Investigating 16th century knitting with citizen science: An archaeological experiment into fleece and fulling

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Published in:
Archaeological Textiles Review

Publication date:
2018

Nº 60

ARCHAEOLOGICAL TEXTILES REVIEW

2018 issue

Archaeological Textiles Review

ATR is published by the Society Friends of ATN, hosted by Centre for Textile Research in Copenhagen.

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Print: Grafisk
University of Copenhagen

Subscription information: To purchase a copy of the latest *Archaeological Textiles Review*, please visit: www.webshophum-en.ku.dk/shop/archaeological-textiles-333c1.html. Information about institutional subscriptions is also available here. This will also provide membership of the Friends of ATN.
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ISSN 2245-7135

Contents

Projects

Obituaries

Conferences

Editorial

Welcome to the diamond issue of the *Archaeological Textiles Review* 2018. It is an achievement worthy of celebration to have kept an independently-funded peer-reviewed journal up and running for 60 issues. We endeavour to strike a tone which embraces both scholarly articles and current affairs in textile-related matters. We are pleased to report that we are still going strong thanks to the staunch support of the Friends of ATR, which we very much value. Many thanks to you all!

For the ATR team, 2018 has been a turbulent year. Ulla Mannering has been on a long-term sick leave, but is now fully recovered and back on track. This is also why there has been no Annual General Meeting of the Friends of Archaeological Textiles Newsletter this year. We will provide more information about the next AGM on our homepage www.atnfriends.com at the beginning of 2019. Further, Ursula Rothe has left the editorial board and suggestions for a new, preferably native English speaking, editor are welcomed, and can be emailed to evaandersson@hum.ku.dk.

This year's issue is primarily dedicated to the study of knitwork with articles on protocol and terminology, and evidence for the craft's origins and development. The nine joint articles by Jane Malcolm-Davies, Ruth Gilbert, Susanne Lervad, Helena Lundin, Lesley O'Connell Edwards, Annemarieke Willemsen, Maj Ringgaard, Sylvie Odstrčilová and Rosalind Mearns are important contributions to the formation of a more standardised way of addressing and describing knitted items in an archaeological and historical context. We hope that readers will appreciate this initiative and continue the scholarly development of our scientific languages, which are imperative for modern textile research.

While this issue concentrates on knitwork, the editors would like to bring needle binding into better focus. We encourage our readers to submit articles about this technique for future issues. This issue presents five project descriptions about on-going and up-coming textile research projects. It is inspirational to see how textile research and the many excellent researchers working within this field are capable of creating new and innovative projects that successfully generate large sums of external funding.

We welcome new contributions to forthcoming issues and encourage you to send them to us as they are ready, so that we may spread the editing work over the year and have time for the peer review process. The deadline for contributions is **1 May** each year. Please also remember to send us news of projects, PhDs, publications and conferences, so that we can continue to be a hub for the archaeological textile community.

The Editors

Klaus Tidow celebrates his 80th birthday

Beautiful summer weather provided a wonderful backdrop for the handing over of a photo album to celebrate Klaus Tidow's 80th birthday on 15 July 2018 in Neumünster. Fit and joyful, Klaus and his wife Dörte arrived by bike. It was a great pleasure to see

Klaus at all the symposia, meetings and workshops that have been documented in this photo album that also impressively demonstrates Klaus' long working life.

It is clear that NESAT would take up a lot of space in the photo album. After Susan Möller Wiering had recited a multi-verse poem about Klaus, an ice cream was needed to cool the emotions. Thanks to Annette Siegmüller and Christina Peek from the The Lower Saxony Institute for Coastal Research in Wilhelmshaven, who all helped with the compilation of the photo album and to all colleagues who contributed photographs. Klaus is still actively involved in textile archeology. Nevertheless, it is good to know that he has deposited his most important works and records in digital format with me for safe keeping. We all hope that on his 90th birthday we will be invited back for more ice cream!

Johanna Banck-Burgess

Jane Malcolm-Davies and Rosalind Mearns

Investigating 16th century knitting with citizen science:

An archaeological experiment into fleece and fulling

Abstract
An archaeological experiment was undertaken as part of the *Knitting in Early Modern Europe* (KEME) project to determine the best modern match for the fleece used in surviving 16th century knitted caps. Circular test swatches, known as 'swircles', were created by volunteers from a variety of fleece. The experiment demonstrated that, through citizen science, members of the public can contribute meaningfully to academic textiles research. It recorded a number of useful insights into the process of involving volunteers in experimental archaeology. The aim was to recreate the thick nap observed on the extant cap linings. Half the swircles were hand-fulled and brushed to raise a nap by the volunteers. The nap raised from a Wensleydale yarn most closely resembled the length of the preserved naps but Bluefaced Leicester fleece provided a softer and more even coverage. No tested fleece provided a combination of these features to sufficiently mimic the extant nap.

Key words: Knitting, 16th century, cap, fleece, fulling, experimental archaeology, citizen science, crowdsourcing, volunteer

Introduction
A surprising number of 16th century knitted caps and cap linings are preserved in museum collections across Europe. Numbering more than 100, these somewhat unglamorous items have, until recently, remained largely unstudied. Little is known about early knitting, the treatments applied to the finished caps or the materials used to construct them. Yet, with the growth of historical reenactment as a serious leisure pursuit (Hunt 2003), as well as an increased interest in historic dress and knitting generally, more information on how these items were constructed is now in demand. Research, conducted by the *Knitting in Early Modern Europe* (KEME) project and others, has provided some insights, but questions remain about how the neat, silky nap observed on the extant caps and linings was achieved.
The KEME project recognised that this wide public interest in knitting history could provide a wealth of knowledge, and designed an experiment to investigate the method and materials used to create the nap using volunteer knitters. Volunteers worldwide were invited to knit circular test swatches, known as 'swircles', from a yarn of their choice. Half of these were then hand-fulled and napped with the remaining half left untreated as controls. These were compared to one another and the extant record to determine which yarn, and the fleece from which it was made, produced the best reconstruction of the 16th century nap.
The experiment was also intended to test whether members of the public could meaningfully engage in academic textile research through citizen science, also known as crowdsourcing. Using its broadest definition, citizen science is the involvement of non-specialist volunteers in the collection of scientific data (Clark & Illman 2001; Lewenstein 2004; Silvertown 2009; SOCIENTIZE/European Commission's Digital Science Unit 2013). The *Oxford English Dictionary* now defines it as: "Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (2014).

Fig. 1: Reconstructed split-brimmed cap prototype made by Rachel Frost for The Tudor Tailor based on a range of similar caps (inventory nos: Museum of London 5013; 5004; A6347; A7608A; Cuming Museum TN3338/1506). See https://kemeresearch.com/caps to view the originals (Image: © The Tudor Tailor)

Crowdsourcing has been widely employed in biology and other natural sciences with, for example, volunteers recording species sightings or rare phenomena. It has, however, had limited published use in textile archaeology (for some reported examples, see Hopkins 2013). The KEME project was designed to test the feasibility of citizen science in the field by using volunteers for the fleece and fulling experiment. The swircles provided by the volunteers and the results they produced were intended to link directly to the scientific outcomes of the KEME project (Malcolm-Davies 2016).

