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October 30, 2012

TO: Lorena Madrigal, AAPA President

RE: "Biological Anthropology in the Genomic Era":
Report on 2010-11 interviews and survey of the AAPA membership

Dear Dr. Madrigal:

We are submitting this report entitled "Biological Anthropology in the Genomic Era" to the AAPA Executive Committee. This document reports on the combined results of interviews that took place from 2010-11 (of biological anthropologists and of researchers in related disciplines), and an AAPA member-wide survey that took place in 2011.

We ask that you read this report with one caveat in mind: In the report, we comment on the fast pace of the genomic era. Even over the course of this study (from 2010-11), changes in genomic technology and infrastructure changes have taken place. We therefore expect that much of the urgency expressed by respondents one to two years ago – and that is reflected in our report – would be reduced should the same individuals be interviewed or surveyed today.

The information derived from the interviews and survey has been invaluable. First, our presentation of results at the 2011 AAPAs allowed us to engage in fruitful dialogues with our colleagues about genomics (*see* Hulsey BI, Pack FL, Cabana GS. 2011. Biological anthropology in the genomic era. Am J Phys Anthropol 144(S52): 171). Second, via the American Association of Anthropological Genetics (AAAG), we have implemented of workshops and webinars in response to survey and interview results. For example, as AAAG President from 2011-12, Cabana created an Education Committee to develop AGAR workshops (Application of Genomics to Anthropological Research). In January 2012, AGAR featured prominent genomicists who showcased genomic methods and research as applied to anthropological questions. This two-day workshop drew sixty biological anthropologists, ranging from anthropological geneticists, to skeletal biologists, human biologists, primatologists, and paleoanthropologists. In 2013, AGAR will focus on computational approaches to genomics. And, at the 2013 AAPAs, AAAG will be holding a workshop on teaching genomics in the anthropology classroom.

We thank you for the opportunity to conduct this work. Please feel free to contact us should you have any questions.

Sincerely,
Graciela Cabana, Brannon Hulsey, and Frankie Pack

"Biological Anthropology in the Genomic Era": Report on 2010-11 Interviews and Survey of AAPA membership

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Human genomics is a fast paced research area that has been primarily oriented toward human health and disease research, though it has also given substantial attention to human variation and origin studies (e.g., Rosenberg et al., 2002; Green et al., 2010). As anthropological geneticists, we had a general understanding of the challenges facing the relatively narrow subfield of anthropological genetics: anthropological geneticists have been relatively slow to develop genomic approaches, in large part because new genomic technologies and methodologies require money, accessibility, new laboratory skill sets, and bioinformatic training. What was yet unclear was how a relatively late entry into the genomic era was impacting the field of Biological Anthropology more broadly, if at all. Therefore, this project's goal was to address how biological anthropologists in general, and anthropological geneticists in particular, could reposition themselves to face the challenges mentioned above.

Toward this end, we interviewed and surveyed consenting professionals on the ways in which any challenges posed by the genomic era may affect their practice of biological anthropology in US-based academic institutions. Questions were structured around three areas: (1) general attitudes relating to genomics, (2) teaching, and (3) classroom teaching and mentoring. Throughout our inquiry, we treated molecular anthropologists as a special category of respondents with the presumption that of the diverse practitioners of biological anthropology, they would be both the most informed about genomics and the ones with the most at stake vis-à-vis genomics.

This report focuses on North American concerns within a certain sector of the academy; this is because an overwhelming number of respondents were located in North American-based academic, mostly doctorate-granting, institutions. We nevertheless hope that the points covered here will provide some food for thought for our colleagues in other locations, positions, and circumstances.

GENETICS, GENOMICS, AND THE "GENOMIC ERA"

Before we present and discuss the interview and survey results, a discussion of the "genomic era" is in order. The genomic era has been in place for about two decades, and refers to this current moment in which "genomics" has enabled scientists to use powerful technological tools for sequencing the genomes of entire organisms, including humans.

Formally speaking, the term "genomics" should be subsumed under that of "genetics," the latter being an overarching term for the study of biological inheritance. Nevertheless, the term seems to have gained a life of its own that is apart from "genetics." The separation of terms, even in the scientific literature, is semantically significant: The term "genetics" is often associated with a singular focus on genes along with the application of classic Mendelian principles of inheritance in which one or a few gene(s) represent(s) one trait. This simplified perspective represents "genetics" as the study of single genes and their effects and "genomics" as the study of the functions and interactions of all the genetic material in the genome. It can, but does not necessarily, include a study of interactions with environmental factors. We recognize that lay and professional persons alike often draw a distinction between the two terms as a meaningful way of highlighting the changes in technology, informational content, and even ways of thinking, brought about by genomic-level advances in recent years, as "genomics" indeed represents a new, emergent, techno-scientific field (Zwart, 2008). Nevertheless, we support the formal hierarchy of "genomics" as encompassed by "genetics."

