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THREATS TO THE PROMISE OF SYNERGY IN INTERDISCIPLINARY RESEARCH

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Introduction

Much of the current optimism regarding the polydisciplinary approach to scientific problems arises from the belief that interacting members of different disciplines, through the exchange of ideas, will generate greater insight into problems than would researchers from any single discipline. This added insight is assumed, in turn, to stimulate more innovative and comprehensive problem solutions than those offered by monodisciplinary efforts.

Although we share this belief in the potential of polydisciplinary interaction, we also believe that positive outcomes are by no means a necessary consequence of this approach. Polydisciplinary efforts may produce confusion as well as insight; they may produce mundane summaries of previously known facts instead of innovative new approaches. We believe that the manner in which research problems are defined, the nature of the criteria used to evaluate proposed solutions, and the social context in which these investigations take place, all affect a polydisciplinary team's potential to generate the intellectual exchange necessary for innovation.

The purpose of this paper is to consider how these factors may affect the innovative, or _synergistic_, potential of such teams. We view intellectual synergy as a potential, rather than necessary, consequence of exchange of ideas, and our objective here is to locate the conditions under which the likelihood of synergy will be maximized. To this end we first offer an analysis of the possible outcomes of any polydisciplinary research effort, differentiating those which represent synergy from those which do not. Next we examine the relation of various social factors to the potential research outcomes, suggesting that many settings are likely to result in outcomes which do not reflect synergy. Finally we offer a description of those settings we believe are most likely to produce synergistic outcomes.

In the current discussion we first wish to consider research outcomes independent of their relative success or failure. As we shall demonstrate later in this discussion, "success" in scientific problem solving is at times difficult to evaluate, and is totally dependent on the criteria used to evaluate a given solution. Specifically we want to differentiate *synergistic* from non-synergistic outcomes. Therefore we will temporarily set aside notions of success or failure and examine the ways in which a given body of knowledge may be applied to a problem.

We may view any organized body of knowledge as a *knowledge set*. That body of knowledge possessed by the discipline Chemistry, for example, is a knowledge set. Knowledge sets may in turn be viewed as containing four types of elements. First, they contain *facts*, or observations. Second, they contain *techniques*, which are either methods for the collection of facts (e.g., methods for measuring temperature), or proven methods of altering the physical world (e.g., construction methods). Knowledge sets also contain *approaches* which are either predispositions for viewing the world or beliefs about how the world is organized. The belief of some social scientists that behavior is affected by attempts to balance cognitions and affect, or Einstein's belief that "God does not play dice with the universe," are examples of approaches. Finally, knowledge sets contain *theories*. Theories are approaches which have been refined to the point where they explain and make predictions about specific events in the physical world, and which are subject to empirical verification procedures.

The *application* of a knowledge set to a given problem may or may not result in a problem solution. In some cases the application may be straightforward, such as the use of a specific technique to resolve a question of fact. In other cases the application of the entire knowledge set may produce no more than a partial solution to the problem. In any case, by application we mean the attempt to utilize the elements of a knowledge set to resolve a given problem, whether this attempt is successful or not.

In a polydisciplinary setting two or more knowledge sets are applied to a given problem. In some cases the solution offered by a polydisciplinary team will be interactive; that is, the problem solution offered will contain elements from two or more of the knowledge sets being applied. Also, in some cases the solution offered may be innovative; that is, at least some elements of the solution are foreign to all of the knowledge sets being applied.

We define as synergistic, problem solutions which are both interactive and innovative. Thus, synergy represents the simultaneous application of two or more knowledge sets to a given problem such that the problem solution contains some elements of each set plus some elements contained in neither.

Possible Outcomes of Polydisciplinary Efforts

A synergistic outcome is only one of several possible outcomes of a polydisciplinary effort. The other possibilities include:

(1) No solution offered;
(2) Multiple partial solutions offered;
(3) A solution which is neither interactive nor innovative;
(4) A solution which is innovative but not interactive;
(5) A solution which is interactive but not innovative.

Since our subsequent analysis will attempt to demonstrate how social factors may play a major role in determining which of the possible outcomes a given team will reach, let us briefly review each of the six possibilities we have outlined.

The first is obvious and requires no further explanation. A polydisciplinary team works on a problem and fails to provide any solution whatsoever.

We believe the second alternative to be a typical result of many polydisciplinary projects. In this situation a polydisciplinary "team" exists only on paper, for instance, when members of various disciplines jointly submit a proposal to work on various aspects of a given problem. An example might be that of chemists, geologists, and petroleum engineers submitting a proposal to work on the problem of developing new and more efficient energy sources. Once funded the "team" would then divide into discrete disciplinary subteams each working on its own aspect of the problem. The products of these efforts may eventually be presented in a single final report, but the partial products would be identical to those which could have been produced through a series of monodisciplinary investigations.

The third alternative represents a standard monodisciplinary solution to some problem. A single discipline intellectually or socially dominates the polydisciplinary setting and the remaining disciplines are relegated to a support role. Outcome (4) is similar except that the essentially monodisciplinary approach results in some innovation.