Background – The KEME Project

KEME aimed at investigating the development of knitting in Europe as a distinct form of textile craft in the Early Modern period (University of Copenhagen, 2017a). It is generally acknowledged that knitting emerged in Europe during the Middle Ages and quickly developed into an industry in the Early Modern period (Thirsk 2003, 562). Due to its similarity in appearance to netting, needlebinding, sprang and others, very close examination is often needed to determine whether an archaeological find is knitted or constructed in another way (Rutt 1987, 7-9). This difficulty has led to knitting being overlooked in the archaeological record and museum collections. Yarn-based objects are often incorrectly or minimally labelled (Malcolm-Davies 2018a, 2). The KEME project sought to address this by identifying knitted objects in museum collections across Europe and north America which resulted in more than a 100 16th century knitted caps and cap linings being brought together as comparative evidence (University of Copenhagen 2017a).

Despite their geographically diverse locations, the way in which these caps were constructed was found to be relatively uniform (Malcolm-Davies 2018a, 2). Most appeared to have been knitted in the round using more than two needles with random increases or decreases to create a circular crown and/or to form one of six shape variations (Malcolm-Davies & Davidson 2015, 223, 225-8; Buckland 2005, 31-32). Two-ply or two-thread unplied yarn spun from a variety of fleece was most commonly used with no apparent preference for S or Z spin (Malcolm-Davies & Davidson 2015, 225-6). After being knitted, the caps appeared to have been treated to produce a thick nap. This raised nap was then clipped to an even finish producing a surface similar to that found on modern plush toys (Museum of London 2016). Dyeing appears to have been the final process after knitting, fulling and napping. This is

indicated by the fact that some caps showed evidence of the dye not having penetrated to the core of the yarn and the surface of the caps appearing paler where the nap had been lost (Maeder 1981).

Using this information, the reconstruction of a split-brimmed cap (fig. 1) was undertaken (Malcolm-Davies & Davidson 2015, 224). Although the final shape of this reconstruction was close to the original, the surface treatment did not replicate the silky nap seen on the extant caps (Malcolm-Davies & Davidson 2015, 230). It was hypothesised that this was partly due to the type of fleece used. Modern European fleeces differ from those available in the 16th century but the precise differences are unknown (Malcolm-Davies 2018a, 4; Schjolberg 1992, 152; Ryder 1984, 342-343; Ryder 1964, 7).

A microscopic investigation of the extant caps also revealed that the fleece fibres appeared to have been stripped of their outer scales. This led to the conjecture that fulling had been applied as part of the construction process as, unlike felting which is designed to enmesh loose fibres by rubbing them together, fulling smoothes woven or knitted fibres. Therefore, an experiment was designed to test these theories.

Experiment Design

To narrow the investigation to a manageable experiment, it was decided that a test swatch should be developed to avoid the need to construct a complete cap for each type of fleece to be tested. The extant knitted circular cap linings, which have the same nap as the caps, were chosen as the basis for this swatch. As a flat piece of knitting, their construction was easily explained in modern knitting instructions, with a reduction in diameter to 12.75 cm to make them even more practical to produce (fig. 2). The linings also provided a clear subset of items to which the swatches could be compared. The circular swatches were nicknamed 'swircles'. These swircles were to be constructed from a wide range of sheep's fleece and then fulled to test which knitted and finished fleece most closely resembled the original nap on the extant linings. Volunteers would be recruited to choose the fleece, knit and full swircles, and report their results. The volunteers would have access to the original material via an online database, which they could examine and comment on to contribute to the scientific record.

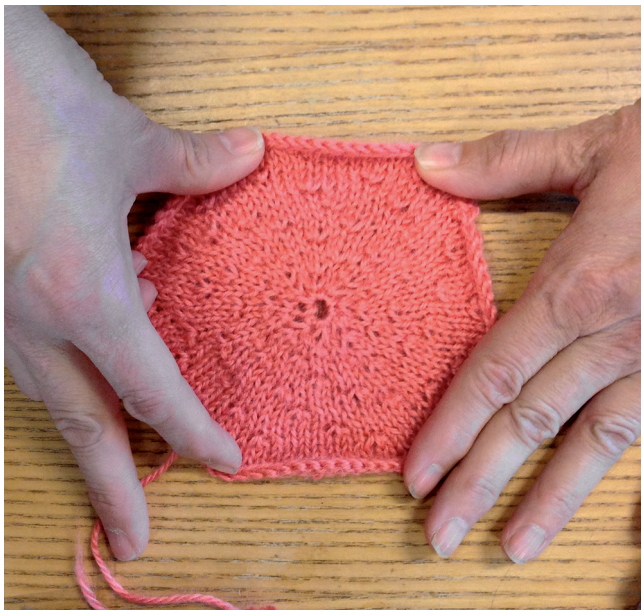


Fig. 2: A completed Wensleydale swircle (circular swatch) before fulling during a phase 1 workshop (February 2017)

The decision to involve volunteers, however, posed several challenges for the design of the experiment. For example, the widespread public interest in knitting history had the potential to provide a large pool of volunteers but there was no guarantee that those recruited would have the necessary familiarity with archaeological material to provide useful samples and observations. Access to the KEME database was seen as a potential solution as it would allow volunteers to consult the archaeological record directly and learn from it. The database was hosted online (fig. 3) and made accessible via usernames and passwords issued to the volunteers. Initially, the database contained high-resolution photographs and relevant accession information on the cap linings, and this was expanded to include one category of caps (the split-brimmed examples) towards the end of the experiment (Malcolm-Davies 2018a, 3-4). A link to an online questionnaire provided the opportunity for the volunteers to add observations on each item in the database, if they wished to do so.

Concern about a lack of archaeological expertise proved to be unfounded. The registration information collected confirmed that many volunteers already had appropriate skills. A quarter identified themselves as being primarily motivated to volunteer for professional or tertiary education reasons (fig. 4). A further 21% came from a reenactment background. This gave nearly half the KEME volunteers a wide basis of professional or amateur knowledge of experimental archaeology and the reconstruction of historic textiles.

