Despite these debates, a growing body of research in Africa is now demonstrating that lithic artifacts can provide valuable insights into the mechanisms of cultural transmission.[8,9,13,15,18,24,25] This paper explores the extent to which lithic artifacts can be used as reliable indicators of cultural transmission in the MSA. By reviewing existing research and examining case studies, we aim to contribute to the ongoing discourse on the role of lithic artifacts in understanding early human social connectivity.

Lithic technology and cultural transmission

Cultural transmission refers to the transfer of knowledge, ideas, beliefs, and behaviors across generations through instruction and mimicry.[26] Cultural transmission can be vertical, horizontal, or oblique.[27–30] Vertical transmission occurs when cultural knowledge is inherited across generations, typically from parents to children, ensuring the stability of complex tool-making techniques as young learners observe and refine skills taught by experienced individuals.[28,31] Horizontal transmission occurs among peers within the same generation, facilitating the rapid spread of innovations within social groups.[26,29] Oblique transmission involves the transfer of knowledge from non-parental adults, such as mentors or community leaders, allowing for both the preservation and adaptation of cultural traditions over time[30] (Figure 1, Table 1).

Cultural transmission operates through various mechanisms: direct (content-based) transmission, where traits are adopted for their effectiveness or memorability; indirect transmission, where traits are copied from admired or successful individuals; and frequency-dependent transmission, where traits spread due to widespread use (e.g., conformity).[27] Observational learning and imitation also play key roles in the spread of cultural ideas. This learning process involves acquiring behaviors by observing others, while imitation is the direct replication of observed actions, often without understanding their underlying principles.[27] Both processes shape human behavior across generations, ensuring cultural continuity and adaptation.

