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Netherlands Journal of Geosciences

Original Article

Cite this article: Mol J, and Jansen R. Earth sciences in degree programmes in archaeology and in archaeological commercial practices in The Netherlands. *Netherlands Journal of Geosciences*, Volume 104, e11588. https://doi.org/10.70712/NJG.v104.11588

Received: 05 November 2024
Revised: 05 April 2025
Accepted: 11 April 2025

Keywords:
Education; interdisciplinarity; labour market; multidisciplinarity; transdisciplinarity

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Earth sciences in degree programmes in archaeology and in archaeological commercial practices in The Netherlands

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Abstract

Earth sciences are generally considered an important science discipline and a key in the solution of present societal problems. They are also important for interpreting the development of mankind in the past. The dynamics of landscapes are strongly intertwined with occupation patterns and are essential to interpret and date stratigraphical sequences linked to archaeological sites. Archaeologists thus need to have knowledge of earth sciences. But are they really educated in this field of sciences? This article discusses the way earth sciences are part of educational programmes in archaeology of several renowned international universities and compares them to the Dutch archaeological degree programmes. Next, it discusses the role of earth scientists and the application of earth science in the Dutch archaeological commercial practice and argues that earth sciences are not used to its fullest potential. Vice versa, also earth scientists can benefit from a more integrated approach, since they use archaeological data sparsely. It is argued that the present multidisciplinary approach should be turned into a transdisciplinary approach that already starts in the educational system, which may result in more innovative research outcomes in today's archaeological practices.

Introduction

In archaeological research, earth sciences were once considered the foundation needed to explain cultural changes in the past, which became known as processual archaeology (a.o. Binford & Binford, 1968; Clarke, 1968). Later, this theoretical concept was deemed too simplistic and was further developed into post-processual archaeology (a.o. Hodder, 1985), in which social sciences theories also played an important role. Present archaeological research has evolved into a discipline that employs tools and techniques from both the social and natural sciences, including earth sciences, which is the focus of this article.

Archaeological data consists of archaeological features, material culture, and their environmental context. The analysis of these data often involves methods of which many are originally developed in the earth sciences. These include well-established methods such as relative and absolute dating, isotope research, soil science, sedimentology, geophysics, and geographical information systems (GIS). This implies that an academic degree programme in archaeology needs to include at least the basics of earth sciences, to be able to apply mentioned methods meaningfully.

However, as science-based methodologies increasingly form the basis for innovative research projects in archaeology (e.g. Garba et al., 2024; Pilaar Birch & Szpak, 2022), the application of these data requires more than a basic understanding of sciences. The extent to which this should also be part of a core curriculum in an archaeology degree is a topic of debate, as archaeology is a very broad discipline, and the inclusion of a new topic inevitably comes at the expense of another.

Methodology

This article is based on a literature review of policy documents, archaeological excavation reports, websites and academic articles. Firstly, an outline is offered how earth sciences are incorporated into archaeological curricula of a selection of international programmes in the UK, USA, Germany, which are then compared to the programmes in the Netherlands. Secondly, we discuss the implications of the present Dutch archaeological heritage management and how earth sciences are currently applied in the day-to-day archaeological practice. The concepts of multi-, inter- and transdisciplinarity are discussed in relation to

archaeology and earth sciences and the effect on the archaeological labour market.

Earth sciences in archaeological degree programmes

In today's academic landscape, universities are organised as research institutions, where each discipline has its own theoretical framework and standardised educational programmes defined by degree systems (Thompson Klein, 2017). Traditionally, archaeological degree programmes are accommodated within faculties of humanities and social sciences, leading to art degrees in archaeology. However, there is a growing trend towards offering science-based degree variants, primarily at the graduate level, which include more earth sciences content. Table 1 lists a selection of prestigious international universities from the USA, UK and Germany, that clearly show this trend.

All BA degree programmes offer the basics of earth sciences on an undergraduate level, but usually integrated in an archaeological course. For instance, the Department of Archaeology at Cambridge University (UK) includes earth sciences methodologies in a course titled 'Archaeology in Action' within its BA in archaeology programme, teaching students archaeological methods and landscape mapping.