We believe that outcomes (3) and (4) together characterize the result of many polydisciplinary efforts. Although a team may begin its work with the intention of producing an interactive product, social forces may result in a degeneration of commitment to this goal. Conflicts of ideas or approaches and the need to produce <u>something</u> may together result in the evolution of an essentially monodisciplinary perspective on the research problem.

Outcome (5) (interactive but non-innovative) might easily be produced by "fact finding" types of investigations. If the goal of a polydisciplinary team is to "look at all aspects" of a given problem, then the solution is likely to reflect all available knowledge which might have some applicability. Elements of all the applied knowledge sets are likely to be represented in the solution. Once the facts are collected, however, the team is likely to consider its task complete and innovation is therefore unlikely.

As stated earlier, a synergistic solution is both interactive and innovative. The solution contains elements of more than one of the disciplines being applied as well as elements which represent some new knowledge. Some instances of synergy may be trivial, as when facts from two disciplines are put together without rhyme or reason to produce new facts for which no interpretation is offered. An example of such practice would be the correlation of birth rates and sunspot activity to answer the question of whether background radiation affects human reproduction. The correlation coefficient produced through this procedure would represent new knowledge in the sense that the value of the coefficient was previously unknown, but the "solution" would really do little to answer the original question.

The "synergy" which we intuitively identify with polydisciplinary research produces something other than such trivial outcomes. A problem solution which both produces such correlations and _explains_ them as well corresponds more closely with the ideal. Notice that such a solution of necessity contains as elements one or more _approaches_ or _theories_. At least some theoretical interpretation is necessary to establish the specific relevance of facts to the problem at hand. Relating sanitary conditions to the incidence of disease thus required some theory relating disease-carrying organisms to unsanitary environments; and relating the moon to tidal activity required some theoretical notion of gravity. We believe that literally all scientific "innovations" involve either the creation of a new approach or theory or some new application of a previously existing one.

The social implications of this argument are profound. If synergy required merely an exchange of facts or occasional consultation between disciplinary representatives, then polydisciplinary research teams could work under almost any physical or social conditions. If we assume, however, that the exchange of ideas necessary for synergy may require exchange of theoretical knowledge across disciplines, then we also see the need either for some intense and prolonged interaction between the members of different disciplines, or for a single scientist who is familiar with the theoretical knowledge of the various disciplines being applied, to serve as an integrator of ideas. This argument suggests that some social settings, those which foster interaction and exchange of ideas, are most appropriate if a synergistic product is the research goal.

To properly frame the following discussion, let us specify at the outset that we view scientific research teams as being similar in many respects to other kinds of work groups. The singular nature of scientific activity notwithstanding, members of research teams experience the same interpersonal stresses and seek the same kinds of rewards as do people in other work settings, and we believe that the way in which a team deals with the ongoing social processes which produce tension and gratification will affect a team's synergistic potential as much as will the caliber of intellect represented in the team membership. In the wrong setting great minds may be bound to perform trivial research.

We do not intend to argue that the proper social conditions will allow otherwise mediocre researchers to generate important scientific breakthroughs. We do not believe that synergy is producible on demand. We do argue, however, that some types of settings will strongly discourage synergistic outcomes, directing them toward one of the alternative outcomes discussed earlier.

A crucial event in the life of any research project is the conceptualization of the research problem. Who defines the problem and the manner in which it is defined establish the intellectual boundaries of the investigation and heavily influence the social structure of the team. To illustrate this point, consider a team composed of economists, sociologists, political scientists, and engineers, who are attempting to forecast mass transportation needs and usage in the United States twenty-five years hence. The problem might be formulated in several ways. They include:

(1) By the client or funding agency;

(2) By that individual disciplinary representative acting as principal investigator;

(3) By the entire team through discussion of alternative conceptualizations.

Of the three alternatives listed we believe that (2) is the least likely to produce a synergistic product and (3) the most likely. If the problem is defined from the perspective of a single discipline, the theoretical knowledge most likely to generate problem solutions will be contained within the approaches and theories current in that discipline. The probability of some new theoretical perspective being developed is low, and the problem solution is likely to be non-innovative even if it is in some sense interactive.

If various perspectives are discussed before one is selected, however, the likelihood that the theoretical stance of any single discipline will predominate is somewhat lower. Deficiencies common to all of the proposed approaches may be discovered, thus documenting the need for innovation and orienting the team in that direction.

Implications of Problem Definition for the Social Structure of the Team

In addition to setting intellectual boundaries for the investigation, the problem definition phase also affects status relations among team members. Although we all enjoy viewing science as a rational pursuit unfettered by personal concerns, all available evidence suggests the opposite. Scientists are as sensitive to issues of status, prestige and reward as are people in any other work setting. If sociologist Smith is working together with economist Jones on a problem defined as lying within Jones' disciplinary territory, Smith is more likely to defer to Jones' judgment than Jones is to Smith's. Although such deference is in many cases warranted, it may be dysfunctional if Smith has an idea which he fails to put forth because he fears violation of Jones' domain.