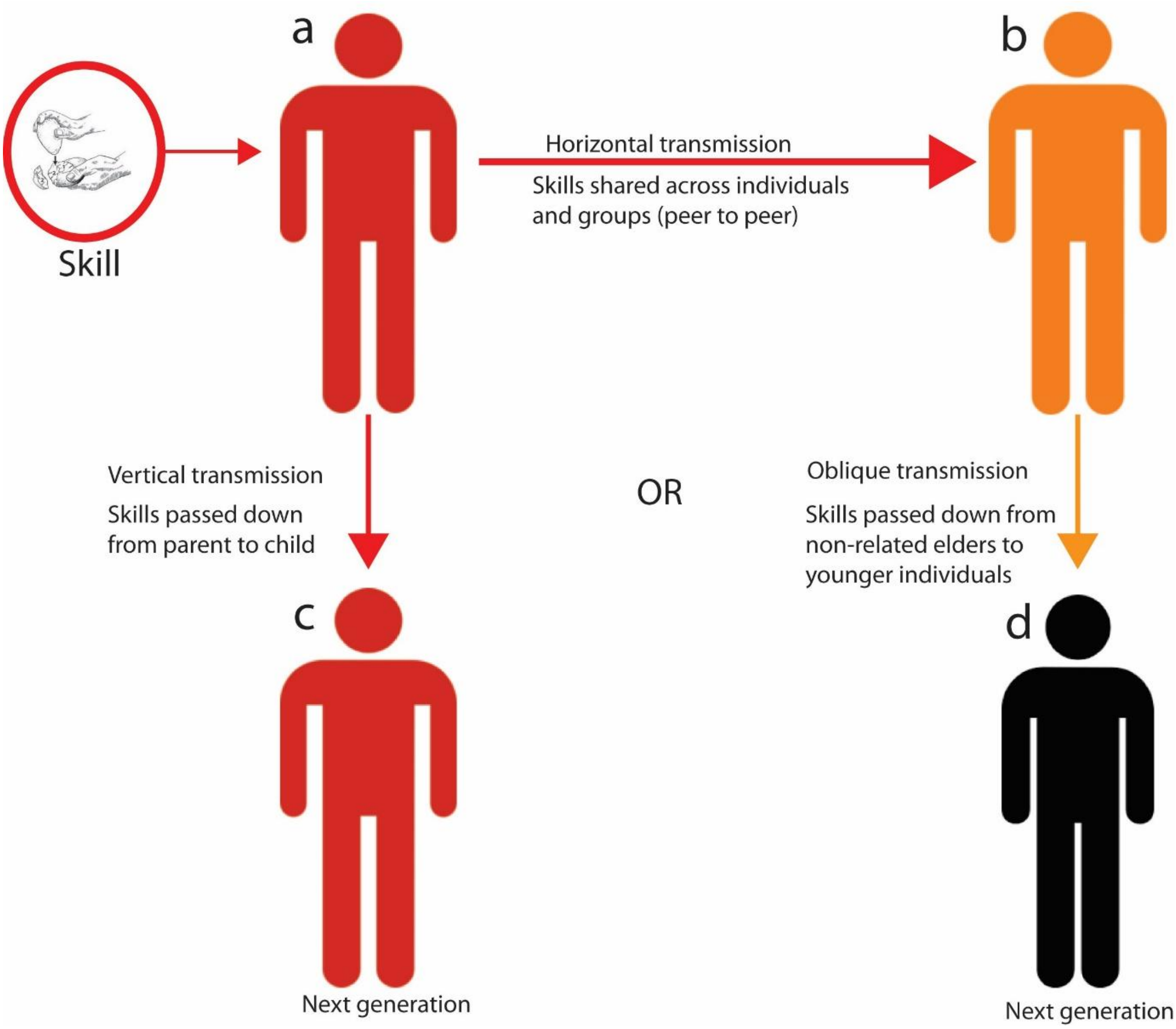

Figure 1: An illustration depicting vertical, horizontal, and oblique transmission.

Table 1: Summary of cultural transmission types, highlighting their sources of knowledge, rates of cultural change, and balance between stability and innovation.

Type of Transmission	Source of Knowledge	Rate of Cultural Change	Stability vs. Innovation	References
Vertical	Family, parents, direct lineage	Slow and gradual	High stability, low innovation	Cavalli-Sforza and Feldman[28], Shennan[31], Liu and Stout[32]
Horizontal	Friends, same-age group, neighboring communities	Rapid	High innovation, cultural variation	Boyd and Richerson[26], Lycett[29]
Oblique	Mentors, experts, skilled individuals	Moderate	Balance of stability and adaptation	Mesoudi and O'Brien[30]

Several models demonstrating the use of lithic artifacts to infer cultural transmission have been proposed, with Tostevin's[7] Behavioral Approach to Cultural Transmission (BACT) being one of the most prominent. As a middle-range model, BACT connects theoretical cultural frameworks with archaeological evidence to assess knowledge transfer through lithic artifacts, drawing on various experimental studies.[33–37] By integrating empirical data, BACT offers insights into how lithic technology—and, by extension, cultural knowledge—was transmitted within and between groups, informing our understanding on the flexibility and ability of early human cognition and social organization in the past.

The BACT model recognizes stone tool production as a complex skill requiring strategic decision-making throughout the lithic reduction process.[7] Because of their complexity, some lithic reduction processes are more likely learned and transmitted over time through direct teaching, imitation, and social learning, than resulting from independent innovation. Some approaches require precise replication.[7] BACT identifies five key domains in lithic artifact production that can indicate knowledge transfer: core modification, involving diverse knapping techniques and reduction strategies; platform maintenance, including preparation through faceting and attributes like platform angles and thickness; core exploitation, reflected in consistent flake removal strategies; dorsal convexity maintenance, ensuring core shape and structural integrity; and retouched tool morphology, demonstrating cultural continuity across assemblages.[7,38,39] For comparative analysis, BACT evaluates assemblages based on blank production and tool retouching.[7] To assess acculturation, assemblages are classified as the substrate (earlier assemblages), the acculturator (influencing later assemblages), and the product (blending influences from both).[7,39]