A second concern was the volunteers' anticipated level of craft skill. In order for the swircles to be suitable simulations of the cap linings, consistency across the knitted samples was required. The use of knitting instructions, although one step towards

uniformity, was no guarantee of consistency across multiple volunteers. A suitably large cohort was identified as the best way of counteracting any outliers in craft skill. A target of 100 volunteers was set for the experiment. Details were promoted on social media to achieve this. KEME accounts were set up on Facebook and Twitter as well as on the knitting forum Ravelry (*Strickersvej – Knitters Way*; *#Strickersvej; Early Modern Knitting*, 2017b). Potential volunteers were directed to an online registration form hosted by SurveyMonkey (*Early Modern Knitting*, 2017). SurveyMonkey, as the name suggests, facilitated the collection of information on the volunteers, including data on self-assessed knitting skill. Of the volunteers recruited, 40% identified themselves as being expert knitters with this figure increasing to 43% when the 'other' responses were recategorised (fig. 5). Only two non-knitters were identified in the whole group with both stating that their interests lay in analysing the archaeological record rather than contributing knitted

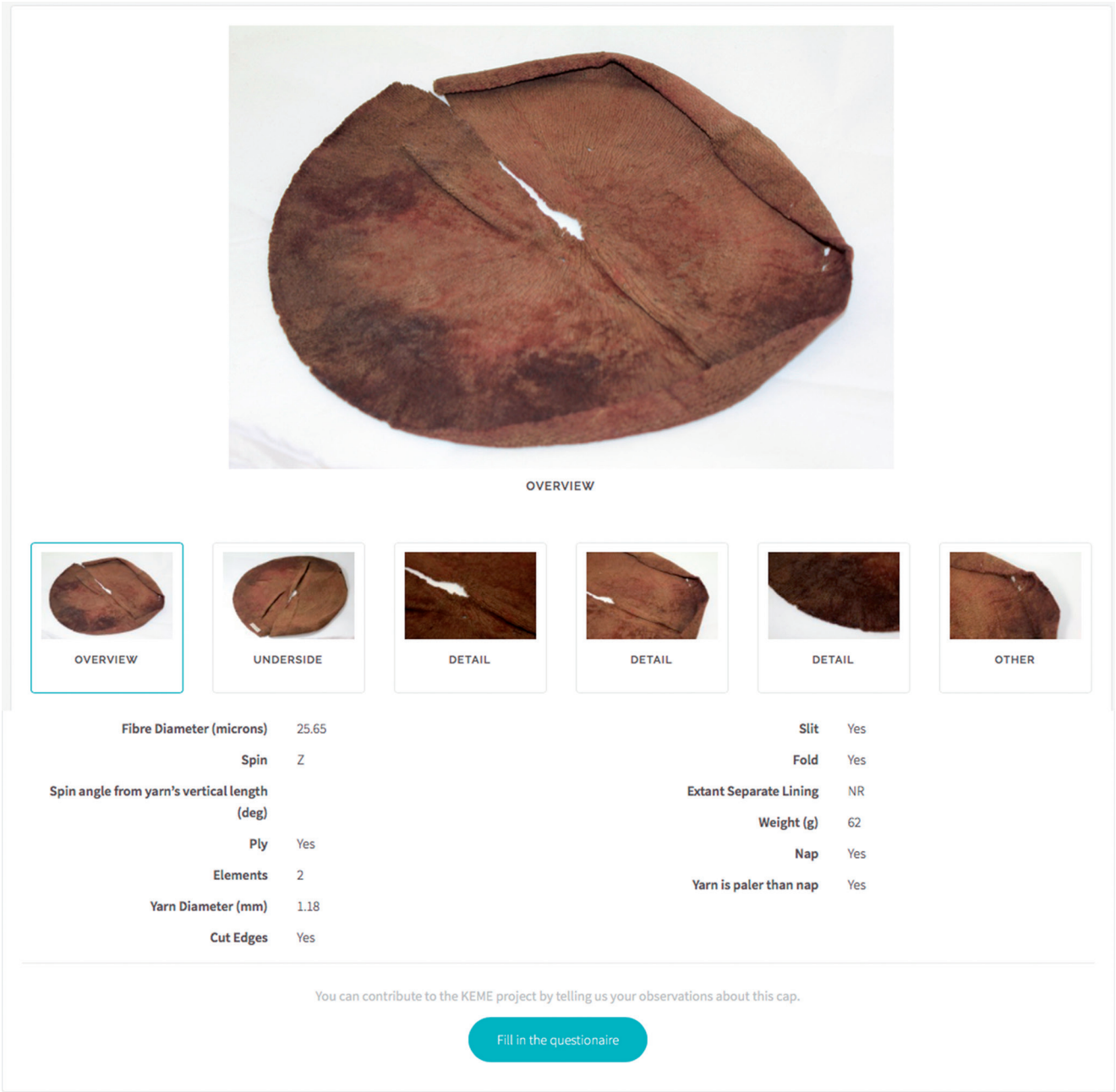


Fig. 3: Screenshot of part of the KEME database entry for a cap lining at the Victoria & Albert Museum, London (inventory no 1563A-1901). Visit: https://kemeresearch.com/caps/44 for more details.

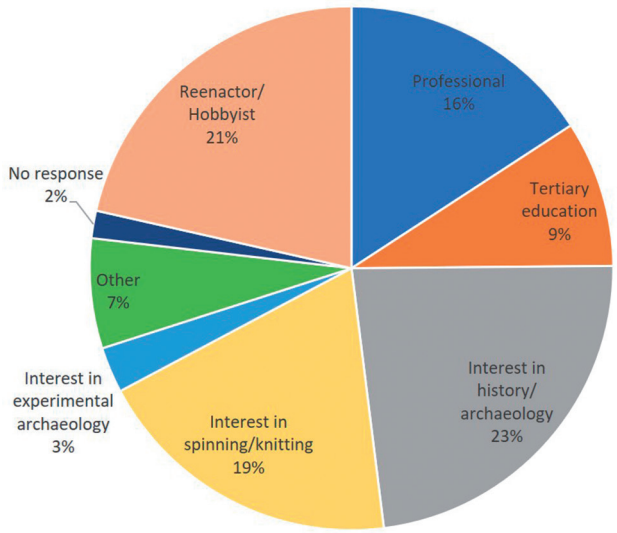


Fig. 4 (left): KEME citizen scientists' primary motivations for volunteering (based on 177 volunteers' responses). Many respondents gave multiple reasons for volunteering but, as these varied in number, only the primary motivation is represented here

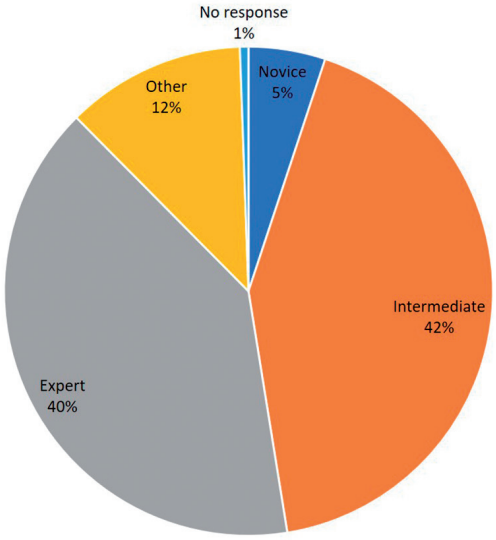


Fig. 5 (right): Self-assessed knitting skill of KEME citizen scientists (based on 177 volunteers' responses)