The genomic era made its debut in 1990 with the launch of the international Human Genome Project (HGP). The HGP could be characterized as a call to identify and catalog all genes found in the

human genome. This effort was coordinated by the U.S. Department of Energy and the National Institutes of Health (NIH) and fulfilled by myriad national and international players. Certainly by 1990, the capability of sequencing at a genomic scale was already in place. These capabilities were first showcased by the partial sequencing of the bacteriophage ΦX174 of *E. coli* (Sanger et al., 1977), but the procedures to do so had not yet become fully routinized and accessible to a wide constituency. By the time of the HGP's culmination in a rough human genome draft in 1993, developments in sequencing technology had accelerated to such an extent that they subsequently spurred the genomic era in which we now find ourselves. We are currently working at a time in which "next generation" sequencing (i.e., relatively low cost and high throughput), with the expectation of immediate forthcoming developments in computational, data storage, and data sharing technologies.

The current stumbling blocks are data storage and analysis. Throughout the 1990s and early 2000s, "technology has driven genomics" (Green et al., 2011:205) – that is, the focus had been on developing the technology to sequence genomes quickly and at low cost, as per the original HGP mandate. Viable sequencing technology is now in place, so the next hurdle is in dealing with the resulting "fire hose of data." For example, a single person's genome consists of 3 billion base pairs, so that the challenge of storing the genomic information of multiple individuals is daunting. The problem does not end with data storage, however – the downstream analysis of those data is also a significant issue. Thus the field of bioinformatics, concerned with the application of statistics and computer technology to the management of biological information, is gaining traction.

Because of this shift in priority from sequencing technology to data management and analysis, some would argue that we have already transitioned away from the "genomic" into the "post-genomic" era. The idea is that the genomic era consisted of the development of technologies that allowed us to sequence entire genomes. In contrast, the post-genomic era brings to us the development of technologies and methods that allow us to quickly and easily annotate genomes (find and tag locations of interest). It also more abstractly refers to anything that is coming after the development of the so-called "next generation" sequencing technologies, such as the development of other '-omics' (e.g., "proteomics" or "metabolomics").

This increasing ability to "read" whole genomes with greater accuracy (and at lower costs) is offering us the possibility of insight into formerly unappreciated variations in genome architecture. The molecular typing methods that we have relied on for the last decade or two have made the typing of certain kinds of variants *de rigueur*: point mutations, or single nucleotide polymorphisms (SNPs), and short tandem repeats (STRs), among others. Perhaps more significantly, other so-called structural variations, such as large-scale duplications and reversals, additions or omissions, that are due to sometimes simple, sometimes amazingly complex molecular mechanisms, also differentiate individual genomes. Structural variations may be responsible for much of the genetic differences among organisms (Mills et al., 2011) and are now more readily accessible to researchers. The better we understand the architecture of genomes, the better we will be able to elucidate the complex interactions between genomes and environments.

Regardless of what we call this present moment or what we may imagine the future to hold, it is clear that these technological and intellectual developments are happening rapidly – in fact *so* rapidly that the question of genomics' impact on the "doing" of biological anthropology has gained some urgency in the last few years. For anthropological geneticists specifically, this means accessing genomic technologies and developing the appropriate skills and knowledge base to know what questions to ask and what hypotheses to test. For biological anthropologists generally, this means being able to put genomic level data in a broader intellectual context, ranging from new theoretical understandings in biology (c.f., Wray, 2010) to the ethical and social implications of genomic research.

METHODS

We employed a three-phased methodology that consisted of oral (phone) interviews conducted prior to, and immediately after, a targeted web-based survey. The pre-survey set of interviews was skewed toward investigators who currently run projects that heavily rely on genetic data. These initial discussions informed the subsequent survey questionnaire and post-survey interviews, both of which accessed a broad representation of the bioanthropological discipline. The post-survey set of interviews served to probe more extensively into the attitudes and experiences vis-à-vis genomics that did not necessarily come up in the initial interviews but were revealed in the survey.

All interviewees and survey takers received the same initial set of questions eliciting basic information as well as general opinions and attitudes with regards to genomics and the field of biological anthropology. Following this, interviewees and survey takers responded to questions that served to assess the ways in which the genomic era may affect their practice of biological anthropology within two additional domains: research, and classroom teaching and mentoring.

This combination of methods was designed to fit the nature of this exploratory work: The survey allowed us to query a large number of professionals that presumably relate, in some way, to the disciplinary category of biological/physical anthropology. Web based surveys are relatively low-cost, permit rapid data collection, and provide reliability in the data collected in that all participants are answering the same questions or subset of questions. Online surveys are conversely somewhat disadvantageous in that they do not allow much room to explore intriguing new insights that often come up in the course of a conversation. For this reason, we also utilized oral interviews to explore any nuances within the issues raised by genomics.

Interviews and interviewees

We interviewed researchers who self-identify as biological/physical anthropologists, evolutionary biologists, and/or human geneticists (n=27). As much as possible, we chose interviewees with the purpose of maximizing diversity with respect to research specialties, career stages, and home institutions (academic versus private foundation; doctorate-, masters- and other degree granting institutions). All interviewees were located at North American institutions. Seventy-six percent of all interviewees claimed primary expertise in genetics.

All phone interviews were conducted within the span of a year. The pre-survey interviews took place in March and April of 2010, and the post-survey interviews in March and April of 2011. Interviews consisted of two parts: (1) questions eliciting basic information, such as place of employment, position, and research foci, and (2) questions that were open-ended and designed to gauge subjects' level of knowledge of genomics as well as general attitudes and opinions with respect to the role of biological anthropology in the genomic era.