MSc-degrees in archaeology often specialise in bioarchaeology (including palaeobotany, palaeozoology, and human osteology), and typically incorporate GIS, archaeological materials, and geoarchaeology, all of which are grounded in earth sciences methodologies, but focus on the applications in archaeological research. The University of Sheffield (UK) is noted for its integration of humanities and sciences in their graduate programmes, though they do not offer undergraduate degrees. University College London (UCL) (UK) offers, next to traditional programmes, an MSc in environmental archaeology and in palaeoanthropology and Palaeolithic archaeology, which clearly rely on the interpretation of geological data and methodologies.

German universities offer traditional archaeology degree programmes often with a strong regional focus. Their graduate programmes, both MA and MSc, typically span 2 years. The distinction between Sciences and Arts is evident, as MSc degrees in archaeological sciences are offered by

Table 1. Examples of archaeological programmes in the UK, Germany, USA

University	Programmes offered	Earth Sciences courses	Website
Cambridge University	**Degree programmes** BA MA (1 year) MSc (1 year), including MSc geoarchaeology	BA: included in archaeological courses MSc Geoarchaeology	Department of Archaeology | (cam.ac.uk)
University College London (UCL)	**Degree programmes** BA, BSc MA in Archaeology (1 year) MSc including MSc in Environmental Archaeology (1 year) MSc in Palaeoanthropology and Palaeolithic archaeology (1 year)	BA: included in archaeological courses MSc: 15 ects course in geoarchaeology (optional)	UCL Institute of Archaeology | Institute of Archaeology – UCL – University College London
Sheffield university	**Degree programmes** MA Archaeology and Heritage (1 year) MSc Bioarchaeology (1 year)	Included in archaeological courses	Department of Archaeology | Archaeology | The University of Sheffield
Heidelberg University	**Degree programmes** BA Byzantine Archaeology and Art History, BA Classical Archaeology, BA Near Eastern Archaeology, BA Ur- und Frühgeschichte MA Byzantine Archaeology and Art History, MA Classical Archaeology, MA Near Eastern Archaeology, MA Ur- und Frühgeschichte (2 years) MSc Geoarchaeology (2 years)	In BA In MA included in archaeological courses In MSc 50% of the programme are courses in earth sciences	Studium – Universität Heidelberg (uni-heidelberg.de)
Universität Tübingen	**Degree programmes** BA Ur- und Frühgeschichtliche Archäologie und Archäologie des Mittelalters (in German) MA Archaeology (2 years) MSc Archaeological Sciences and human Evolution (2 years)	In BA included in archaeological courses and also as elective in 60 ects Nebenfach Naturwissenschaftliche Archäologie In Master included in archaeological courses	Verzeichnis der Studiengänge | Universität Tübingen (uni-tuebingen.de)
Yale University	**Major**	Offered as electives	Undergraduate Program in Archeaological Studies | Council on Archaeological Studies (yale.edu)
Stanford University	**Major**	Offered as electives	Undergraduate Program | Archaeology Center (stanford.edu)

https://doi.org/10.70712/NJG.v104.11588

Science faculties, while MA degrees are taught in Arts faculties. For example, Tübingen University offers a 2-year MA in archaeology within the Faculty of Humanities and an MSc in Palaeolithic archaeology within the Faculty of Science. At Heidelberg, the interdisciplinary master's programme in Geoarchaeology is a collaboration between the Faculty of Chemistry and Earth Sciences and the Faculty of Humanities.

In the United States, universities typically do not offer undergraduate degree programmes in archaeology but rather majors, which are more flexible and do not have a compulsory core curriculum. For example, Yale University offers a major in archaeology where courses in Earth Sciences can be chosen as electives. Their MA in Archaeological Studies offers the same flexibility, allowing undergraduate earth sciences courses as options. Similarly, Stanford University (USA) offers a major without a core curriculum, leading to individualised programmes and making direct comparisons with the strict European degree programmes difficult.

In the Netherlands, four research universities offer archaeology degree programmes, listed in Table 2: Vrije Universiteit Amsterdam and University of Amsterdam (which offer a joint programme, ACASA), the University of Groningen, and Leiden University offer BA and MA programmes. Additionally, Saxion University of Applied Sciences offers a 4-year undergraduate programme, which is focused on the archaeology in the Netherlands. All programmes offer the possibility to choose courses from other academic programmes in the elective space.

The programme of Leiden University is discussed in more detail next, as an example of the Dutch academic education in archaeology. Contrasting Amsterdam and Groningen, Leiden's programmes are offered by a Faculty of Archaeology rather than a Faculty of Humanities, which made it easier to offer also a science degree. Leiden University offers three international degree programmes: an undergraduate degree in Archaeology (BA), a 1-year graduate degree programme (MA or MSc), and a 2-year honours degree programme (RMA or RMSc). Each year, approximately 120 students enrol in the BA programme, and around 100 students join the Master's programmes. The programmes are taught in English and attract many international students from around the world; approximately 30% of the bachelor's students and 50% of the master's students are international.