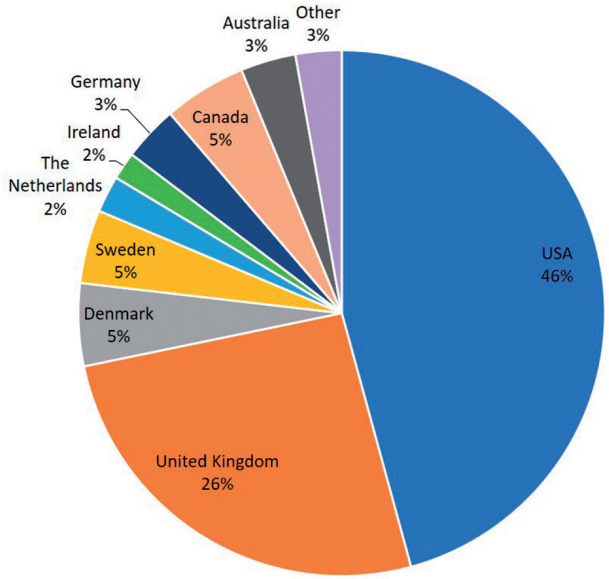


Fig. 6 (left): The locations of KEME citizen scientists around the world (based on 177 volunteers' responses)

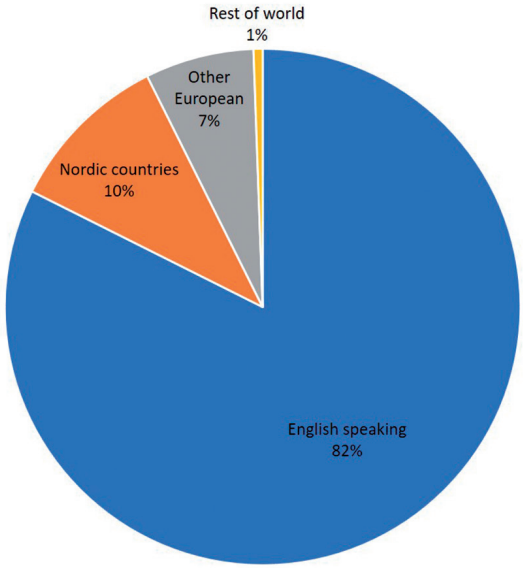


Fig. 7 (right): KEME citizen scientists divided into language groups (based on 177 volunteers' responses)

samples. Therefore, as with archaeological awareness, concerns about craft skill were largely unfounded.

By promoting the experiment online, it was also hoped that volunteers from a wide geographical area would be recruited and that this would increase the number of locally sourced fleece included in the results. Of those recruited, 46% of volunteers were in the United States followed by 26% in the United Kingdom (fig. 6). The remainder were located worldwide but, when divided into language regions, English-speaking countries accounted for 82%. This is likely due to the fact that English was the only language used to promote the experiment. Nordic countries provided the bulk of the remainder at 10% and this can be explained by the KEME project being based at the University of Copenhagen in Denmark (fig. 7).

The success of online recruitment, however, created another challenge for the KEME team – how to communicate with the volunteers. A mailing list was set up using MailChimp from which e-newsletters

Guidelines for Utilising Textiles in Experimental Archaeology

- Raw materials should be selected according to our knowledge of fibres.
- Tools should be reconstructed on the model of precise copies of archaeological artefacts.
- The primary parameter to be investigated is the function.
- All processes must be performed by skilled craftspeople.
- Each test should be performed by at least two skilled craftspeople, in order to secure a more objective assessment of the results.
- All processes must be documented, and some filmed.
- All products must be submitted to textile analysis by external persons.
- On the basis of the established typology, the tools will be reconstructed by experienced craftspeople. Experimental testing will be conducted with the aim of analysing the functioning of the tools, time consumption, and the quality and quantity of thread and textile.

Fig. 8: Guidelines for experimental archaeology developed by the Centre for Textiles Research, University of Copenhagen

could be sent. These were designed to report updates on the experiment, additional instructions and news from the wider KEME project. Newsletters were emailed to volunteers about every two to four weeks, depending on the stage of experimentation. Additionally, two seminars were held at the Centre for Textile Research in Copenhagen. One was at the start of the experiment in February and another in August 2017. During these seminars, local volunteers were introduced to the database and shown how to full and nap their swircles. These events were free to attend, and an overview of each seminar was emailed to all volunteers. Further workshops were held in the United States for volunteers attending conferences on reconstructing historic dress (Malcolm-Davies 2016, 70; Wolfe 2018).

Another important consideration during the design phase was the question of copyright, especially for photographs. Although details of the knitted linings and caps were made available on the database, the copyright for some of the photographs remains with the museums which hold them. Sharing this information, even to progress the research aims of the project, was therefore problematic. The project leader needed to ensure that the data was appropriately secured to satisfy the concerns of some of the participating museums. It was decided that a formal agreement with each volunteer was the best means of achieving this assurance. All volunteers were asked to agree to the terms of the experiment, which included following all copyright restrictions, before they were issued with login details for the database. This agreement was included in the registration process.

Method

The methodology adopted for the experiment was one focused on producing empirical results. This drew on previous work on the need for standards in archaeological textiles research and aligned with the wider KEME project aims (Vajanto 2014). The *Guidelines for Utilising Textiles in Experimental Archaeology*, developed by the Centre for Textiles Research, were also followed (fig. 8). However, some of the requirements, such as the use of historically accurate tools, were not relevant for the experiment (University of Copenhagen, 2017b; Andersson Strand 2015). But other guidelines, such as the need to control key variables (for example, swircle size), were adopted. Volunteers were issued with instructions and asked to knit four identical swircles, each with a diameter of 12.5 cm. It was decided not to restrict the volunteers to certain fleeces but to allow them to draw upon their own expertise in making a selection. Although the original caps showed evidence of being knitted from undyed yarn, it was decided not to make this a requirement because this would be too restrictive. The only condition placed on yarn choice was that no anti-shrinking agent (such as superwash brands

Fig. 9: A Shetland swircle fulled and napped with a teasel (*dipsacus fullonum var sativus*) (Image: Rosalind Mearns)

employ) had been applied to the chosen fleece as this would hinder the fulling process. Once a volunteer had completed four swircles, they were instructed to subject two of them to hand fulling for a period of 45 minutes.

Once dry, the same two swircles were napped, again for a period of 45 minutes. Ideally, a natural teasel would be used to raise the fleece fibres but, if this was not available, a brush with soft bristles could be used instead (fig. 9). Volunteers were advised to avoid cat combs and other similar metal brushes as the stiffness of the bristles would break the fibres rather than lift them from the knitted fabric. Finally, one fulled and one untreated swircle were to be sent to the project leader with the volunteer retaining the other two swircles so they could complete an online questionnaire. This asked volunteers to document their swircles including the type of fleece used, details of the yarn and knitting needle size.

Concurrently, volunteers were asked to use the KEME database to record the characteristics they observed in the photographs of the extant cap linings. In particular, measurements of the diameter of the yarn, spin and ply were requested. Instructions on how to take these measurements were provided in a project newsletter. These observations were recorded via another online survey which was linked to the database (*Knitting in Early Modern Europe*, 2017). This information would then be coupled with the swircle results to inform the final evaluation of the project.

