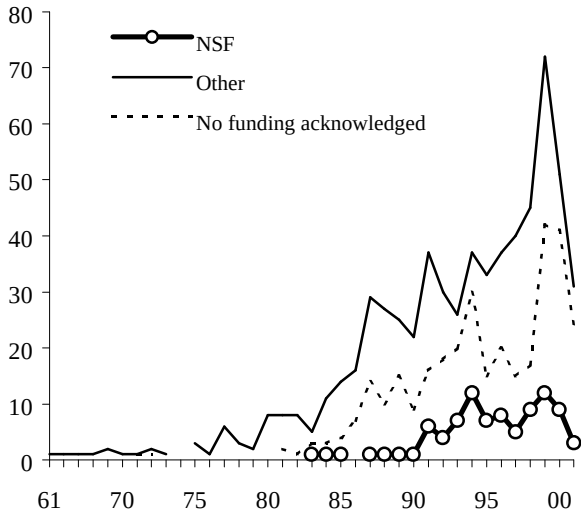
VI. NSF funding of core papers fundamental to tissue engineering

In this section, we begin discussion of the 1,056 analysis paper set with an examination of NSF's role in supporting core papers fundamental to tissue engineering.

Figure 3 - Number of NSF funded papers by year



In the analysis set, 31% of papers did not explicitly acknowledge a source of funding. Of the 727 that did, 89 or 12% acknowledged NSF support. Figure 3 displays the number of NSF funded papers in each year compared with the number of papers acknowledging other funders and the number acknowledging no support sources. Since 1990, NSF has had a fairly steady presence in supporting tissue engineering related work.

However, NSF funding is not evenly distributed across tissue engineering. NSF tends to fund scientific as opposed to clinical research. Of the papers that acknowledge a support source, 20% of non-clinical papers acknowledge NSF support whereas only 3% of clinical papers acknowledge NSF support. Appendix 4 Table A illustrates this, comparing the field distributions of papers acknowledging NSF support with papers acknowledging other funders and papers that do not acknowledge research support. Non-clinical fields are in bold. Almost 90% of NSF-supported papers are in non-clinical fields, whereas half the papers supported by others are non-clinical. The lists of fine fields by support type clearly demonstrates NSF's emphasis on basic research. The papers not acknowledging funding are rather similar in distribution to the papers supported by other funders.[7,8]

We might expect that if NSF focuses support on non-clinical fields that its research tends to be more basic. That this is so is indicated in Table 3 which is based on CHI's classification of Science Citation Index journals into four levels of "basicness." Each level contains journals reporting roughly the same type of research, from level 4 basic research to level 1 clinical observation. The table indicates that compared to other funders, NSF funds a higher share of the most basic papers, level 4, and a lower share of the most applied, level 1. NSF also funds a higher share of papers in the two leading journals in the field – Biomaterials and Journal of

[7] Excluded from this analysis are 116 papers not classified into fields. These are papers in journals not covered in the *Science Citation Index*. See the bottom of the table.

[8] The field analysis and the level analysis below are based on CHI's classification of *Science Citation Indexed* journals into fields and level of basicness.

Biomedical Materials Research (both classified as level 2). The share of papers in these two journals has been removed from level 2 and is reported on a separate line in the table. NSF funds one-quarter of the core papers fundamental to tissue engineering that acknowledge funding and are published in these two journals.

Table 3 – How basic is NSF-funded research?

Level	NSF	Other	None
4	42%	34%	27%
3	11%	14%	9%
2	1%	14%	11%
1	1%	19%	34%
Biomaterials & Journal of Biomedical Materials Research (2)	44%	18%	18%
Number of papers	81	576	276

A reasonable interpretation of all this is that NSF support is targeted to basic research and biomedical materials. NSF has supported 15% of the basic work in tissue engineering and up to one-quarter of the biomedical materials work. Others support the clinical work which is such an important part of tissue engineering, and so NSF's overall presence is somewhat less, about 12%, judging by papers that acknowledge funding agency support.

A. Institutions

Another way of examining NSF's role in the field is to examine papers and funding by institution. This is the purpose of Appendix 4 Table B. Table B lists institutions and the number of papers that list their address. The institutions are ordered descending on number of papers. The table also reports the share of papers that acknowledge NSF support as a fraction of those acknowledging any support. The final three columns tally the number of papers that list NSF support, the number that list support sources but do not mention NSF and the number that acknowledge no support source.