Beyond the BACT framework, knapping is recognized as a cognitively demanding skill that requires complex motor coordination and planning, making it a transferable practice passed from experts to novices.[40–43] To better understand this transmission process, researchers have been shifting from group-based analyses to the identification of individual knappers in the archaeological record through measurable knapping standards.[41] Comparative studies between novice and expert toolmakers have identified key indicators of expertise, such as material removal efficiency and flake symmetry.[41]

Additional evidence comes from geometric morphometric analysis of Levallois cores from sites across Europe, Africa, the Indian subcontinent, and the Near East, which reveals remarkable consistency in geometric properties across diverse regions.[42,43] This uniformity suggests that replicating Levallois technology required specialized skills acquired through direct learning, reinforcing the role of apprenticeship-based instruction.[43] Similarly, evidence from Initial Upper Paleolithic blade technologies in Siberia, Zabaikal, and North Mongolia suggests that the recurrence of specific blade production methods as cohesive technological "packages" supports the idea that these techniques were learned and transmitted rather than independently reinvented.[44] The structured nature of these lithic traditions, facilitated by learning mechanisms such as indirect bias or conformist transmission, underscores the role of cultural transmission in the spread of blade technologies across early human populations.[44]

Further supporting the role of lithic artifacts in inferring cultural transmission, the long-distance movement of raw materials is widely interpreted as evidence of social connectivity among early groups. Archaeologists use site-to-source distances to estimate the extent of social networks, with data from the European Paleolithic supporting this approach.[45,46] In Africa, geochemical sourcing studies show that MSA people transported obsidian tools and cores over distances exceeding 30 km at Porc Épic[18] and 140 km at Songhor and Muguruk[47,48] suggesting enhanced mobility and exchange networks compared to earlier periods. Evidence from the site of Olorgesailie suggests that early *Homo sapiens* engaged in long-distance raw material transfers by 300,000 years ago, reflecting expanding social landscapes and intergroup connections.[49]

Lithic technology and cultural transmission in an African context

Lithic artifacts have been widely used to study cultural transmission in the southern African MSA.[13,15,17,50] Mackay et al.[13] suggested that glacial periods (MIS 4 and 2) fostered social interaction, while interglacials (MIS 5 and 3) led to population fragmentation and localized lithic traditions. During MIS 5**,** flaking techniques varied regionally, with flake production at Blombos irregular blade production at Cape St. Blaize, and non-standardized reduction strategies at Klasies River**.** Pointed artifacts dominated summer rainfall regions, while denticulates were more common in winter rainfall areas, suggesting social fragmentation. MIS 3 saw similar divergence post-Howiesons Poort, with unifacial points and scrapers replacing backed artifacts, reduced blade production, and reliance on thicker flakes.[13] Sites like Sibhudu and Umhlatuzana produced hollow-based points, while Rose Cottage and Sehonghong had high scraper frequencies, reflecting smaller, more isolated groups. In contrast, MIS 4 and 2 show widespread transmission, notably in the Still Bay and Howiesons Poort industries, where bifacial point production and radial core reduction were consistent across sites like Blombos Cave, Hollow Rock Shelter, and Sibhudu. The movement of non-local fine-grained raw materials, as seen at Diepkloof, further suggests long-distance networks. These patterns indicate that environmental shifts shaped technological traditions, with harsher climates promoting connectivity and resource abundance leading to regional differentiation.[13]

Pazan et al.[15] provide further insights into the role of lithic technology in assessing cultural transmission through their study at Melikane Rockshelter in Lesotho. Their analysis of MIS 5 lithic artifact assemblages reveals how population fragmentation influenced knowledge exchange and stone tool production. The Melikane inhabitants utilized both blade-based and bipolar flaking techniques, adapting their lithic strategies to a mobile lifestyle shaped by environmental constraints.[15] When compared to sites such as Blombos, Border Cave, Diepkloof, Klasies River, Pinnacle Point 5-6, and Sibhudu, significant regional variation in lithic traditions emerges. Despite shared climatic conditions in some areas, highland groups at Melikane appear to have been relatively isolated from lowland populations, limiting technological diffusion. This suggests that cultural transmission was not always widespread but often influenced by geographic barriers and local resource availability, underscoring the complexity of knowledge exchange in southern Africa during the MSA.[15]

