



A citation network analysis of lithic microwear research

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ABSTRACT

The introduction of lithic microwear research into the wider archaeological community by Keeley (1980) was concurrent with the development of the processual paradigm and the adoption of the scientific method. Subsequently, lithic microwear research has benefited from over 35 years of innovation, including the introduction of novel methodological and analytical procedures. The present study employs a citation network to objectively analyse the development of microwear research. Given developments in technology, as well as the institutional isolation of early microwear research, the present analysis considers the citation network that stems from Keeley's seminal 1980 volume. The 363 papers identified as having cited Keeley (1980) in the subsequent 35 years were treated as individual nodes within the citation network. Before analysis, nodes were assigned attributes, including the type of research published and whether they were supportive of three key aspects of Keeley's experimental program: the ability to determine the function of the tool and to ascertain the type of worked material from microwear, as well as the use of high-powered microscopy techniques. Emergent properties of the papers, including closeness centrality, indegree and betweenness centrality, are used to test for significant differences between paper attributes. Similarly a clustering algorithm is used to objectively define distinct clusters of important papers within the discipline. Results indicate that a small number of nodes in the network maintain statistically significant influence on the form of the citation network. These important nodes and the distinct 'schools of thought' identified are discussed in the context of Keeley's initial contribution to the sub-field.

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1. Introduction

The advent of processual archaeology in the 1960's (Binford and Binford, 1968; Clarke, 1973) marked the adoption of progressively scientific methods within archaeological research. The timing of this shift to include more quantitative methods closely aligns with the development of lithic microwear analysis as a sub-field of archaeological research. In turn, lithic microwear research offers a rare opportunity to examine how a sub-field's accepted knowledge developed in context of the wider adoption of the scientific method. Although many of the key ideas of lithic microwear research were originally conceived of by Semenov (1957) in the 1950's, its introduction into the wider academic community would not occur until the 1960's (Semenov, 1964), developing through the 1970's (Tringham et al., 1974; Keeley, 1974; Odell, 1975; Hayden, 1979) and resulting in its establishment as a paradigm (*sensu*

Kuhn, 1962) in the 1980's subsequent to Keeley's seminal volume (Keeley, 1980). An excellent review of this development was conducted by Stemp et al. (2015) who note that Keeley (1980) was motivated to publish, at least in part, by what he viewed as the limited applications of Semenov's original methods in the 1970's. Further, immediately subsequent to this period the introduction of high-powered microscopy marked the beginning of a trend of increasingly sophisticated metrological and tribological instruments utilised by the sub-field (Stemp et al., 2015). Perhaps as a result of the proliferation of these technologies, as well as the continued use of expert qualitative analysis, many methodologies currently exist within microwear studies and there have been calls for standardisation (Evans et al., 2014; Van Gijn, 2014). Yet, in some form, microwear analysis is replete in the literature as it is often included in site reports and therefore can be considered a substantive sub-field.

In the spirit of "critical self-consciousness" (Clarke, 1973:7), synonymous with processual archaeology, a citation network analysis of lithic microwear studies is employed here to objectively assess the development of three key ideas in this sub-field. Several

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other fields have engaged in critical, reflexive analysis, including medicine (Greenberg, 2009, 2011), ecology (Barto and Rillig, 2012) and genetics (Voracek, 2014). These studies have all employed citation network analysis, which applies established mathematical graph theory to the network of citations connecting articles that comprise the core of accepted knowledge in a given discipline. The development of common knowledge in a field involves many other materials and processes including: books, conference discussion, posters, interpersonal interactions and, increasingly, content on social media. However, peer-reviewed journal articles are a detailed, standardised record of academic discourse, which can be used to distinguish accepted knowledge at the core of a field from more contentious ideas, and are amenable to network analysis. This method is particularly advantageous as it is largely objective, requires few initial assumptions, and is increasingly practical with the availability of platforms to conduct it.