These programmes cover a broad range of archaeological research, aiming to understand the development of past cultures, ranging from the first hominids in Africa, to the role of heritage and museums in contemporary societies world-wide. Earth sciences are introduced to all first-year undergraduate students through an introductory course Landscape Dynamics 1 that covers the main concepts (Table 3), similar to the programmes in Amsterdam and Groningen. Concurrently, students take archaeological courses on human origins and early farmers, applying several of the methods introduced in the earth sciences course. In Landscape Dynamics 2 humans are introduced as a main factor in the development of (cultural) landscapes. Other courses in the programme also incorporate these concepts, including on-campus practicals in archaeological field techniques and material studies. By the end of the first year, students apply their knowledge in the field, by practicing archaeological excavation techniques, drawing sedimentary profiles, and creating coring transects.

In the second year, students are introduced to GIS and palaeoecology, which provide the knowledge and tools to understand and process archaeological and environmental proxy data. These courses are part of the compulsory core curriculum. The second-year programme also includes elective courses, each with a maximum capacity of 20 students, to facilitate practical components. These electives cover topics such as isotope archaeology, zoology, botany, predictive modelling, and research-based case studies in specific regions. In these courses, students engage in active research that often includes an earth sciences component and follow-up field projects (Figure 1). In their final BA-year students also undertake a small research project of their choice, typically a literature review. This project requires them to demonstrate their ability to integrate multidisciplinary data into a coherent and structured argument.

Table 2. Archaeological degree programmes in the Netherlands

University	Programmes offered	Earth Sciences courses	Website
University of Groningen	**Degree programmes** BA, MA (1 year), RMA (2 years)	Introductory courses in BA	Archaeology | Bachelor's degree programmes | University of Groningen (rug.nl)
Vrije Universiteit and University of Amsterdam (ACASA)	**Degree programmes** BA, MA (1 year), RMA (2 years)	Introductory courses in BA	ACASA – Vrije Universiteit Amsterdam (vu.nl) Bachelor Archeologie – Universiteit van Amsterdam
Leiden University	**Degree programmes** BA, MA or MSc (1 year), RMA or RMSc (2 years)	Introductory courses in BA	Bachelor's Archaeology – Vrije Universiteit Amsterdam (vu.nl)
Saxion University of Applied Sciences	**Degree programme** BSc (4 year)	Introductory courses, focused on Dutch practice	ARC Archeologie Deventer Voltijd | Hogeschool Saxion

https://doi.org/10.70712/NJG.v104.11588

Table 3. Courses that include earth sciences-based methodologies in the Dutch archaeology degree programmes