Cultural transmission in the MSA is evident in technological parallels between Florisbad and Klasies River, despite their geographic and functional differences.[50] Both sites share a unidirectional parallel reduction method, producing similar flakes and tools, indicating knowledge exchange as early as MIS 5–4. This challenges assumptions that site function dictated lithic strategies, as both Florisbad (a hunting site) and Klasies River (a residential cave) display expedient technologies linked to low mobility.[50] Their consistent *chaîne opératoire* suggests lithic knowledge was shared across broader landscapes, complicating interpretations of regional variability.[50]

Expanding on the evidence for cultural transmission in southern Africa, the Howiesons Poort techno-tradition provides another compelling case.[17] This period is marked by increased technological complexity, particularly the standardized manufacture of backed implements—small, modified blades probably integrated into composite tools.[17] While such tools existed earlier, their intensified and widespread production between 65,000 to 60,000 years ago suggests shifts in both cultural learning and environmental adaptation.[17] A comparative analysis of assemblages from Howiesons Poort Shelter, Sibhudu, Klasies River, Rose Cottage, Pinnacle Point 5–6, Klipdrift Shelter, and Diepkloof revealed a consistent production template across regions, reinforcing the role of cultural transmission in shaping lithic technology.[17] The study further compared these patterns with an Australian outgroup, highlighting that the observed standardization reflects strengthened long-distance social networks.[17]

Further reinforcing the role of lithic technology in tracing cultural transmission, a recent study in the Kalahari Basin and its adjacent regions applied BACT to assess social learning in MSA assemblages.[51] Through a comparative analysis of MIS 5 sites in and around the Kalahari Basin, including Ga-Mohana Hill North Rockshelter, Erfkroon, Florisbad, and White Paintings Rockshelter, the study highlights technological similarities across five BACT domains.[51] These consistencies—such as the use of locally available raw materials, core maintenance through *débordants*, and standardized blank production—suggest a shared technological tradition and ongoing knowledge transmission among MIS 5 groups in the region. The study further inferred that this connectivity may have reflected their adaptation to the harsh Kalahari environment, given the argument that social networks function as survival strategies in marginal environments.[52]

The eastern African context also provides significant examples of scholars using lithic assemblages to infer cultural transmission. Ranhorn's[8] research applies BACT to investigate knowledge transfer in MSA lithic technologies, using controlled knapping experiments to distinguish between different learning mechanisms, including imitation, emulation, and the absence of transmission. Results suggest that core reduction strategies, rather than flake characteristics, offer more reliable indicators of cultural transmission.[8] By employing three-dimensional photogrammetry, the study quantified Levallois and discoidal reduction methods, applying these techniques to MSA sites in Kenya and Tanzania, including Nasera, Kisese II, Koobi Fora, and Lukenya Hill. The findings highlight how both raw material availability and learned traditions shaped technological variability, with sites like Nasera reflecting demographic and environmental influences on the Middle to Later Stone Age transition, while Koobi Fora demonstrated technological consistency across materials, reinforcing the role of cultural transmission.[8]

Building on this, Blinkhorn et al.[25] examined how lithic technologies spread from eastern Africa to Arabia and the Levant, further underscoring the role of cultural transmission. Analyzing sites such as Aduma A5 and Omo Kibish in eastern Africa, Mundafan and Al Wusta in Arabia, and

Skhul and Qafzeh in the Levant, their study identifies directional shifts in Levallois core reduction techniques. The persistence of centripetal Levallois strategies and recurring core shapes indicates the intergenerational transfer of cultural knowledge among mobile hunter-gatherer groups, with skills transmitted across generations.[25] Additionally, minor variations in knapping techniques, independent of environmental or technological constraints, point to cultural drift. These findings support the existence of a shared technological tradition originating in eastern Africa throughout the Pleistocene, emphasizing the long-distance transmission of tool-making practices despite regional adaptations.[25]