We consider the distribution of papers that find evidence for and against three central tenets of Keeley's (1980) experimental microwear program; "... that with the use of high magnification ... one can almost always isolate the used portion of the tool and reconstruct its movement during use, as well as, in the majority of cases, determine exactly which material was being worked" (*Ibid.*:78). Specifically we assess support for: the use of high-powered microscopy methods within microwear research, and the use of this method to determine both tool function and the type of worked material. Since worked material and implement function determination are based on identifying the used portion of a tool, as described by Keeley above, we do not focus on this latter aspect of his work. The present analysis makes no comment on the efficacy or suitability of microwear analysis or its methodologies but instead asks to what extent the sub-field is still characterised by Keeley's (1980) formative ideas. The network is predicted to be mostly supportive of these ideas since they initially defined the sub-field. Similarly, types of paper and their position in the network are also analysed to identify the most influential types of papers in the sub-field. Review papers are predicted to be the most influential type of paper since they draw together the current state of the field at the time of publishing and are often referenced as primer for the reader of original research articles. Finally, emergent properties of the network and sub-clusters within it are analysed in an effort to identify distinct 'schools of thought' within the discipline.

2. Methods

2.1. Node selection

Given developments in technology, as well as the political isolation of early studies in the field, the present analysis considers the citation network that stems from Keeley's 1980 volume. A list of potential papers that could be in the citation network was drawn from journal articles that cited Keeley (1980) and were published in the subsequent 35 years to May 2015. From these papers only those which concerned microwear in some way and were written in English were validated as nodes in the network.

Only English language papers were validated as broadening this selection criteria would likely result in strong language barriers obscuring more subtle structural variation, analysed here to chart the development of key ideas in the discipline. Works preceding Keeley (1980) were not included in the analysis as, although they may reveal much about the establishment of microwear as a sub-field in the Western archaeological literature, they are much fewer in number than those that succeed it and were not written when the sub-field was established *per se*. It would, for example, be inappropriate to categorise these early articles as being supportive of a central idea of the sub-field before this paradigm was

formalised in the literature.

To sample the relevant literature other citation network studies have used indexed databases of research articles, such as Scopus or PubMed. In the case of archaeology, which has many out-of-publication titles, these databases may not cover the same amount of literature as Google Scholar (Google Inc., 2015), and so this non-indexed database was used. Book chapters are omitted from the present analysis as they are not always available online and so were not compatible with the data collection method used here. Further the availability of printed resources and the potential lack of a peer review process for book chapters may introduce additional variation to the citation network from this distinct publishing process. It would be of interest to extend this analysis to book chapters and non-English language research in the future, but it is beyond the scope of this paper. It could be argued that, as the network is a snapshot of the sub-field in 2015, any papers with a high number of citations are simply the beneficiaries of time. Certainly, the longer something has been part of the literature, the greater the likelihood it has been cited. This would, however, be the case at any cut-off period and controlling for the effects of time by weighting citations may artificially distort the structure of the network in unforeseeable ways. Nevertheless, this potential effect of published year is noted in the discussion.

The 363 validated papers were treated as nodes in the network and each was assigned several attributes separately by authors AK and CD. In rare cases of discrepancy each was re-evaluated. Papers were first categorised as independently supportive, neutral or unsupportive of three key aspects of Keeley's (1980) model: the ability to determine the function of the tool and determine the type of worked material from microwear traces, as well as the use of high-powered microscopy methods. Direct quotes reflecting these respective views from each paper are given in [Supplementary Information 1](#). The criteria used to assign a support categorisation for each variable are given in [Table 1](#). Each paper was also assigned a type dependent on the main academic focus of the work ([Table 2](#)).

2.2. Network creation

In order to build the network connections between nodes each citation was treated as a directed edge. The edges were directed since papers could not cite future literature and therefore information could only pass through the network in a directed manner. In order to compute all the edges in the network the reference or bibliography section from papers was either gathered manually as an unformatted text file or, where possible, as a standardised .ris file. Due to natural language inconsistencies across reference lists in papers (such as abbreviations or the inclusion of special characters), a natural language processing algorithm written in Python 2.7.13 (Van Rossum and Drake, 1995) by BP was used to extract occurrences of paper titles in these reference lists. From this newly structured data, a graph could be generated by assigning directed edges from title papers (sources) to cited papers (targets). In order to control for Type 1 errors, matching titles were evaluated for percentage character similarity and any above 80% were manually verified as either a correct citation or a similar but different paper. This was important for papers that discussed sites with special characters in their name that could be transliterated differently depending on the formatting. Further some important papers in the field contain 'nested titles' that contain the full title of another paper preceded by something akin to "a reply to" or suffixed by "in context". Since these titles were longer, the exact character match only represented a percentage of the full title and manual verification was able to eliminate incorrect citations of similarly worded paper titles. Finally where papers appeared to reference each other reflexively this was manually verified (see results). This process

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