Topic	Courses offered in 2024–2025			
	Groningen University	ACASA	Leiden University	Saxion University of Applied Sciences
Weathering and soil formation	BA1: Geoarchaeology BA1: Conservation and Arch. Sciences BA1: Archaeological Fieldwork BA honours: Anthropocene: How Humans Shape(d) the Earth (elective)	BA1: Environmental Archaeology BA1: Field School 1	BA1: Landscapes Dynamics 1 BA1: Field School 1	BA1: Erfgoed in het landschap BA1: Cultuur en landschap in de Vroege Prehistorie en Bronstijd BA1: Sporen en structuren BA1: Uitwerken Sporen en Structuren BA1: Uitvoeren Bureauonderzoek BA1: Fieldschool: Vooronderzoek
Stratigraphy, sedimentology, landscapes	BA1: Geoarchaeology BA1: Introduction to Dutch Prehistory BA1: Archaeological Fieldwork RMA: Landscape Archaeology: Europe's Settled Landscapes	BA1: Environmental Archaeology BA1: Field School 1 BA2: Archaeology of Prehistoric and Roman Europe BA2: Field School 2 (European and Mediterranean track) BA3: Environmental Archaeology and the Anthropocene (elective) BA3: Science in Archaeology 2 (elective) MA: Research Skills 2	BA1: Landscapes Dynamics 1 BA1: Landscape Dynamics 2 BA1 Field Techniques BA1: Field School 1 BA2: Surviving the delta (elective) BA2: Field School Zeeland (elective)	BA1: Cultuur en landschap in de Vroege Prehistorie en Bronstijd BA1: Erfgoed in het landschap BA1: Uitvoeren BureauonderzoekBA1: Fieldschool: Vooronderzoek BA1: Fieldschool BA2: Archeologisch Vooronderzoek BA2: Op zoek naar het verleden BA2: Cultuur en Landschap in de VME BA2: Cultuur en Landschap in de LME
Climate change	BA1: Geoarchaeology BA2: Foragers & Incipient Farmers of NW Europe (elective) BA honours: Anthropocene: How Humans Shape(d) the Earth (elective) RMA: Anthropocene (elective)	BA1: Environmental Archaeology BA3: Environmental Archaeology and the Anthropocene (elective)	BA1: Landscapes Dynamics 1 BA2: Deep history	BA1: Erfgoed in het landschap BA1: Uitwerken sporen en structuren BA2: Ecologische Archeologie
Rocks and minerals	BA1: Archaeological Fieldwork BA1: Introduction to Artefact Studies	BA2: Archaeological Materials in Context BA2: Field School 2 (Mediterranean track)	BA1: Material Studies 1 BA2: Material Studies 2 MSc: Material culture (elective)	BA1: Erfgoed in het landschap BA1: Vondsten in context BA1: Cultuur en landschap in Vroege Prehistorie en Bronstijd
Palaeoecology	BA1: Introduction to Bioarchaeology BA2: Archaeobotany BA2: Zooarchaeology BA2: Integrated bioarchaeology RMA: Anthropocene (elective)	BA1: Environmental Archaeology BA2: Science in Archaeology BA2: Field School 2 (European track) BA3: Science in Archaeology 2 (elective)	BA2: Bioarchaeology BA2: Botany (elective) BA2: Zoology (elective) MSc: Archaeobotany (elective) MSC: Archaeozoology (elective)	BA1: Erfgoed in het landschap BA2: Ecologische Archeologie
GIS, remote sensing	BA2: Archaeological Data Analysis BA3: Ruimtelijke analyse (elective) MA: Regional synthesis	BA1: Field School 1 BA2: Digital Archaeology BA3: Advanced Digital Archaeology (elective) MA: Digitisation of Past and Present MA: Digital Practice in Archaeology (only for Digital track) MA: Imaging and Assessing the Landscape (elective offered by VU)	BA2: GIS BA2: Predictive modelling (elective) MSc: Computational Archaeology (elective)	BA1: Uitwerken sporen en structuren BA1: Uitvoeren Bureauonderzoek BA2: Digitale Archeologie BA2: Op zoek naar het verleden BA2: Graven in het Verleden

(*Continued*)

https://doi.org/10.70712/NJG.v104.11588

Table 3 (Continued). Courses that include earth sciences-based methodologies in the Dutch archaeology degree programmes

Topic	Courses offered in 2024–2025			
	Groningen University	ACASA	Leiden University	Saxion University of Applied Sciences
Scientific methods (dating, Isotopes, aDNA)	BA1: Geoarchaeology BA1: Conservation and Arch. Sciences BA2: Foragers & Incipient Farmers of NW Europe (elective)	BA1: Archaeological Sources BA1: Environmental Archaeology BA1: Archaeology of Prehistoric and Roman Europe BA2: Science in Archaeology BA3: Environmental Archaeology and the Anthropocene (elective) BA3: Science in Archaeology 2 (elective)	BA1: Landscapes Dynamics 1 BA1: Landscapes Dynamics 2 BA2: Isotope research (elective) BA2: Palaeolithic Archaeology (elective) BA2: Dutch Prehistory in a European Context (elective) MSc Scientific Methodologies (elective) MSC Current issues in archaeological science (elective) MSc The Archaeology of Hominin Diversity (elective)	BA1: Sporen en structuren BA1: Fieldschool BA2: Ecologische Archeologie BA2: Funeraire Archeologie
Geophysical prospection techniques	BA1: Geoarchaeology BA1: Archaeological Fieldwork	BA2: Field School 2 (European track)	BA1: Field Techniques	BA1: Fieldschool: Vooronderzoek BA2: Op zoek naar het verleden BA2: Archeologisch Vooronderzoek

Figure 1. Prospective research at Walcheren, Zeeland. This is an interdisciplinary research focusing on the environmental context of archaeological features (photo J. Mol).