Web based survey and survey respondents

We distributed an online survey to the AAPA 2011 membership that remained open for the entire month of February 2011. The survey was administered using Qualtrics.com, Inc. (Provo, Utah, USA). Electronic invitations to participate in the study were sent to all 2011 AAPA members with an email address on file; the email contained a link and password to a protected internet site. Qualtrics.com collected, encrypted, and stored survey responses. The survey utilized skip logic, a feature that allows researchers to tailor questions such that respondents bypass questions not relevant to them based on previous answers. The survey was designed in a multiple-choice format with occasional open-ended text entries. The survey was kept to a manageable size of 15-30 minutes total participation time to minimize fatigue or disinterest that would lead participants to quit the survey before answering all questions. Only fully completed surveys were considered in the final analysis.

Forty one percent of the 2011 AAPA membership completed the online survey. Ninety two percent of survey respondents were in-residence at academic institutions as faculty (tenure-track/non-tenure track/tenured), graduate students (masters and doctoral levels, or the equivalent), or post-doctoral researchers. The remaining eight percent of survey respondents were in non-academic institutions as research scientists (including curators and post-doctoral researchers) in nonprofit or commercial sectors, or as independent researchers. Most participants (86%) were located in North America (United States and Canada); the rest were evenly distributed among 16 other countries (n=57; 14%). See Figure 1 for more details about survey respondents.

Of those positioned in academia, 80% were primarily affiliated with Anthropology departments (or the equivalent)[1], and the rest in departments of Anatomy, Ancient History, Biological Sciences, Demography, Forensic Science, Genetics, Public Health, Statistics, and/or in medical schools (or their equivalents).

Fourteen percent of respondents claimed primary expertise in genetics. This consisted of ten percent of all faculty, 16% of all students, and 53% of all postdoctoral researchers.

Analysis

To best assess trends among differing relevant constituencies, we broke down interview and survey responses in terms of respondents' (1) level of self-identified genetics expertise, and (2) professional status either in, or outside of, academic institutions. For the latter, our categories were: academic faculty, graduate students, academic and non-academic postdoctoral researchers, and non-academic "other" (research scientists/managers, and independent researchers). The responses of postdoctoral fellows and non-academic "others" usually only figure in the discussions that include all respondents; this is because few postdoctoral fellows and non-academic researchers ("other") responded to our survey and consented to interviews, and also because their responses did not differ from the general trends. From this point on, we will refer to the category of respondents (interview and survey) claiming genetics as a primary expertise as "GE" (genetics expertise) and all others as "NGE" (non-genetics expertise).

This is exploratory work, and as such, we forwent a formal statistical analysis of results. Instead, we discuss trends in interview responses combined with raw data summaries of survey results. Any trends inferred from these data are to be considered suggestive and deserving of further study.

RESULTS AND ANALYSIS

What follows is a presentation of results combined with analyses, broken down by thematic areas: (1) General Attitudes, (2) Research, and (3) Teaching and Mentoring.

1. General Attitudes re: The Genomic Era and Biological Anthropology

The section on "general attitudes" was designed to gauge respondent impressions and perceptions of what the genomic era entails. Interestingly, trends in responses varied little according to professional status: opinions among faculty, students, post docs, and "others" tracked each other very closely. However, distinct differences did exist between those who claimed primary genetic expertise and those who did not.

Interview results. GE interviewees repeatedly used the metaphor of a "double-edged sword" to describe the concurrent opportunities and challenges presented by the genomic era. Accordingly, GE

[1] Anthropology department equivalents include any kind of academic institutional unit that subsume the field of anthropology. These could take the form of "combined" departments (such as departments of "Sociology and Anthropology") or higher-level schools (such as Arizona State University's "School of Human Evolution and Social Change"). From here on out, the terms "anthropology department(s)" and "anthropology" will refer to all such institutional equivalents.

interviewees simultaneously expressed excitement over the potential of new findings and understandings offered by genomics, while voicing anxieties ranging from the more practical (such as generating genomic data), to the far-reaching (what this might mean for biological anthropology). Importantly, the numerous challenges were seen as those that *currently* impact anthropological researchers, while opportunities were framed in terms of potential *future* gains. These challenges and opportunities will be addressed further in the discussion section of this report.

GE interviewees also noted an increased pace of change in genomic research and development. The underlying tenor of several GE interviews was that any potential opportunities of the genomic era might manifest themselves only if anthropology "steps up" to handle the challenges.

Finally, all categories of respondents saw genomics as presently data- and technology-driven, more so than question-driven, and those research questions are driven mostly by biomedical concerns. And, because genomic-level data and technology have pushed research fields forward without the concomitant development of sophisticated analyses of those data, it may be too easy to leave behind concerns about the interpretation of data, who they affect, and what their implications are. Therefore, respondents articulated the concern of too easily falling into the trap of simplistic question development or interpretation. For example, some specifically argued that use of genomic technologies and data are driving a resurgence of an emphasis on classification, to the point of re-essentializing race.