Additionally, recent evidence from West Africa, specifically MSA technologies at Bargny, Senegal, dated to 150,000 years ago, provides a case study for evaluating lithic artifacts as indicators of cultural transmission.[53] While the stone tool technology shares characteristics with other late Middle Pleistocene assemblages across Africa, it remained remarkably stable in West Africa until the Holocene. This continuity suggests that stable environmental conditions, including mangrove ecosystems, may have sustained long-term cultural transmission over innovation-driven change.[53]

Cultural transmission versus convergence

The interpretation of lithic technological similarities across different regions hinges on distinguishing between cultural transmission and convergence. Cultural transmission, as previously defined, involves the passing of knowledge, ideas, and behaviors through teaching and imitation.[8,26] In contrast, convergence refers to the independent emergence of similar technological solutions due to shared environmental pressures, raw material constraints, or functional needs, rather than direct cultural exchange (Figure 2).[21] While these concepts are foundational to lithic studies, the challenge lies in reliably differentiating between them, as both processes can produce similar technological outcomes.[21,54]

A key issue in current approaches to cultural transmission in lithic analysis is the tendency to assume shared traditions based on superficial technological parallels.[21] Several studies argue that tool forms indicate knowledge transfer, yet they often overlook the possibility that these similarities result from independent innovation rather than social learning.[19,21–23,44,55] The physical constraints of stone tool production make it inevitable that different groups working with similar raw materials under comparable environmental conditions will develop analogous solutions.[21,56] Consequently, claims of cultural transmission based solely on similar tool forms risk oversimplifying the complexity of technological evolution in the MSA[21].

An example of such convergence can be seen in early blade production. Wilkins and Chazan[57] highlight technological convergence in early blade production, drawing from sites in South Africa, Kenya, and Israel dating to between ~500,000 and 400,000 years ago. While these blades share overall morphology, differences in core organisation, platform faceting, flake-to-blade ratios, and retouch patterns, and well as the large geographic distance, suggest independent development rather than shared cultural transmission.

Interpreting the meaning of similarity and difference in stone tool technology is inherently complex, as multiple factors influence the ways in which traditions are transmitted, and technologies evolve. While humans are widely recognized for cultural transmission, they are equally distinguished by their capacity for innovation.[5,26] They continually refine and enhance technologies to better align with their specific needs and contextual demands. Additionally, disparities in raw material availability often lead to technological modifications, making it difficult to determine whether differences in assemblages reflect environmental constraints or independent innovation.[58] These factors underscore the limitations of simplistic comparisons and highlight the need for more nuanced analytical approaches.