Table 3 shows a list of all Dutch bachelor's programmes, which include earth sciences. The data are based on course descriptions from the university websites and has been confirmed by staff members of the different programmes. It clearly demonstrates that the core curriculum of the various bachelor's programmes is similarly structured, though the regional focus varies. Both Groningen University and Saxion Applied University focus on the archaeology of the Netherlands and prepare students for the demands of the Dutch professional market within the core curriculum. In contrast, ACASA and Leiden University have a more international orientation and offer more courses on World Archaeology. Here, students can choose additional courses on the archaeology of the Netherlands, but they can also specialise in the archaeology of other parts of the world.

The master's programmes are more difficult to review and compare, as most programmes offer such flexibility that there is no clear core curriculum incorporating earth science methodology. However, this does not mean that these topics are not offered; they are typically included in the many research-

https://doi.org/10.70712/NJG.v104.11588

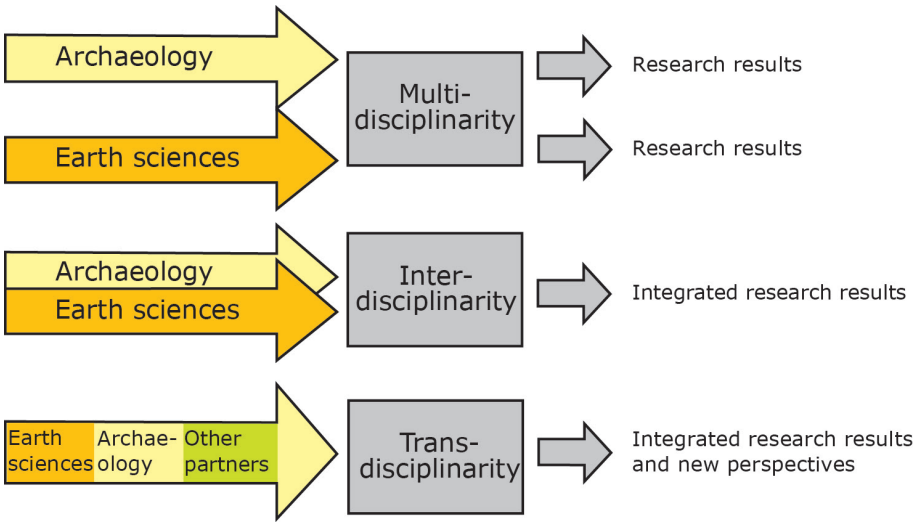

Figure 2. Summarising the different types of disciplinary research.

based courses that students can choose from. These can range from bioarchaeology to material analysis (such as isotopes and chemical analysis) or GIS modelling.

In the master's programme of Leiden University, the large number of students allowed us to offer many elective courses and students can opt for four main tracks, Applied Archaeology (MA), Archaeological Sciences (MSc), Heritage and Museum Studies (MA) and World Archaeology (MA). Lately, the MSc-specialisation Archaeological Sciences, that focuses on computational archaeology, material culture or bioarchaeological data, has become the most popular track, with about half of the students choosing this specialisation. The courses offered in the graduate programme include earth science methodologies, but they are always presented in the context of archaeology and based on current research projects conducted by the staff. The research master's programme offers more flexibility and allows for an individualised programme.

In conclusion, it can be stated that in most archaeology programmes in UK, Germany, USA, and the Netherlands earth sciences are included as a tool for archaeological research. Only in Germany are there master programmes with a compulsory earth sciences component taught within a Science Faculty. Importantly, these courses differ from regular courses; their course objectives suggest they offer an integration of both disciplines, making them interdisciplinary rather than merely multidisciplinary. This important difference will be discussed in more detail next.

This conclusion implies that archaeology programmes generally teach only the basic foundations of earth sciences, with the possible exception of the 2-year MSc degree programmes in Germany. However, in all universities, individual students can master earth sciences at a higher level by carefully selecting their electives, internships and thesis subject. But how does this translate into daily practice in the Netherlands after they graduated?

Earth sciences in the Dutch archaeological daily practice

Our highly segmented academic education persists in the professional, non-academic labour market. Both earth sciences and archaeology have its own theoretical background and argumentation, caused by more or less standardised education as defined by the degree system. Subsequently, these disciplines have their own journals, meetings, and professional organisations and are often protected by standards, such as certifications and licensing (Turner, 2017). This is also the case with the Dutch system in archaeological heritage management, which underwent large changes from the nineties onwards when the European Valletta Treaty was implemented (Council of Europe, 1992; van den Dries & van der Linde, 2012; van den Dries & Willems, 2007).