Survey results. Turning toward broader disciplinary attitudes, about half (46%) of all respondents indicated that the genomic era *generally* calls for professional reorganization at one or more levels (individual researchers, institutions, funding agencies, and/or professional organizations) (Fig. 2). More specifically to our discipline, an overwhelming proportion of respondents (72%) felt that the genomic era presents challenges to bioanthropology, with approximately one fourth of those claiming that the discipline is *not* adequately meeting challenges (Fig. 3). When all survey respondents were asked what those challenges to bioanthropology might be, respondents listed general ones, such as research, funding, methods development (technology and bioinformatics), teaching, and mentoring, as well as ones that were more directed at the discipline, such as maintaining anthropological significance, ethical considerations, and public engagement.

The 24% of respondents who answered that bioanthropology is *not* adequately meeting the challenges of the genomic era provided detailed responses to the follow-up question of how and/or why the field is not doing so. The individual responses were broad ranging, but generally addressed issues relating to infrastructure, teaching and training, funding, and the current intellectual state of biological anthropology. The individual responses are organized by respondent status and thematic topics in the accompanying supplementary table.

Finally, when asked specifically whether bioanthropology is adequately incorporating genomic research and findings in specific areas – research, teaching, and/or mentoring – answers were equivocal in all three cases, across all professional statuses, and regardless of whether one claimed GE status or not. That is, a third of the time, all respondents answered "Yes" to those questions, a third "No," and a third "Not sure."

GE survey response trends were similar but magnified: 90% of GEs felt that the genomic era presents challenges (versus 68% of NGEs), 71% felt that the genomic era calls for general professional reorganization, and more than half of GE respondents saw the discipline as inadequately meeting challenges (Figs. 2-3).

2. Research

This section on research is concerned with whether and how genomic data, method, or theory are being incorporated into bioanthropological research. We were also interested in how respondents' were funding their research projects (both genetic-based and not), and with what level of funds.

Interview results. Interviewees listed multiple obstacles for entry into the research aspects of the genomic era. Among the more practical concerns, *access* to the relevant technology, such as high throughput sequencers and their proprietary biochemistries, is limited and uneven. A limited number of institutions have acquired the requisite technological capabilities. Another perceived challenge relates to *data interpretation*: Bioinformatic resources are as yet poorly developed, although this state of affairs is changing quickly.

The above listed two concerns – access to technology and to bioinformatics tools – are not unique to anthropologists. One challenge that may differentially impact anthropology, however, is funding. This includes *sources* of funding as well as *appropriate levels* of funding for genomic level research. Interviewees noted that projects generating and analyzing genomic data demand significant funds, which include both the cost of analyses and of personnel (lab techs, graduate students, and/or postdoctoral researchers). This may mean that funding sources typically tapped by biological anthropologists, such as the National Science Foundation (NSF), may not be able to fund as many projects as previously. For projects with higher budgets (e.g., above a half million US dollars), the only viable option is to solicit funds from the NIH, but to do so, the project often must be more biomedically oriented.

Costs will eventually decrease, but as one interviewee put it, "anthropologists often wait for prices to drop before they use the newer technology." Consequently, anthropologists do not tend to lead the charge in research that is perceived as "cutting edge."

Survey results. This survey section's respondents consisted of faculty and postdoctoral researchers only, who listed "research" as one of their professional duties and responsibilities. These two constituencies exhibited no systematic differences in responses, while significant, across-the-board differences were again evident between GEs and NGEs.

Half of all survey respondents (49%) were engaging genetics in their research. They were accessing genetic data derived from various, non-mutually exclusive sources: their own labs (including sending samples to a commercial laboratory), collaborators, published research, and very occasionally, public databases.

For GEs, we were interested in finding out more specifically what kinds of genetic data were generated and bioinformatics analyses conducted, and what kinds of available resources existed to do so. Sixty five percent of GEs were generating genomic-level data (n=31) and were using a wide variety of platforms (e.g., high throughput sequencing, microarrays, etc.). These technologies were being accessed a third of the time at respondents' labs, a third of the time at shared core laboratory facilities (either in-house or at external academic institutions), and a third of the time via private biotechnology companies.

In terms of bioinformatics analyses, 75% of GEs conducted some to all of their own bioinformatic analyses. The 25% who were not conducting their own bioinformatics analyses were accessing bioinformatic resources/personnel within their home institutions or at external institutions, but rarely via private companies.

To fund recent genetic-based projects, 55% of GEs were obtaining funds from the National Science Foundation (NSF), 30% from the NIH, and between 10-20% from various other (smaller) granting agencies, such as the Wenner-Gren and the Leakey Foundations. Total budgets tended to be up to $100,000 (46%), or between $100 – 500,000 (35%), though some (19%) were obtaining more than $500,000 (Fig. 4).

Like GEs, NSF was the primary funding source for NGEs' recent projects (46%). This result was followed by the Wenner-Gren Foundation (30%) and various other smaller granting agencies. Total budgets were overall smaller than that of GEs, with 46% in the range of $50,000 or less (Fig. 4).

3. Classroom Teaching and Student Mentoring

The focus of this section is training, teaching, and mentoring practices within the context of North American anthropology departments and their equivalents.