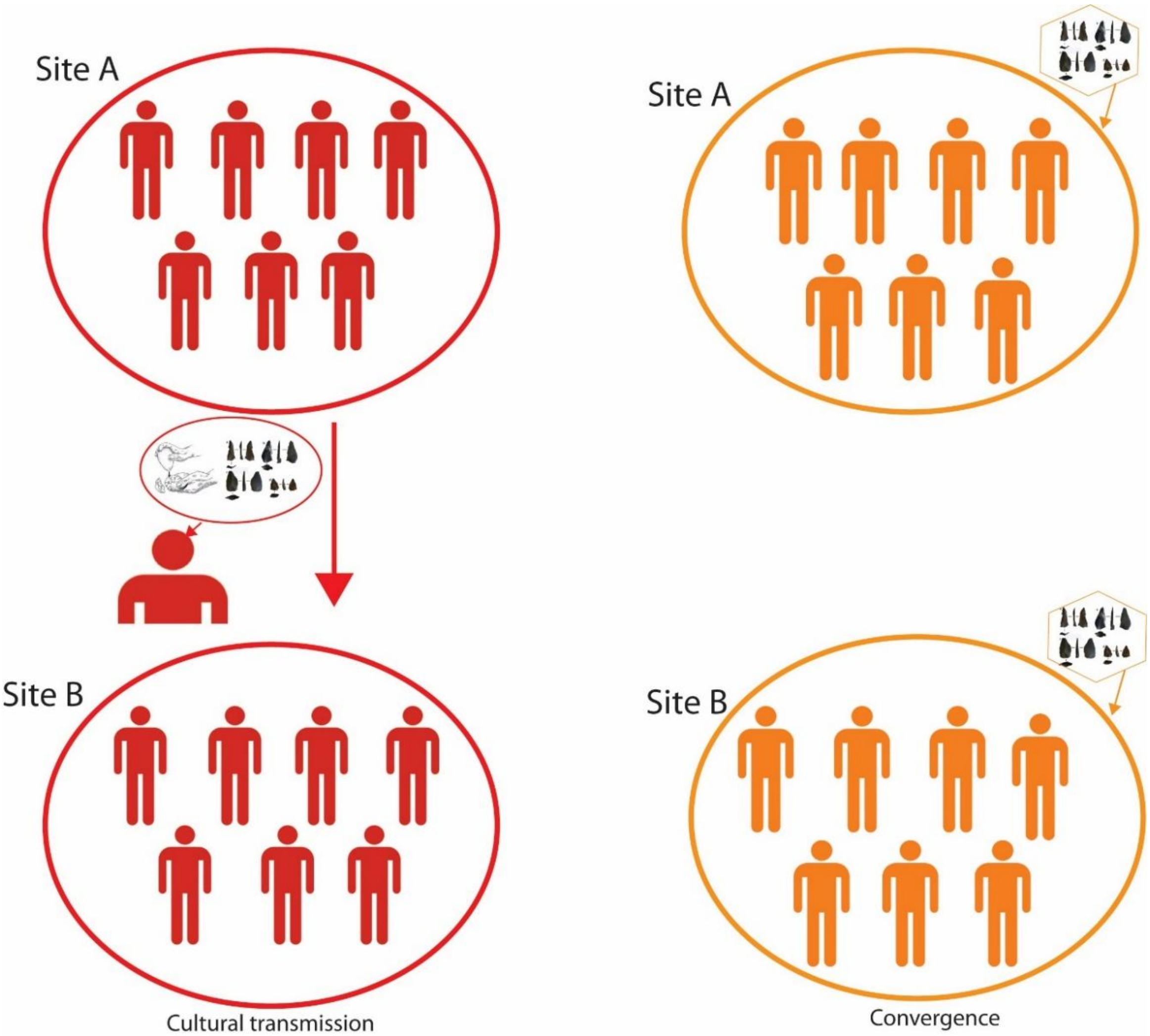

Figure 2: A Schematic illustration of cultural transmission and convergence.

One proposed solution has been to focus on technological complexity as a distinguishing factor.[21,29,42] The assumption is that more complex lithic technologies—those involving numerous sequential, mutually reliant, and structured stages—are less likely to arise independently.[7,21,59] Examples include heavily retouched tools and structured Levallois core reduction strategies. However, while this approach reduces the likelihood of coincidental similarities, it does not eliminate the possibility.[21] Even highly structured technological systems can emerge in parallel due to cognitive and functional constraints rather than direct knowledge transmission. Furthermore, the definition of complexity itself remains ambiguous, raising concerns about its reliability as a diagnostic criterion.[21]

A more rigorous approach requires moving beyond typological assessments and employing advanced methodologies to isolate genuine instances of cultural transmission. Techniques such as geometric morphometrics[42], detailed reduction sequence analyses, and models rooted in middle-range theory like BACT[7] offer promising avenues for distinguishing between convergence and social learning. However, these methods are not without limitations. While they often provide robust quantitative assessments of technological variation, they remain constrained by the interpretative frameworks applied to them.

Ultimately, the assumption that visually similar lithic artifacts necessarily imply cultural transmission is an oversimplification that risks misrepresenting the complexity of early human technological behavior. However, research is increasingly identifying lithic assemblage traits that help distinguish between cultural transmission and convergence, offering new ways to assess past social connectivity (Table 2). We continue to need a critical and methodologically rigorous approach—one that integrates multiple lines of evidence, considers the full range of potential explanatory factors, and acknowledges the limitations of current analytical techniques. By refining these methods, researchers can move beyond broad generalizations and develop a deeper understanding of the role of social learning in past human societies.