The Valletta Convention envisions a more structured and sustainable approach to conducting archaeological research to avoid unforeseen and undesirable 'rescue archaeology'. A crucial first step is the archaeological inventory of a region by prospective researches such as surveying, coring, trenching, and/or predictive modelling well *before* new developments are carried out. Next, a systematic evaluation should lead to the valuation and in- or ex-situ preservation of archaeological sites. The latter includes excavations.

At the same time, the conduct of research is governed by market principles, based on the idea that the 'developer' bears the cost of the needed archaeological investigations. This has led to the commercialisation of archaeology and an increase in archaeological research that is largely development-driven instead of research-driven. Approximately, 5–6% involves excavations, while the remainder consists of inventories conducted through borehole surveys and test trenches. It has transformed archaeology from solely an academic discipline into a development-led practice (Willems, 2012). Nevertheless, it also led to a substantial increase in job opportunities for archaeologists as well as earth scientists, both in (prospective) field research and desk-based policymaking (van Londen et al., 2012).

The present-day practice in the Netherlands has been remodelled in a regulated system, in which all archaeological investigations, including borehole surveys, are exclusively allowed by registered professionals in certified companies. This is regulated by standards developed by the professional market, in which the degree programme, total years of experience after graduation, and minimum number of annual

https://doi.org/10.70712/NJG.v104.11588

field days have been defined (Ondernemersplein, 2022). Earth scientists can be accredited and act as specialists (such as palaeobotany, palaeontology, sedimentology) or as prospectors (physical geography), provided that they have knowledge of the archaeology of Northwestern Europe. Conversely, archaeologists are only accredited if they have sufficient knowledge of the soils and geology of the Netherlands (SIKB, 2022). This status must be renewed every 4 years.

Kristiansen (2009) argued that development-led archaeology has led to a fact-based archaeology instead of a research-based archaeology, in which knowledge gaps are the main reason to perform research. This was partly contested by van den Dries (2011), who emphasised the positive outcomes, such as the considerable increase in accessible reports and the large number of field assessments that could be used as valuable resources for landscape research. But she also stressed that the most crucial step in contract archaeology is *who* decides on research questions, the scale and scope of the research work, and exemptions and selection (van den Dries, 2011). An even more crucial aspect is however *what* is going to be excavated. Both steps, who and what, have been decentralised in the Netherlands and appointed to the local authorities. It provides municipalities with a pivotal position in the archaeological system, which is filled in differently per municipality (Jansen, 2014). However, according to van den Dries (2011), these local authorities do not consider the main academic knowledge gaps but feel more responsible for city branding. In addition to this, what is going to be excavated and what is not, is in practice regularly formulated by commercial consultants, to whom the strict certification standards do not apply. At present, new archaeological data are largely determined by sites discovered as a result of development projects, which often does not lead to new insights. In general it can be stated that although projects have a so-called 'landscape approach' the outcome of a project is site-based. An evaluation of the effects of this legislation confirms this and emphasises the limited contribution of contract archaeology to the current academic discourse (Knoop et al., 2020).

This leads to the inevitable conclusion that the new legislation has resulted in a system in which fieldwork and basic documentation are mainly done on locations that are being developed and of interest to the local authorities that often have a local point of view. This results in biased site-based data, where many parts of the Netherlands are underrepresented, potentially leading to biased results. In our opinion, archaeological fieldwork in the Netherlands could benefit from a more academic and regional perspective in which research is put in a wider international and multidisciplinary framework, by cooperating with other disciplines, such as earth sciences. This could potentially lead to real interdisciplinary or even transdisciplinary innovative research themes, which are shortly discussed next.

Lessons learned? A multi-, inter- or transdisciplinary future?

Multidisciplinary research can be regarded as research performed by separate disciplines that keep their original identity, in which the application of knowledge from one discipline is used to contextualise the other (Thompson Klein, 2017). Archaeological degree programmes are multidisciplinary by nature, since archaeological research makes use of methods from social and natural sciences. This is emphasised in the end qualifications of such degrees, which states that archaeologists should be able to understand and incorporate these data into their results. However, multidisciplinarity does not mean that archaeologists and earth scientists share a common language, it merely involves a subdivision of tasks. Integration around shared themes or questions in research projects is often lacking.