Results

The experiment was initially designed to conclude in August 2017 but, when this date arrived, it became apparent that there was enthusiasm from some of the volunteers to continue the experiment into 2018. Therefore, for the purposes of this report, the results presented here are from the initial phase and were collated in August 2018. These figures have since risen as more volunteers have joined the experiment.

A total of 177 people volunteered to participate in the KEME experiment, by September 2017. This was well in excess of the 100 initially sought. All volunteers who completed the online registration and copyright agreement were accepted as there was no methodological or logistical reason to exclude them. A total of 13 volunteers sent completed pairs of swircles to the project leader and completed the online swircles questionnaire (table 1). Some volunteers sent more than one set of swircles which brought the total to 20 pairs. Three of the fleeces (Ryeland, Shetland, and Wensleydale) were tested by more than one volunteer allowing for the comparison of results from different experimental contexts (table 1). Control sets of swircles were also constructed by a member of the KEME project team to provide materials for participants to full and nap at the seminars. The phase 1 set fulled at the February 2017 seminar consisted of commercial yarns made from Shetland; Ryeland; Black Welsh Mountain; Zwartbles/Merino; and Wensleydale fleece (see Malcolm-Davies 2016 for results). The phase 2 set fulled at the August 2017 seminar were knitted from specially spun yarn from Wensleydale; Romney; Lincoln Longwool; Early Merino; and Shetland fleece (detailed results forthcoming).

The fulled and napped Bluefaced Leicester swircle provided the softest and smoothest coverage from the range of fleece tested by the citizen scientists, but it lacked length when compared to the 16th century cap linings. One of the Wensleydale swircles more closely achieved this length but did not produce consistent coverage (fig. 10, left). The two volunteer-made Wensleydale swircles were knitted at different gauges (table 1). One was knitted very tightly and the other more loosely (fig. 10, left and centre). When subjected to fulling, they reacted in different ways. The tightly-knitted swircle became fluffy while the loosely-knitted swircle developed a ridged texture. The volunteer's Ryeland swircle was also of interest because, after napping, it had developed a texture similar to fur (fig. 10, right). This was noteworthy as it has been hypothesised that the original purpose of napping was to imitate the texture of European furs and velvets (Malcolm-Davies 2018a, 1). However, none of the experimental fleeces provided the combination of even coverage and fibre length to mimic the extant plush nap on the originals.

Online response number	Fleece	Handspun	Yarn diameter (mm)	Spin	Spin angle (degrees)	Ply no. of elements	Wales per 10 cm	Courses per 10 cm	Needle size (mm)	Cover factor before fulling*	Diameter before fulling (mm)
25	Bluefaced Leicester	No (carded)	5	None	NR	1	28	34	3	0.13	130
23	Ryeland	Yes (carded)	3	Z	11-25 (Medium)	1	30	40	2.3	0.19	127
1	Romney	Yes	2	S	11-25 (Medium)	1	40	50	2	0.23	125
32	Highland Wool	No	3	S	1-10 (Loose)	4	24	38	2.75	0.23	132
22	Merino (medium)	No	3.5	S	26-45 (Tight)	3	21	29	2.75	0.23	134
26	Wensleydale	No	2	Z	NR	4	36	48	2	0.24	130
24	Unknown	No	3	S	NR	3	25	30	3	0.24	120
31	Shetland (pre-washed)	No	2.5	Z	11-25 (Medium)	2	35	24	2.5	0.28	128
17	Romney	Yes	1	Z	NR	1	65	65	2	0.31	125
15	Polwarth	Yes	2	S	NR	2	30	32	2.25	0.32	120
30	Shetland (unwashed)	No	2	Z	1-10 (Loose)	2	35	24	2.5	0.35	127
29	Shetland	Yes (combed)	2	S	26-45 (Tight)	1	35	24	2.5	0.35	125
13	Shetland	No	2	S	11-25 (Medium)	2	25	33	2.75	0.35	120
9	Border Leicester	No (combed)	1.5	I	1-10 (Loose)	3	25	38	2.75	0.44	125
14	Wensleydale	Yes	2	Z	1-10 (Loose)	2	25	16	4	0.51	134
27	New Zealand lambswool	No	1	S	26-45 (Tight)	2	30	40	2	0.58	120
16	Gulf Coast Native	Yes (combed)	1	Z	11-25 (Medium)	2 unplied	28	33	3.5	0.66	133
19	Shetland	Yes (carded)	1	Z	11-25 (Medium)	2 unplied	28	28	3.5	0.71	134
21	Babydoll Southdown	Yes (carded)	1	Z	11-25 (Medium)	2 unplied	28	28	3.5	0.71	144
18	Ryeland	Yes (carded)	1	Z	11-25 (Medium)	2 unplied	28	28	3.5	0.71	140

Table 1: A summary of the swircles received from KEME citizen scientists (NR= not recorded; NA = not applicable).

Hand fulling (mins)	Mallet fulling (mins)	Diameter after fulling (mm)	Shrinkage %	Nap height (mm)	Napping time (mins)	Description	Spinning	Participant
Up to 20	61 to 80	115	12	4	Up to 20	Soft	NA	Carol Evered
21 to 40	Up to 20 mins	118	7	3	Up to 20	Soft	Lendrum double-treadle spinning wheel	Margaret Gouin
NR	NR	125	0	0	Up to 20	Soft; Matt (dull)	NR	Cindy Craft
21 to 40	21 to 40	122	8	1	Up to 20	Soft; Rough (fuzzy); Matt (dull)	NA	Kristen Howard
21 to 40	21 to 40	140	-4	1	Up to 20	Rough (fuzzy); Matt (dull)	NA	Sigrid Ellis
Up to 20	60 to 80	125	4	4	Up to 20	Soft	NA	Carol Evered
Up to 20	62 to 80	115	4	4	Up to 20	Soft	NA	Carol Evered
29	29	120	6	4	Up to 20	Soft; Matt (dull)	NA	Barbara Logan
Up to 20	Up to 20 mins	115	8	4	21 to 40	Rough (fuzzy)	Drop spindle	Grace Vibbert
30	30	117	3	3	Up to 20	Soft	Majacraft Suzie spinning wheel	Sandy Bardsley
32	32	115	9	3	Up to 20	Soft; Matt (dull)	NA	Barbara Logan
30	30	125	0	4	Up to 20	Rough (fuzzy)	NA	Barbara Logan
Up to 20 mins	0	104	13	1			NA	Anna Gunnar
30	30	128	-2	1	Up to 20	Rough (fuzzy); Matt (dull)	NA	Lesley O'Connell Edwards
41 to 60	41 to 60	90	33	3	41 to 60	Rough (fuzzy)	Replica c15th spindle & distaff	Amie Flory
NR	NR	95	21	0,5	NR	NR	NA	Tine Jensen
10	10	97	27	2	Up to 20	Soft; Matt (dull)	Bobbin & flyer wheel	Ann Durham
30	30	110	18	2	21 to 40	Soft; Matt (dull)	Bobbin & flyer wheel	Ann Durham
25	25	115	20	2	21 to 40	Soft; Matt (dull)	Bobbin & flyer wheel	Ann Durham
40	40	115	18	2	21 to 40	Rough (fuzzy); Matt (dull)	Bobbin & flyer wheel	Ann Durham