Interview results. Interviewees linked a perceived lack of exposure and training of relevant method and theory among anthropologists to departmental, infrastructural issues. Interviewees often stated that most anthropology departments tend to be small, and as such, cannot "afford" to hire anthropological geneticists. Anthropology departments, then, tend to be short-changed on appropriate faculty to teach content courses, such as anthropological/human genetics, and analytical and methods-based courses, such as wet lab techniques, population genetics, and molecular phylogenetics. In turn, this means that anthropology students, whether graduate or undergraduate, may not be getting sufficient training in these areas.

Survey results. The survey did not address whether departments had molecular anthropologists or equivalent faculty at their institutions. It did evaluate, however, whether and how genetics was being incorporated into overall faculty classroom teaching and mentoring practices. This section's respondents comprised only of faculty who listed "classroom teaching" and "mentoring" as part of their professional duties and responsibilities.

Given the fast pace of genetics-based findings, how were respondents incorporating new information into the classroom? Both GEs and NGEs (96% overall) kept up with current genetics-based findings through published literature and other media, through conferences, and through discussions with colleagues and collaborators; few did so by attending special courses or extra-curricular workshops. Though respondents found mechanisms to keep up for teaching purposes, they nevertheless expressed interest in additional training venues for teaching purposes, developed as continuing education-type workshops both within and outside of home institutions.

In terms of mentoring, the survey addressed two issues: (1) the extent to which faculty-student mentoring in genetics occurred, and (2) whether any roadblocks to effective mentoring existed. This section's respondents consisted of faculty who listed "mentoring" as one of their professional duties and responsibilities and all graduate students.

In undergraduate and graduate mentoring, many faculty report encouraging students to take genetics-based courses, whether "in house" (i.e., within anthropology departments or equivalent) or in departments outside of anthropology. At the graduate level, fewer professors seemed to encourage bioanthropology students to take external courses on genetics, but the stated reason for this difference is that genetics classes are simply not available at the graduate level at their institutions. Graduate student responses closely track and therefore confirm the degree of encouragement reported by professors.

Additionally, because we were interested in understanding the ways in which undergraduate anthropology majors are being prepared to engage with genetics, we asked faculty whether they felt that incoming graduate students have the necessary background to take graduate level courses in genetics. Half of all respondents responded affirmatively (61% of GEs; 49% of NGEs). The half of responding faculty who did not necessarily feel that incoming graduate students were well prepared were encouraged to comment via text boxes. Several pointed out that student backgrounds are in fact highly variable, so that anthropology graduate courses are often forced to accommodate this diversity of backgrounds. Many commented on the nature of US undergraduate anthropology programs: because undergraduate curricula emphasize a "holistic" anthropology, majors are required to take courses representing the entire field of anthropology. Some respondents claimed that this left little room in student schedules to take more specialized courses in bioanthropology, much less in other related fields such as biology or genetics. Others said that US undergraduate anthropology programs do not typically require their students to take biology-related courses outside their major, beyond any basic university-

level requirements. Finally, several commented along the lines that undergraduates majors in anthropology to avoid "hard" science because they perceive anthropology as being "science lite."

SUMMARY OF RESULTS

Noteworthy systematic differences in attitudes occurred between two respondent classes only: GEs and NGEs. Otherwise, response trends among respondents in different career stages and positions (academic faculty, graduate students, academic and non-academic postdoctoral researchers, and non-academic "other") tracked each other so closely that little to no attitudinal differences were observable.

Results from the initial set of interviews indicated to us that GEs in particular felt certain anxieties with respect to the genomic era, and subsequent survey and interview results indicate that NGEs do as well, though at times, the placement and magnitude of those anxieties differed between the two respondent groups. GEs – particularly early career GEs – often stated that the genomic era will "pass us by," and that without significant reforms, the bioanthropological discipline will fail to attain relevance with respect to the "cutting edge." Thus GEs exuded a sense of urgency in establishing reforms across multiple areas. In contrast, though many NGEs agreed that the discipline must be responsive to the genomic era, the majority of NGEs trusted in the discipline's ability to ultimately do so. However, several NGEs expressed fear that their expertise would become devalued as the genomic era progresses, to the point of becoming obsolete (from what we could tell, most or all NGEs articulating these thoughts focused on the use of the skeleton in their research).

General attitudes towards genomics can be summarized as follows: GEs were more likely to agree that the genomic era presents challenges to bioanthropology and that the discipline is not adequately meeting those challenges. The challenges appear evenly distributed across research, teaching, and mentoring domains for GEs, while NGEs placed more emphasis on teaching and less emphasis on research and mentoring. While NGEs were split on whether the genomic era necessitates reorganization within bioanthropology, the majority of GEs agreed that reorganization is necessary. GEs and NGEs cited individuals, institutions, and funding agencies as the appropriate levels for reorganization. As far as individual needs for training in genetics, GEs were most concerned with gaining such training for *research purposes* in contrast to NGEs who were more interested in training for *teaching purposes*.

For the section on classroom teaching and student mentoring, both faculty and students reported taking advantage of genetics classes and other training opportunities – if it made sense to do so given individual research agendas – whether offered within or outside anthropology departments. Additionally, a notably high level of concern was expressed over the typical curricula offered within anthropology departments as this tremendously impacts undergraduate and graduate training.