One of the main differences between archaeologists and earth scientists lies in their focus areas and often scale of research. Archaeologists – especially in a commercial and professional context – usually concentrate on small, specific sites, while earth scientists often conduct research that encompasses broader geographical overviews and longer time spans. Despite these differences, both disciplines can significantly benefit from each other. For instance, archaeologists can contextualise a site within its larger landscape, and geographers can utilise archaeological findings to more precisely date events such as floods, compared to conventional dating methods, which have relatively large errors (e.g. Pierik et al., 2017; Toonen et al., 2025). This approach is typically multidisciplinary.

In contrast to multidisciplinarity, interdisciplinarity of research and education integrates concepts, methods and terminology. Earth sciences can be regarded as interdisciplinary by nature, as it uses methods and techniques developed in for example chemistry (geochemistry), physics (geophysics), biology (palaeontology) and social science (geography) (Baker, 2017). As an example, proxy records and processes from the past can be applied to predict future events, thereby contributing to current problems. This is called methodological interdisciplinarity, according to the definition of Thompson Klein (2017). More and more archaeological research is nowadays also focused on this type of research; current issues, such as human migration and humans' adaptation to climate change, can benefit from comparison with evidence from the (deep) past and needs such an interdisciplinary approach.

The next step is transdisciplinarity, in which the complexity of research is acknowledged and specialists from different disciplines together construct an overarching synthesis that leads to problem solving (Leavy, 2019; Thompson Klein, 2017) (Figure 2). Victor Baker, an earth scientist, discusses examples of inter- and transdisciplinarity in the earth sciences and has stated that transdisciplinarity '… involves new perspectives that go beyond what may have been part of any of the disciplines involved' (Baker, 2017). Furthermore, another example of transdisciplinarity in which archaeologists play an important role is human evolution, which has evolved into a separate research theme in which the boundaries between biology, earth sciences, anthropology and archaeology appear to have been disappeared (e.g. Cohen et al., 2012; Zan et al., 2024).

An inter-, multi- or transdisciplinary future starts with making students aware of such concepts to allow this approach in their later work. When applied to academic degree programmes, it should be noted that interdisciplinarity is increasingly used as a branding concept. In the United States of America, many universities offer a degree in interdisciplinary studies, such as Berkely University. Similarly, universities in the Netherlands are also looking into the development of interdisciplinary programmes or minors, for example, the University of Amsterdam, that has erected an institute dedicated to this subject. Despite the claim of these programmes that they offer interdisciplinary programmes, these usually are

https://doi.org/10.70712/NJG.v104.11588

multidisciplinary, or at the most methodological interdisciplinary, which means that students are offered theoretical concepts of more than one discipline and have to combine these themselves into an interdisciplinary approach, which is a challenging task for early academics.

Interdisciplinary approaches in (post)academic research are therefore much better feasible, since it involves experienced researchers. An example of this approach in archaeological research is the internationally recognised excavation of two Late-Mesolithic settlements on a Late Glacial river dunes in the Dutch fluvial district, in 1998 and 1999 performed by Leiden University and Archol, an archaeological company (Louwe Kooijmans, 2001a, 2001b). Here, archaeologists cooperated with many specialists, including palaeobotanists, zoologists, geologists and GIS-experts, which started already during the fieldwork. The first stage was multidisciplinary, in which each specialist reported their individual findings, such as a landscape reconstruction around the settlement (Mol, 2001, 2003).

The next step involved integrating some of the disciplines. For example, a complex chronostratigraphic sequence of natural and cultural processes was compiled through close collaboration between the archaeologist and geologist – a truly interdisciplinary approach, as they relied on each other's expertise to interpret the complex sequence (Mol & Louwe Kooijmans, 2001). The final step was the synthesis of all disciplinary data, offering a holistic understanding of the way of living of Mesolithic people in this part of the Netherlands (Louwe Kooijmans, 2001b). This makes it a truly transdisciplinary approach.

Nowadays, such projects, executed by a consortium of a company and university are rare, but it should be noticed that all larger archaeological companies in the Netherlands have included earth scientists in their prospection and excavation teams, which clearly shows that they value an interdisciplinary or transdisciplinarity approach.

As also more and more large research projects are interdisciplinary in nature, such as the prestigious European Synergy Grants (e.g. Kirchner, 2023), academic researchers from different disciplines will gradually develop a more common language, which will also become part of the different curricula, since most academic programmes are research-based. After all, it cannot be expected of early academics to develop these skills themselves and implement this approach in their later work.