*Cover factor W per cm × YD) + (C per cm × yd) divided by (W per cm × YD) × (C per cm × YD) where W refers to wales, C to courses and YD to yarn diameter (Malcolm-Davies et al. 2018, 10-24, in this issue)

Fig. 10: Three swircle pairs knitted by KEME citizen scientists: the left (by Carol Evered) and centre (by Amie Flory) pairs are made from Wensleydale fleece; the set on the right (by Ann Durham) is made from Ryeland fleece. The yarns used for the centre and right pairs were handspun from fleece for the project by the volunteers (Image: Rosalind Mearns)

The high quality of the swircles demonstrated an interesting variable in the creation of the nap. As might be expected, the gauge of the knitting made a difference to the length and density of the nap. The tighter the knitting (that is, the more wales and courses per 10 cm), the more even and dense the nap (Malcolm-Davies et al. 2018, 10-24, in this issue). None of the swircles were loosely knitted; the gauge range was 21 to 65 wales per 10 cm and 16 to 65 courses per 10 cm before fulling, which provided a useful range of tightly-knitted fabrics for comparison (table 1). The cover factor is calculated from the yarn diameter and the gauge. It provides an indication of the extent to which the area is covered by yarn and provides a useful comparison between fabrics. The higher the number, the closer the fabric, with a maximum of 1 for the complete cover provided by heavily finished fabrics (Malcolm-Davies et al. 2018, 10-24, in this issue). The cover factor for the swircles ranged from 0.13 for the Bluefaced Leicester to 0.71 for the Babydoll Southdown, one of the Shetlands and one of the Ryelands (table 1). This compares with a smaller range for the extant linings which is from 0.14 to 0.44 (table 2). This comparison suggests that a longer fulling time may be more important than coverage since the most successful yarns (two Wensleydales and a Bluefaced Leicester) were fulled for more than 40 minutes.

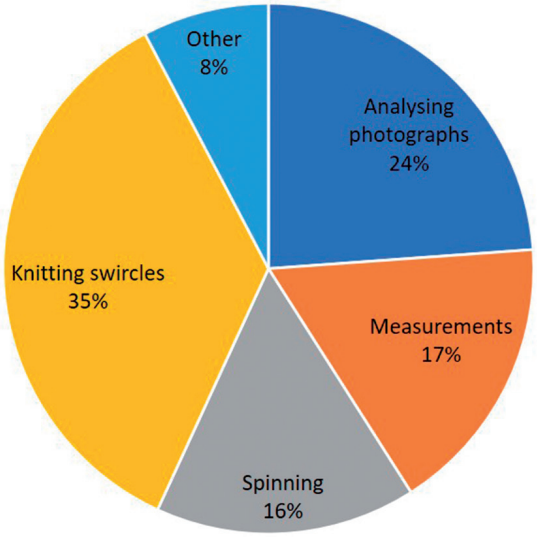
Interestingly, ten of the 20 pairs of swircles from citizen scientists were made from hand-spun yarns even though this was not a requirement of the experiment. Volunteers were invited to spin their own yarn, if they wished to do so. The high return rate of hand-spun yarn was unexpected as only 11% of volunteers identified themselves as expert spinners during registration. A further 16% stated that they had no spinning experience. This suggests that those with spinning skills were more likely to commit additional time to the experiment by producing their

Lining	Location	Yarn diameter (mm)	Wales per 10 cm	Courses per 10 cm	Cover factor
EkBc-1:39762H(L)	Memorial University, Newfoundland	5.68	24	28	0.14
22392(L)	Museum of London	2.15	24	40	0.31
1562A-1901(L)	Victoria & Albert Museum	1.45	36	56	0.31
74.42/1(L)	Museum of London	2	24	40	0.33
5005(L)	Museum of London	1.28	36	64	0.34
1563A-1901(L)	Victoria & Albert Museum	1.18	48	48	0.35
22390(L)	Museum of London	1.38	32	56	0.36
A5456(L)	Museum of London	1	48	64	0.36
A6060(L)	Museum of London	1.28	36	52	0.37
T.191A-1958(L)	Victoria & Albert Museum	1.29	40	44	0.37
A6342(L)	Museum of London	1.35	32	52	0.37
4570*(L)	Museum of London	1.1	40	56	0.39
C21.1939.2.2.2(L)	Leicester City Museum	1.33	32	48	0.39
MA1315(L)	Museum of London	1.32	32	48	0.39
T.618-1913(L)	Victoria & Albert Museum	1.76	28	28	0.41
1574-1901(L)	Victoria & Albert Museum	1.73	28	28	0.41
22389(L)	Museum of London	1.23	28	64	0.42
MR81A6961(L)	Mary Rose Trust, Portsmouth	1.08	36	56	0.42
22391(L)	Museum of London	1.52	24	44	0.42
5004(L)	Museum of London	1.43	28	40	0.42
A6346(L)	Museum of London	1.01	36	56	0.45
T.618B-1913(L)	Victoria & Albert Museum	1.08	32	48	0.48
T.618A-1913(L)	Victoria & Albert Museum	1.44	28	28	0.50
ABCM: 1948.5HN(L)	Buckinghamshire County Museum	1.17	28	40	0.52
T.188-1958A(L)	Victoria & Albert Museum	1.25	24	40	0.53
22388(L)	Museum of London	1.05	28	44	0.56
A26567(L)	Museum of London	1.59	20	24	0.58
5010(L)	Museum of London	1.00	28	40	0.61
T.619A-1913(L)	Victoria & Albert Museum	1.38	20	28	0.62
1575-1901(L)	Victoria & Albert Museum	1.08	24	32	0.68
5013(L)	Museum of London	1.02	20	36	0.76
Averages		**1**	**30**	**44**	**0.44**

Table 2: Data from extant Early Modern knitted cap linings

own yarn specifically for the project. Such a generous contribution of time-consuming labour and expertise had not been anticipated when the experiment was designed and represented a welcome bonus to the project.

A total of 13 people completed swircles questionnaires which matched the 20 pairs received in the post (although a few questions were skipped). There were also some incomplete questionnaires which suggest that some volunteers created additional swircles but they were not sufficiently motivated to finish the questionnaire and send their samples to the KEME project team. It also suggests that there may have been even more volunteers who knitted and napped



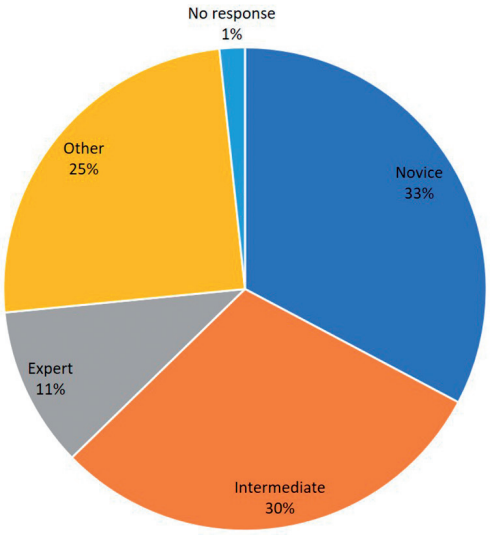


Fig 11 (left): KEME citizen scientists' interests in different aspects of the experiment (based on a total of 415 selections from 177 volunteers' responses). No restriction was placed on the number of options volunteers could select

Fig. 12 (right): Self-assessed spinning skill of KEME citizen scientists (based on 177 volunteers' responses)

swircles but were not inspired to record their results or send them for further analysis (Malcolm-Davies 2018a, 6).