Institutional name variants have been unified to produce this table, but a problem remains. Not infrequently, authors in this area have a dual university/hospital affiliation. Such authors list their addresses on papers in several ways, and this has consequences for the counting of papers by institutions. If authors list one address only, then the other institution gets no credit for the paper. If the author lists two separate addresses on the paper, then both institutions get credit for the paper and it is indistinguishable from a collaboration between researchers at two institutions. If the author combines the institutions in one address (as one might list both a department and a university name) then the first address only is counted here. If time were available to straighten

all this out,[9] it would affect Table B because MIT, Harvard, and the Children's Hospital and Medical Center in Boston employ lead authors in the field who have dual affiliations.

The table reveals that the leading institutions in the area are Harvard, MIT, University of Michigan, Children's Hospital Boston, and the University of Texas. The names of over 350 US institutions appeared on core papers fundamental to tissue engineering; 21 of these institutions produced at least 25 papers. A glance at the table suggests that NSF has had a greater than expected role in supporting work at the leading institutions, that is those producing 25 or more papers. Further analysis reveals that NSF supported 17% of the papers (that acknowledge research support) that were produced by authors working at leading institutions. In contrast, only 8% of the papers from the rest of the institutions acknowledged NSF support. In fact, only 2% of the 186 papers from institutions appearing only once acknowledge NSF support. The institutional analysis elaborates the picture that the NSF role in tissue engineering focuses on basic research and biomaterials research by suggesting that its research is also focused on the core participants in the field. More peripheral, and one-off participants are much less likely to acknowledge NSF research support.

B. Authors

In analyzing the role of NSF funding in tissue engineering, we need to look also at NSF's role in supporting particular authors. Appendix 4 Table C does this for authors with more than 10 papers. The table's seven columns detail:

1. The number of papers that list the author's name. Only authors with more than 5 papers are shown. There are 2,553 author names in all; 135 are listed here.
2. The number of funding agencies listed on the author's papers. That is, the number of agencies from which the author has received funding. This count is not exact because minor funders were recorded in categories such as "non-profit" or "other Federal government."
3. The number of NIH agencies. Researchers acknowledging NIH funding usually list the NIH Institute concerned, such as the National Cancer Institute or National Eye Institute. CHI records these and they are counted here. Note that in the count of agencies, NIH was counted as one agency and multiple Institutes did not add more agencies to the total.
4. The share of papers acknowledging funding that acknowledge NSF funding.
5. The number of papers by funding type where there are three types:
    - Acknowledges NSF funding
    - Acknowledges funding, but does not mention NSF
    - Does not acknowledge funding.

The list reveals that NSF has had a substantial role in supporting the lead researchers in the field. Although acknowledged on only 12% of papers (that acknowledge research support) overall, the

[9] That is, if institutional addresses combined on one line and institutions listed separately were counted the same way.

three most prolific researchers – Vacanti, Langer & Mooney - acknowledge NSF funding on 19%-37% of their papers (that acknowledge research support). BS Kim, LG Cima, JA Hubbell, PM Kaufmann, CT Laurencin and WM Saltzman also acknowledge NSF on one-third or more of their papers. In contrast, NSF has had no role in supporting, amongst others, AI Caplan, LE Freed, VM Goldberg or G Vunjaknovakovic. And A Atala keeps his funding sources a secret.

C. A Note on Government Interest Patents

Among the tissue engineering patents were 19 which contained a statement of government interest. That is, the work underlying the invention had been declared by the inventors to have resulted from a government grant. Of these, NIH had 8, NASA 6, NSF 3, and DHEW 2.

VII. Co-authorship maps and tables

The depiction of co-authorship patterns undertaken in the final stages of the project does not lend itself to easy summary. In this type of work, the intellectual exercise is not aimed at compact verbal descriptions of salient features. Rather, novel graphics were developed to provide intelligible representations of extremely complex patterns, representations that do not distort the phenomenon nor so remove features in an effort at simplification that any deep understanding is precluded.

In this project, the lead authors' webs of coauthorship were portrayed in an innovative, multi-level system of tables and maps. Lead authors were defined as those with 10 or more core papers fundamental to tissue engineering. Three types of maps and tables are presented:

1. An overview map/table portraying links between lead authors

2. For each lead author (not included in a map), a table listing all coauthors, the number of papers collaborated on and the years in which joint work was published. Any NSF-supported work is noted. Finally, information useful for identifying PhD students of the lead author is included.

3. For authors who acknowledge NSF funding, detailed, paper-by-paper maps were produced that depict in some detail the development of the author's work in core papers and patents fundamental to tissue engineering. These maps are multi-dimensional and include: coauthorship, funding, topics, citations, and institutional affiliation. Exceptions to the rule that maps were drawn for lead authors who acknowledge NSF funding are that maps were not drawn for Langer, Vacanti and Mooney whose vast oeuvre and exceptionally interlinked coauthorship patterns precluded mapping using this technique which is best suited to in-depth portraits of smaller oeuvres.