DISCUSSION

Practical Issues

Many of the practical issues surrounding the genomic era were already mentioned in the introductory section of this paper: access to the requisite technologies both in terms of technology and funding, as well as data storage, management, and interpretation. As stated previously, these issues are not unique to anthropology, impacting researchers in all disciplines, but they do impact anthropologists differentially, in that anthropologists cannot leverage resources (both intramural and extramural) towards genomic level studies to the extent that biomedical researchers can.

Indeed, study participants felt daunted by the high price of entry into genomics, and questioned the ability of researchers in anthropology departments (and equivalents) to obtain the necessary resources to be able to do so. Our study results show that GEs nevertheless are creatively accessing

resources: even if GEs cannot (yet) access such technologies at their own institutions, they are sending samples to other institutions' core laboratories or to private companies for the purposes of data generation. They are also obtaining grants of substantial amounts (i.e., over $200,000, if not over $500,000) to cover costs.

The real limitation for all involved seems to be in the realm of bioinformatics. As the (post) genomic era progresses, bioinformatic skills will be at a premium (including complex statistics and computation), as well as a foundational knowledge in anthropology, biology, genetics, and mathematics to deal with the expected complexity of genetic-environmental interactions. Again, this is an issue affecting everyone, and to reiterate, those with resources are able to recruit the currently small cadre of emergent researchers in bioinformatics. As with technology issues, however, we should expect certain bioinformatics issues – such as the availability of user-friendly bioinformatics tools – to resolve themselves in the upcoming years.

Intellectual capacity building

Because the genomic era entails new kinds of interpretive challenges, all disciplines are scrambling to develop the requisite intellectual capabilities. As mentioned in the *Classroom Teaching & Student Mentoring* section above, respondents worried that anthropology departments could not garner sufficient resources, nor budge from their current departmental configurations to develop such capabilities. The more pessimistic respondents characterized the typical anthropology department as having a small budget, high faculty teaching loads (many without graduate teaching assistants), and a shallow curriculum due to the "four field" imperative (i.e., emphasis on general courses across the anthropological subfields at the expense of in depth courses pertaining to biological anthropology). In short, this is a perception of anthropology departments as being unable to actively participate in the genomic era in part due to a relative inability to afford or retain GEs because genetic research will ultimately be compromised for the sake of classroom teaching. Graduate students in turn would suffer from a lack of relevant instruction and training along with an absence of GE mentors. The financial cost of hiring GEs within anthropology departments is certainly a legitimate issue, as GEs relative to NGEs have historically required significant laboratory facilities and research funds to equip and maintain these facilities. In this case, the genomic era may actually ease the cost of hiring GEs, because as more and more wet lab analyses can be affordably outsourced, and molecular genetic data becomes publicly accessible, GEs will require less wet lab and more computational infrastructure.

Role of Biological Anthropology

Bioanthropology could take advantage of the fact that the field of anthropology is simultaneously situated in natural science, social science, and humanities, though individual anthropologists may see themselves as more or all of one than any other. As such, anthropology is uniquely positioned to engage with the full implications of genomic research. For example, bioanthropologists could seize on the genomic era's renewed engagement in gene-environment interactions – rather than on genes alone – and provide rich treatments of the human socio-cultural context. Additionally the fact that the genomic era is already deeply impacting modern society from developments in personalized medicine to genetic genealogy means that ethical standards are being extensively reviewed and revamped (Vitti et al., 2012). Bioanthropologists have a deep stake in these discussions and should develop an active voice in them. All this could be undertaken via collaborations with cultural anthropologists, sociologists, and other social scientists. Effectively then, the genomic era opens up the possibility of renewed inter- and intra-disciplinary collaborations.

Suggestions for action

How can bioanthropologists take advantage of new technologies, as well as the potential research and intellectual advances that may come as a result of their use? We can translate the results of this study into the following suggestions for action:

Continuing education/workshops. Respondents who use genetics for research purposes and/or teaching purposes expressed a need for professional development opportunities. These opportunities may come in the form of workshops sponsored by funding agencies, professional organizations, or individual institutions.

Curriculum reform. Judging from the extensive comments about anthropology curricula, it seems that the best way for bioanthropologists to be prepared to deal with the challenges of the genomic era is to start with educational reform at the undergraduate level, through to graduate level studies. Anthropology undergraduates who are planning to pursue a focus in bioanthropology should have a strong foundation in biology and statistics; incoming graduate students should be exposed to an advanced inter-disciplinary curriculum.

Collaborations. Biological anthropologists have long understood the need to collaborate – and indeed regularly collaborate – with researchers outside the anthropological discipline. The promotion of intra-disciplinary collaboration, however, has been less of a priority. Biological anthropologists do find ways to occasionally collaborate with archaeologists and linguists, but rarely do they do so with sociocultural anthropologists. It would be fruitful to reflect on any barriers to such collaborations. For example, tenure criteria differ across the anthropological subdisciplines, with independent work highly valued for socio-cultural anthropologists (hence the emphasis on single-authored books and articles), and less so for the remaining subdisciplines. Thus, collaboration may not tenable for tenure and promotion purposes.