None of the volunteers described their finished swircles as 'silky' or 'shiny', which were key characteristics of the better-preserved nap found on the original caps and linings. The most common descriptor was 'soft' (12 out of 20), followed by 'matt (dull)' (10 out of 20) and 'rough (fuzzy)' (7 out of 20) (table 1). Respondents were able to select more than one option. These results highlight that further work is needed to accurately replicate the original texture.

Only seven responses to the online database questionnaire which asked for observations of the original material were received from three different people as of September 2017. This was despite 41% of volunteers expressing an interest in contributing to the examination of the extant material online at the point of registration (fig. 11). The small return rate was particularly counterintuitive as the KEME database exhibited a high level of traffic throughout the project, and this was well in excess of what it had been designed to handle (Cox 2017). This small number of database observations could not be used to test the interpretation of the archaeological record proposed by the KEME project. However, this result suggested that more effective ways of inviting and encouraging 'engagement' with the online resources were necessary (Stiller & Petras 2015,163-164).

There was some discrepancy between the number of people who subscribed to the mailing list (190 people) and the number of completed registrations (177 people). It was presumed that the additional mailing list subscriptions were from people interested in the project but unable to commit to volunteering. Using the 'open rate' feature on the MailChimp site, the number of volunteers opening each newsletter, and thereby their collective level of enthusiasm, was tracked. At its peak, 71% of subscribers, or 135 people, opened the newsletter and, at its lowest point 47%, or 90 people, opened it.

Assuming that those who opened the e-newsletters were also those who completed the online registration, thereby displaying the greatest interest in the project, these figures suggest that only half of the volunteers continued to engage with the project after initially registering and receiving some information. This is useful to know as it demonstrates that, in accepting a higher number of volunteers, the experiment was able to stay close to its target of 100 despite losses to the original cohort. It also lessened the significance of receiving only 20 swircle sets as it became reasonable to assume that this number was representative of a share of approximately 90 volunteers rather than 177. The aim of the fleece testing was to achieve a wide range rather than a large quantity. The 20 pairs of swircles tested a total of 13 different fleeces, which was far more than could have been achieved by the core project team in the same time. A swircle completion rate of 15% to 20% is a fair achievement for a far-flung

experiment requesting demanding work and some expense from its volunteers.

Discussion

The inconclusive results provided by the swircles suggest that, despite a variety of fleece being tested, none of them are close to the original, as sheep husbandry history confirms (Ryder 1964). However, other contributing factors became apparent. First, although the methodology was designed to be an empirical one, human error played a part. Volunteers were instructed to full their swircles for at least 45 minutes but how conscientiously this was done seems to have varied. Some swircles showed signs of only being partially fulled and some records indicated swircles had not been fulled for long enough. This was perhaps due to a lack of familiarity with the process amongst the volunteers. They were uncertain of the end result and so stopped rather than continuing until the process was complete and documenting a longer fulling period. Such errors would then have had a direct impact on the resulting nap as the scales on the fleece fibres would have only been partially removed. Therefore, a suitable 16th-century match may have been tested but, due to incomplete fulling, the correct length of nap and coverage was not achieved. Further testing of the same range of fleece with more rigorous observation and recording of the fulling process is needed to resolve this issue.

The way in which the different fleeces were spun into yarn may also have influenced results. The archaeological record indicates that most of the extant caps and linings may have been knitted from a worsted-spun yarn. Fleece prepared for this style of yarn is combed to align the fibres. In contrast, many modern knitting yarns are woollen spun which produces a fluffy, air-filled yarn. Fleece for this style of yarn is carded before spinning. In designing the experiment, volunteers were not restricted in their choice of yarn but, in hindsight, this may have affected the results.

Another explanation for the inconclusive results might be that the extant caps were not actually fulled. The absence of scales observed on the fleece fibres recovered from the archaeological linings could be due to deterioration over time. However, this seems unlikely because a lack of scales was observed in numerous fibre samples from caps preserved in a wide variety of conditions (Malcolm-Davies 2018b, 192). If such an archaeological deterioration marker were to be credible, some variation in the preservation of the fibres would be expected. A more likely explanation is that the caps were subjected to expert manual or mechanical fulling which provided a more vigorous treatment than the hand fulling applied by the volunteers. The use of mechanised fulling mills by cappers in the Early Modern period was much protested on the basis that it was not as effective as that done by hand or foot (Malcolm-Davies 2016, 59). Further experimental research using mechanised fulling could yield interesting results.

The low return rate of the database questionnaire from volunteers had an impact on the scientific aspects of the experiment. The KEME project team hoped that close inspection of the extant artefacts by a diverse group of people would lead to new insights. However, due to the limited number of database questionnaire responses received, this could not be tested. This is important because constructing swircles may help to identify the best modern fleece for reconstruction but only the study of the extant material can verify these findings.

Maintaining volunteer enthusiasm was a somewhat unexpected aspect of the experiment. At the outset, it had been assumed that, given the wide public interest, volunteers would be motivated to actively participate in the project. However, as shown by the discrepancy between volunteer registrations and swircles received, this assumption proved optimistic. It may have been that the cost of postage for the swircles was too expensive or that the online swircle questionnaire was too demanding; with a maximum of 60 questions, it was not a quick or easy task to complete. Yet, no feedback was received to indicate these were issues.

Some volunteers made assumptions about what to do rather than seeking clarification. For example, some original cap linings appear to have been knitted from two single unplied yarns rather than one two-ply yarn. In communicating this information to the volunteers as an interesting observation of the archaeological evidence, some assumed that they were required to knit swircles in this way, which made sourcing yarn much more challenging. This caused confusion until the original swircle instructions were confirmed by the project team. The lack of questions and requests for clarifications from volunteers was puzzling since multiple means of contacting the project team were provided. If the experiment were to be repeated or similar projects devised, more local events for volunteer groups with face-to-face contact with the project team is recommended. This would help to manage misinterpretations and keep volunteers motivated.

Better control of the experiment could have been achieved by providing a list of fleece/yarn, with sources of supply, and inviting volunteers to sign up

to obtain and test a specific example. Alternatively, the materials could have been purchased by the project team and sent out to the volunteers. This would have prevented duplicates and widened the range of materials under review. However, the model used invited volunteers to use yarn they already owned or would like to test, which kept the costs down.