Lessons to be learned: need for interdisciplinarity

We believe that archaeologists as well as earth scientists in and outside academia could highly benefit from such an interdisciplinary approach and will offer some examples.

In today's archaeological practice, the assessment of larger plan areas has become increasingly interdisciplinary. It is typically based on the relationship between landscape and human occupation, which is derived from the integration of archaeological and geological data and is practiced by an interdisciplinary team of specialists. There are several examples of larger research projects, in which interdisciplinary professional teams of earth scientists and archaeologists offer valuable new insights (e.g. De Moor et al., 2020; Isarin et al., 2017). However, this only applies to the initial prospective stages of archaeological research. The final step, defining the research questions and areas that need to be excavated, is still usually not evaluated from an interdisciplinary perspective, which could lead to different choices than the current site-oriented excavations.

Although the necessity of such an interdisciplinary approach is not contested, it is usually limited, in the market driven archaeological market of the Netherlands. In smaller projects, interdisciplinarity is often lacking. In his MA-thesis, Karagiannis (2024) conducted an extensive review of excavation reports from the central Dutch river area, focusing on how the term 'cultural layer' was used. In general archaeologists define a cultural layer as a layer wherein artefacts have been discovered without explaining the processes behind its formation. He showed that most excavation reports relied heavily on archaeological structures, such as postholes or water pits, and used artefacts primarily for the material culture and chronological purposes. Karagiannis determined that many reports failed to define the context of these layers and some even acknowledged they could not determine if the finds were in situ or redeposited.

This example highlights the importance of understanding natural site formation processes, which can result from a complex mix of geological processes, human activities, and post-depositional changes. To accurately interpret findings, an interdisciplinary approach involving both earth scientists and archaeologists is essential, with more environmental data of a larger region and soil micromorphology often providing valuable insights. However, in commercial settings with time and budget constraints and different interests, this is generally not executed. This exemplifies again one of the drawbacks of current heritage management legislation in the Netherlands and the gap that has emerged between academic and professional archaeology partly also as a result of university developments and changing objectives. The RCE-project *Oogst van Malta* tries to break through this and together reach new insights about the past (Habermehl, 2019, 2024).

In addition, not only archaeologists, but also earth scientists can benefit from the large amount of environmental data that has become accessible, after the implementation of the Dutch heritage law, using the channel belt map of the Dutch fluvial district as an excellent example (Cohen & Stouthamer, 2012). Nevertheless, in this example they used the data obtained from archaeological sites mainly as chronological markers, which make this approach more multidisciplinary than interdisciplinary. It is evident that the difference in scale usually makes it hard to use the archaeological data to its fullest potential, but this can perhaps be a next step in this type of research.

We do not argue that only universities should do research, but we like to stress that funding in and outside academia should focus on knowledge gaps, such as defined by the RCE for the Dutch archaeology (https://noaa.cultureelerfgoed.nl/). Since commercial companies have little opportunities to do research, opportunities lie in the cooperation between academia and professionals. Therefore, it is essential that earth scientists and archaeologists from universities and professional companies keep in close contact, cooperate and communicate new findings and innovations.

Conclusions

Besides its value for present and future, earth sciences are also important to research the human past. It is an important discipline in archaeological field data acquisition, interpretation and narration and therefore is included in all national and international degree programmes in archaeology. These degree programmes, however, offer such a variety of subjects that the inclusion of more state-of-the-art theories and methods in earth

https://doi.org/10.70712/NJG.v104.11588

sciences in the core curriculum, leading to a deeper understanding, is unfeasible.

The current lack of interdisciplinarity in higher education has its effect on the present development-driven archaeological practice in the Netherlands. Many archaeological projects are site-focused and not part of a larger research theme. Archaeology could benefit from a broader interdisciplinary perspective, leading to the inevitable conclusion that more cooperation between disciplines is necessary and this starts with education. After all, all academic degree programmes are research-based and can educate archaeology as well as earth sciences students to look beyond their field of expertise.

Acknowledgements

The authors would like to thank the anonymous reviewers for their feedback. Sjoerd Kluiving (VU, ACASA), Stijn Arnoldussen (Groningen University), and Jelle Morée (Saxion University of Applied Sciences) reviewed their own programmes listed in Table 3. René Isarin (Crevasse Advies) and Jos de Moor (Earth Integrated Archaeology) directed us to the interdisciplinary projects conducted in a professional setting.

Competing interests

The authors declare none.

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