Table 2: Criteria for distinguishing cultural transmission from convergence in lithic analysis.

Cultural transmission	Convergence
Spatial and temporal continuity in tool production. If a tool type or reduction strategy persists within a geographically connected region over time, it may be the result of cultural transmission rather than convergence.[8,13,25] **Consistent patterns of reduction strategies across sites.** If similar reduction strategies are found across multiple locations, it may be the result of cultural transmission rather than convergence.[7,9,15,51] **Similar tool types and reduction strategies tied to feasible dispersal corridors or interaction zones.** If similar tool types and reduction strategies are found along plausible dispersal or trade corridors, or interaction zones, it more strongly supports the idea of cultural transmission rather than convergence.[25,45]	**Similar tools appearing in different regions without clear connections.** If the same tool type is found across vast distances with no evidence of contact, it may be the result of convergence rather than cultural transmission.[19,21,57] **Tool types known to be reinvented.** Some tools, like backed artefacts and hafted points, appear repeatedly across time and space, suggesting that they were practical solutions to common problems rather than the result of direct transmission.[22,23,54] **Variability in reduction strategies within the same tool or core type.** If a tool or core type class shows significant variation in reduction strategies across regions, this may indicate convergence rather than cultural transmission.[42,58,59] **Tool types appearing in unrelated cultural or ecological contexts.** If a particular tool form or reduction strategy emerges in geographically or temporally distinct settings with different environmental pressures, it may be the result of convergence rather than cultural transmission.[56,60]

Drivers of human connectedness

Several studies have examined the drivers of human connectedness (Table 3), highlighting three key factors: adaptive social networks, the psychological need for social bonds, and trust and cooperation dynamics.[45,52,61–63] The most prominent explanation is adaptive social networks, where environmental pressures drive the formation of social ties. In harsh environments, social connections facilitate cooperation in locating and sharing vital resources.

In southern Africa, glacial periods of resource scarcity and environmental unpredictability are believed to have strengthened information exchange, fostering social cohesion and intergroup connectivity.[13,64] Ethnographic studies of hunter-gatherer societies in harsh environments, such as those in southern Africa and the Arctic, support this idea, showing how dispersed groups maintained social ties for knowledge exchange, which acted as survival strategies and "safety nets" in times of resource uncertainty.[52,61] Conversely, during interglacial phases, more stable and abundant resources reduced the need for extensive cooperation, leading to more fragmented populations.[13,15,64] Therefore, connectivity and cultural transmission are viewed as adaptive strategies to mitigate ecological instability.[62,65,66]

While this most used theory effectively links social adaptation to environmental pressures, it does not fully account for other fundamental aspects of human connectedness, overlooking the intrinsic cognitive and emotional needs that drive human relationships. Psychological factors, such as the innate human desire for belonging, trust, and emotional security, may have played an equally significant role in shaping early social networks, regardless of environmental conditions.[52]

Furthermore, beyond environmental constraints, cooperation and mutual support likely evolved due to shared risks, collective defence, and cultural transmission. Hunter-gatherer societies across different environments—not just those experiencing extreme scarcity—have relied on complex trust-based interactions, trade, and social bonding to enhance long-term stability.[62] These networks did not solely emerge as a survival mechanism during crises but also as a way to strengthen group identity, reinforce alliances, and ensure knowledge transmission across generations.

Thus, while the environmental model provides a compelling explanation for social connectivity in response to hardship, social bonds were likely driven by a combination of environmental, psychological, and cooperative factors. This broader perspective allows for a more nuanced understanding of how human social networks emerged and persisted across varying ecological and cultural landscapes.