The high non-participation rate between those who registered for the experiment and those who continued to engage with it also needs to be addressed. There are several possible causes for this. First, although the swircles were designed to reduce the amount of time volunteers needed to commit to the experiment, they caused some disappointment. After registration, a small number of volunteers contacted the KEME project team to ask if they would receive instructions to knit a cap as part of the project. Knitting swircles may not have been as inspiring for some volunteers as an actual cap, which may have contributed to the drop-out rate. Other motivations for wanting to participate may also have contributed to this figure. For example, in the initial phase of promoting the experiment online, a cluster of registrations were received from a single university. When the results were collated, no samples or questionnaires were received from this group. These people may have joined collectively as part of their studies without any intention of participating in the experiment. It seems likely that this was not an isolated case. This could also explain the sustained high level of database traffic yet low return rate of the questionnaire.

A further possibility for the discrepancy between registrations and participation may have been a lack of familiarity with academic language. At the outset of the experiment, all volunteers were given free online access to a copy of a journal article recently published by the project leader (Malcolm-Davies 2016). It detailed the results of the KEME project so far and gave the basis for the citizen science experiment. However, although nearly half of the volunteers expressed familiarity with archaeological practices, the formal language of this article, combined with graphs and technical terms, may have intimidated some participants leading to a loss of interest. The combination of all these factors, coupled with illness, personal crises and a lack of time (which were mentioned in some emails and personal conversations with volunteers) could account for the non-participation rate of nearly 50% seen between initial registration and ongoing engagement.

A lack of clarity in communications from the project team may also have contributed to volunteer attrition and the small number of results received. For example, no end date was given at the start of the experiment. A clear start date and end date, communicated at the outset of the experiment with intermediate targets, might help drive volunteer motivation. Publication of some features of the database were delayed and more time than had been anticipated was needed to edit the e-newsletters and other communications. Longer periods passed between updates than was originally intended.

If a similar experiment were undertaken, a planned schedule of e-newsletters and pre-drafting of social media updates would be recommended. Each social media post and newsletter required at least one new and engaging photograph. Sourcing these during the experiment contributed to some of the delays. Unlike the database, the distribution of the newsletters beyond the registered volunteers could not be controlled which precluded the use of any copyrighted images. Stockpiling a variety of suitable promotional photographs would also be advantageous. Yet, despite these issues, very few people chose to unsubscribe from the mailing list suggesting that they wanted to remain connected to the experiment even if they were not actively contributing.

In terms of citizen science, the experiment was successful. The receipt of 20 pairs of swircles added substantially to the material available for review – both in quantity and range of fleece. There was a high level of knitting skill and pre-existing archaeological awareness amongst the volunteers, who demonstrated sufficient expertise to contribute meaningfully. This requirement for expertise in academic research, however, should be questioned before final conclusions are drawn.

There is a predisposition for recruiting experts for experimental archaeology projects but whether this accurately reflects the historical situation that produced the extant items should be considered (Shimada 2005, 607; Millson 2011, 3). It is not necessarily the case that the knitters who produced the extant caps were experts in their craft. Whilst it is true that some understanding is needed to determine which questions are appropriate to ask of a craft, pre-existing contemporary skill can be a hindrance when attempting a reconstruction (Hein 2009, 4; Wood 2010, 13). It can introduce modern assumptions and techniques that were not present in the minds of the original creators (Hudson 2014).

In this context, the provision of knitting instructions for the swircles could be seen as problematic. Although it was deemed necessary to ensure consistency across the volunteer group, 16th century knitters did not use instructions (Botticello 2003, 8). The experiment diverged from the archaeological and historical record

to serve the modern requirements of the volunteers. In doing so, it introduced a new form of expertise – the ability to read instructions. It might have been feasible to ask volunteers to look at the extant material online and work out their own way of knitting a miniature version of a lining. This would have stimulated more engagement with the extant evidence and avoided introducing a modern technique into the experiment. However, the aim of the project was not to compare the presence or lack of knitting instructions or compare the knitted fabric but to establish the best modern material for reconstructing the caps. A swircle knitted by a novice could be fulled and napped in the same way as one made by an expert. That only well-made samples were received from volunteers provides an insight into the willingness of highly skilled individuals to contribute to academic research.

Each volunteer who sent swircles committed a great deal of time and effort to the experiment, well in excess of what had been anticipated. Most of the volunteers who submitted swircles also recorded highly detailed, scientific information via the online swircles questionnaire which made it possible for the project team to compare variables in a systematic way. Nearly everyone uploaded photographs to the specifications requested providing the KEME project with a valuable visual digital record of the experiment's results.

The success of citizen science in this experiment is not just important for the KEME project but the wider study of textile archaeology. Many archaeological projects seek to engage volunteers in order to make them viable. Funding is often restrictive and volunteers are seen as a way of achieving research ends within tight budgets. The large number of volunteers who initially registered for the KEME experiment suggests that not only is citizen science feasible for research but that there is a thirst amongst the public to become involved in such activities. In saying this, the experiment has demonstrated that such activities do need to be carefully planned with a great deal of time invested in communication and encouragement in order to achieve far-reaching results. Care should also be taken not to under value the skills required to participate.

The crowdsourcing lessons learnt by the KEME team have already been applied elsewhere. The Texel Silk Stockings Project is using a modified KEME model of citizen science to reconstruct a pair of 17th century knitted silk stockings recovered from a shipwreck found off the coast of the Dutch island of Texel. The project has also solicited online financial support to buy materials through crowdfunding. It has hosted two workshops in the Netherlands during which swatches of knitted silk were created by volunteers (Leiden Textile Research Centre 2017). Volunteers further afield are now knitting stockings according to the instructions and guidelines developed during the workshops. Preliminary results suggest that this modified approach will produce useful results.

Further research

There is scope for further experimentation because the range of swircles received did not test the full range of potential fleeces for fulling. Another way forward would be to identify the best performing fleece during this first phase of citizen science and ask further volunteers to test them to check that they perform as well in a range of experimental conditions. Investigation into the role of mechanised fulling and the results this can produce would also provide valuable insights. The KEME experiment has continued into 2018, which may widen the range of fleece for which results are available (Malcolm-Davies 2018c).

Conclusion

No satisfactory match for 16th century fleece was found as a result of the fleece and fulling experiment. This was due to a number of factors such as the range of fleeces tested and volunteer awareness of spinning and fulling methods. The design of the experiment sought to limit these human factors, but it was found that room for error persisted. Despite these issues, volunteers were successfully engaged in providing a small number of knitted, fulled and napped swircles. Volunteers were found to possess a level of knitting knowledge in excess of expectations which could be seen in the quality of the samples they submitted. Approximately 50% of initial registrations did not follow through with participation but, as double the number of people initially sought signed up for the experiment, this had minimal impact on the way in which the experiment was conducted. Despite inconclusive results, the experiment demonstrated that, through citizen science, members of the public can be engaged to contribute meaningfully to academic textiles research.

Acknowledgements

We would like to thank the many volunteers who contributed to this project. Without their input, this experiment would not have been possible within the resources available. There are too many people to name here but the KEME Team hopes that in seeing these results our volunteers will be able to appreciate the weight of their contribution to our

collective understanding of 16th century knitting and fulling.

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