Public participation and outreach. Genomics currently enjoys an elevated public profile, given the academic, corporate, and media emphases (and some would say "hype" [Holtzmann, 1999; Marks, 2012]) on personalized genomics as it relates to individual health and disease, as well as on so-called "recreational genomics." More than ever, public involvement is crucial, not only in terms of education and outreach, but also in terms of informed participation. Community collaborations and partnerships can be developed to incorporate the concerns and desires of interested members of the public or entire communities. The more that anthropologists put themselves "out there," the more meaningful and relevant our work becomes.

CONCLUSION

In the course of our conversations, many interviewees (particularly those in the later stages of their academic careers) brought up Sherwood Washburn's famous call for a "New Physical Anthropology," in which Washburn effectively asked the discipline to shift its intellectual priorities in order to take advantage of the new theoretical developments of the day (e.g., the Modern Synthesis) and therefore maintain its relevancy within the scientific community (Washburn, 1951). The immediate effect of Washburn's call was to generate a renewed disciplinary enthusiasm, though ironically, the *long-term* effect has been to create a deeply disturbed discipline (Smocovitis, 2012) – witness the fact that seventy-plus years later, we are still asking ourselves if we have lived up to those expectations (c.f., Fuentes, 2010).

By evoking Washburn's call, our study respondents were expressing sentiments beyond a deep disappointment in the current state of the field (i.e., not having yet lived up to the call) – they were also articulating a certain degree of pessimism about the future state of the bioanthropological discipline, that is, with regard to the discipline's apparent inability to intellectually engage with the theoretical developments in evolutionary biology *since* the Modern Synthesis.

But what might this have to do with genomics and the genomic era? On the one hand, genomics seems to be simply the latest lens through which our internal disciplinary anxieties are magnified. On the other hand, genomics may be changing the biosocial landscape so quickly and radically that foundational ground beneath the bioanthropological discipline may be shifting entirely. Are we in need of another "Washburn moment"?

Certainly, as discussed earlier in this report, we need to develop a better sense of biological anthropology's intellectual contribution to academic and public communities. However, a handful of respondents proposed a more radical solution to our disciplinary woes, which is to seize upon this moment to quickly effect change. On its own, genomics has the potential to force change, whether in academic and commercial realms. Anthropology could take advantage of the momentum generated by genomics and fundamentally reconfigure the "doing" of anthropology.

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FIGURES

Fig. 1. Breakdown of survey participants by career status, then by institution type. "Other career status" refers to respondents in non-academic institutions as research scientists (including curators and post-doctoral researchers) or independent researchers. "Other institution" refers to institutions that are in independent, nonprofit, or commercial sectors.

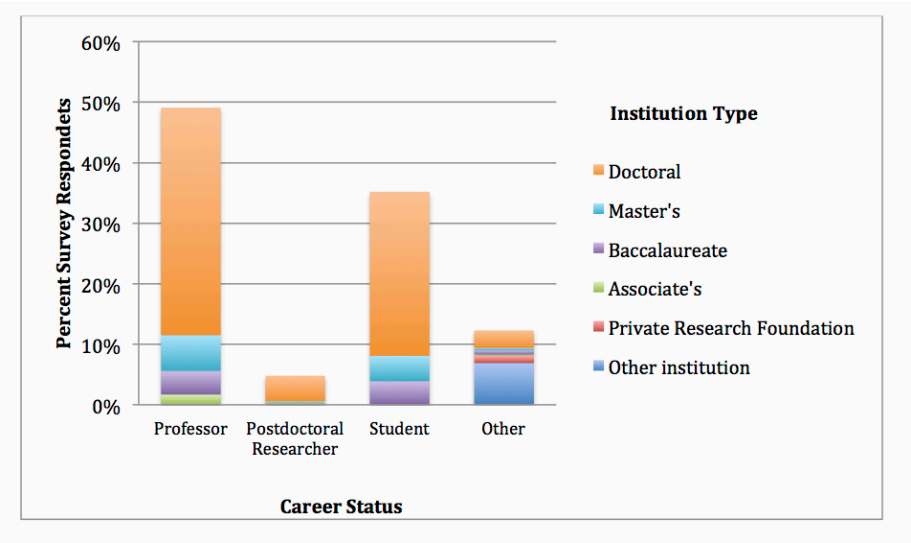

Fig. 2. Survey respondents' level of agreement to the statement, "the genomic era necessitates reorganization at the level of individual researchers, of institutions, funding agencies, and/or professional organizations," broken down further by NGEs/GEs.