Table 3: Potential drivers of human connectedness

Core drivers of human connection	**Description**	**Examples**
Adaptive social networks (survival and resource sharing)[52]	Social connections develop as a crucial adaptation in harsh environments, enabling cooperation in locating and sharing vital resources[52]	- Formation of communities and alliances - Collective resource gathering (water, food, shelter) - Trade, migration, and communication networks for survival[52]
Psychological need for social bonds (cognitive and emotional resilience)[62]	Humans are wired to seek social interactions that provide emotional security and reduce stress, especially in challenging conditions[62]	- Sense of belonging and identity - Emotional and psychological support - Reduced anxiety and loneliness through companionship[62]
Trust and cooperation dynamics (strengthening social stability)[45,63]	The quality of social connections determines long-term cooperation, conflict resolution, and social stability[45,63]	- Trust and mutual aid in times of crisis - Conflict resolution[45,63]

Synthesis and discussion

Recent studies have increasingly used lithic artifacts to infer cultural transmission during the MSA.[7,8,13,15,42,51] The continued focus on this topic reflects a broader consensus that stone tools can provide insights into knowledge transfer across generations. Various analytical methods—such as lithic typo-technological frameworks, *chaîne opératoire* analysis, BACT, and geometric morphometric analysis—have been employed to assess the complexity of knapping techniques and the likelihood of their transmission. The recurrence of specific lithic patterns across different assemblages has been interpreted as supporting the idea of social learning.

Building on this foundation, it is evident that similarities in lithic technology suggest cultural transmission but can also result from convergence. Both factors shape technological patterns, complicating interpretations. However, research is making strides in distinguishing these processes by applying middle-range theories and contextual data, refining our understanding of past social learning and interaction.

Despite these advancements, further work is also needed to strengthen our ability to differentiate cultural transmission from convergence. Experimental research on stone tools and knowledge transmission—particularly controlled studies on imitation, copying, and learning mechanisms—can help refine the methods used to infer cultural connectivity. Integrating these approaches will provide a more nuanced understanding of how lithic traditions were learned, shared, and innovated upon.

Additionally, refining methodologies for studying lithic artifacts requires moving away from outdated culture-historical frameworks, such as NASTIES[67,68] or generic MSA[69–71] classifications, which often obscure rather than clarify patterns of cultural transmission. Several scholars have emphasized that rigid typological classifications hinder meaningful cross-site comparisons.[8,13,24,67,68] The continued reliance on broad categories and assumed similarities risks overlooking the nuanced ways in which lithic traditions evolved within and across different populations. Instead, research should shift toward approaches that directly assess the complexity of lithic artifact production and the sequential learning stages required for replication, such as those outlined in BACT.

Moreover, there is a need for greater consistency in data collection and recording. Variations in theoretical perspectives and analytical priorities across studies often hinder meaningful comparisons.[72,73] Given the durability and widespread presence of stone tools in the archaeological record, structuring datasets for meaningful comparison is essential for drawing reliable conclusions about past knowledge transmission. Standardizing methodologies and prioritizing compatible analytical frameworks would enhance the ability to detect and interpret patterns of social learning more effectively.

Finally, interpretations of cultural transmission in lithic studies have often overemphasized adaptation to environmental pressures while neglecting other key influences on learning and knowledge transfer. Psychological factors, trust, cooperation, and group identity all play crucial roles in shaping how cultural information is transmitted and retained. Future research must move beyond purely ecological explanations and adopt a more holistic perspective that incorporates social and cognitive dimensions of knowledge transmission in early human populations. By integrating these considerations, we can develop a more comprehensive understanding of the processes that shaped technological traditions in the MSA and beyond.

Conclusion

African MSA lithic assemblages provide crucial evidence for early human social networks and the mechanisms of cultural transmission. While technological similarities across regions suggest knowledge exchange, distinguishing between inherited traditions and independent adaptations remains a persistent challenge. Applying comparative frameworks such as BACT, alongside geometric morphometrics, *chaîne opératoire* analysis, and experimental archaeology, enhances the ability to assess whether lithic patterns reflect social learning or convergent evolution. Additionally, integrating lithic analysis with paleoenvironmental reconstructions, spatial modeling, and high-resolution chronological data will provide a more nuanced understanding of the factors shaping technological transmission. Future research should adopt interdisciplinary methodologies to bridge the gap between typological studies and behavioral reconstructions, ultimately refining our interpretations of early human social connectivity and knowledge transfer.

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