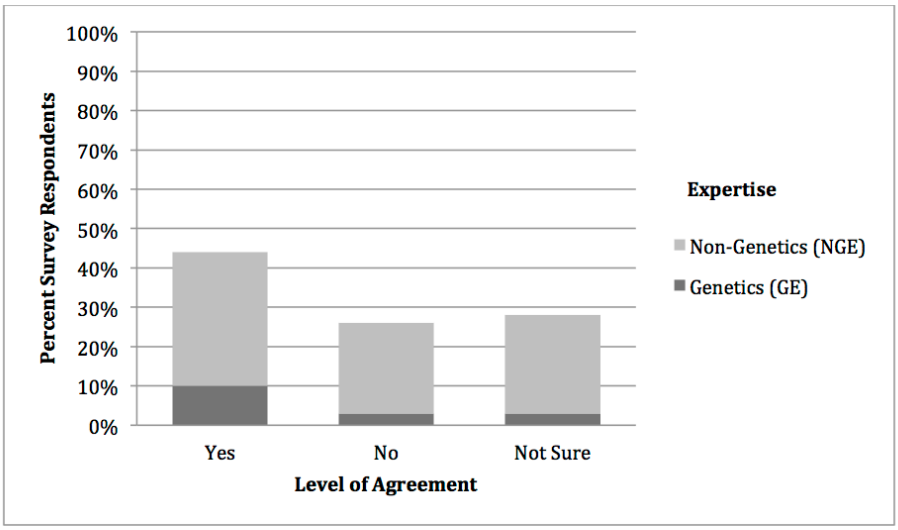

Fig. 3. Survey respondents' level of agreement to the statement, "The genomic era presents challenges to the field of Bioanthropology," broken down further by NGEs/GEs.

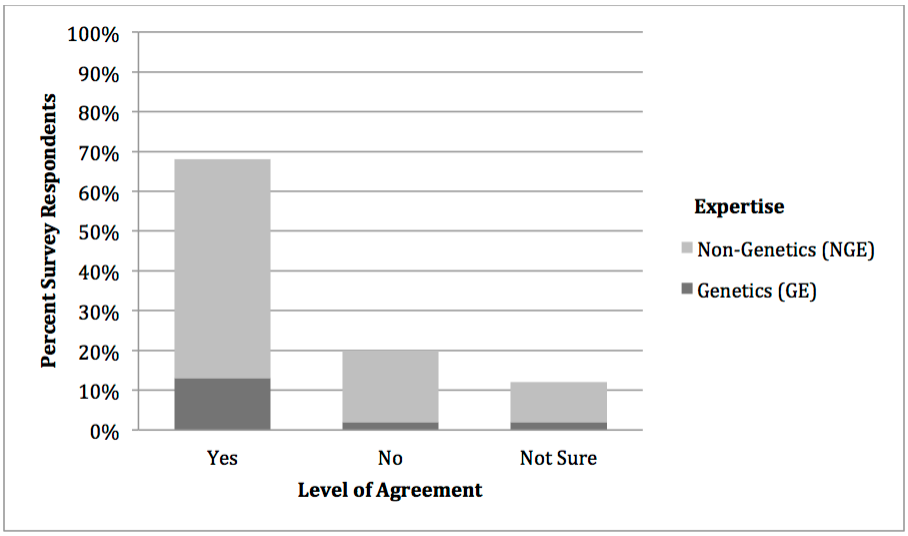
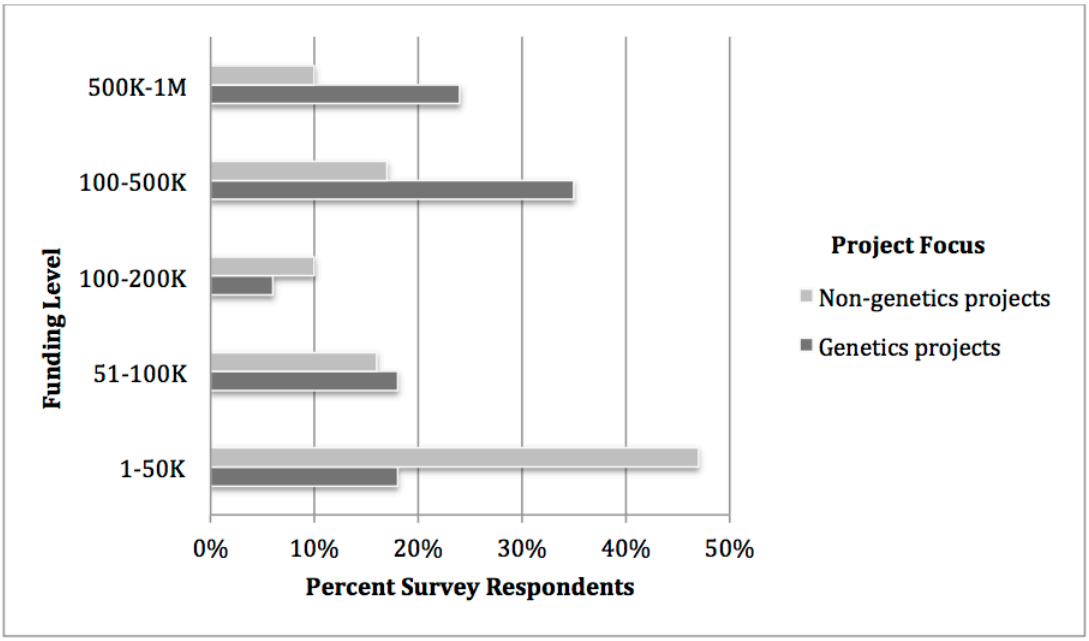
Fig. 4. Differences in acquired funding levels for projects based in genetics-based methods, and non-genetics-based projects.