If one discipline is intellectually dominant in a given research setting, that discipline may be expected to provide a large share of the ideas for problem-solving strategies and techniques. And if a single discipline provides the problem definition it will be predominant in other phases of the research as well. Members of that discipline will acquire high personal status in the setting and will accumulate the various prerogatives of this status.

This is not to say that a team whose status structure is headed by members of a single discipline will produce scientific failures. We do argue, though, that either intellectual or status dominance by a single discipline during the early phases of a research project establishes a pattern likely to be reflected throughout the project's history, and that this pattern is unlikely to result in the exchange of orientations we believe to be crucial to synergy.

Interestingly enough, the current structure of science generally provides the greatest rewards for those scientists who work on problems which are central to their own disciplines. Scientists are positively evaluated for working on "important problems" in their own field and negatively evaluated for not doing so. For example, prizes are awarded for work closely aligned with specific disciplinary traditions, and the editors of technical journals often refuse to publish work, irrespective of its quality, if the work is outside of current disciplinary boundaries. Given that rewards accrue to those whose work remains within the framework of specific disciplines, we should not be surprised if, even in polydisciplinary settings, scientists frequently seek to define problems in such a manner as to reflect their particular disciplinary concerns. Such attempts are likely to produce intense competition, with various team members striving to intellectually and socially dominate the setting. The result of this process is likely to be a problem defined from the perspective of one or two disciplines, similar to case (2) above.

Thus, even if members of a polydisciplinary team attempt to formulate a research problem through exchange of ideas, the result is likely to lead away from synergy. We believe that the likelihood of a synergistic outcome is increased if one or more team members performs a social and intellectual _bridging_ role in the setting. Among the functions of such a role are: to clarify and expedite procedural matters, to promote integration of different points of view, and to "bleed off" tensions by acting as mediator in disputes between other team members. The overall impact is to narrow gaps in the team created either through status competition or intellectual misunderstandings such as, for example, those due to the lack of a common language among team members. Both the characteristics of this role and characteristics of scientists likely to be capable of filling it are more fully discussed elsewhere (Kruse et al., 1975), and we refer the reader to those discussions.

Criteria Setting Also Affects Synergy

Just as problem definition affects the synergistic potential of a team, so does selection of the standard or standards to be utilized in evaluating the success of proposed solutions. The problem definition process sets the intellectual boundaries of an investigation; evaluation criteria do much to guide a team's operation within these boundaries. From the alternatives possible the approach selected by a given team will be heavily influenced by the criteria used to evaluate their efforts.

As we mentioned earlier, the "success" of a scientific investigation is difficult to evaluate. To the extent that the results of a given investigation are eventually recognized as contributory to the advance of science the investigation is, of course, "successful". At the time the research is actually being executed, however, the working scientist frequently cannot anticipate such recognition and must resort to other standards to evaluate the quality of his work.

Numerous standards are available. A brief listing of some of the more frequently used follows:

(1) Development of new theories or approaches which offer some accounting for previously unexplained phenomenon;

(2) Solution of an applied problem;

(3) Generation of data which resolve some existing theoretical puzzle;

(4) Client satisfaction with the product;

(5) Statistical significance of results;

(6) Conformity with traditional canons of scientific practice;

(7) Bureaucratic standards of performance.

We may refer to the <u>operational goal</u> of a research project as the attempt to provide a problem solution which meets one or more such standards. The team will attempt to engage in those activities which are goal directed and avoid activities which are not.

Some of these operational goals are less conducive to synergy than are others. A team which adopts purely bureaucratic standards of performance, for example, is likely to explore only those problem solutions which can be generated "on time, at cost". Such solutions are most likely to result from straightforward applications of existing theory and method and are thus unlikely to be innovative. Similarly, if a team is concerned primarily with proper use of standard techniques to collect data, they are less likely to offer explanations of those facts than would a team which was also concerned with solving theoretical puzzles.

We suspect that evaluation criteria which demand either theoretical explanation or demonstration of a workable solution to an applied problem are most likely to aid in the production of synergy. If a team uses either criteria to evaluate the success of its efforts, they are more likely to review alternative approaches to the research problem in order to locate the best solution, thus maximizing team interaction as well as the probability of considering non-standard approaches.

Historical examples support this contention. The development of the atomic bomb required solution of a series of applied problems, many of which were solved by polydisciplinary teams who produced synergistic solutions. In each case the sole criterion for evaluation was the practicability of a given device or technique, and solutions both innovative and interactive were frequently necessary to achieve operational goals.

Resolution of the structure of DNA supplies an example of a synergistic product generated through an attempt to reach an operational goal of theoretical explanation. Watson and Crick, suspecting that standard approaches to the problem were unlikely to work, combined knowledge from a variety of disciplines as well as original ideas to solve the structure.

Together the problem definition a team reaches and the criteria used to evaluate approaches to that problem heavily influence the team's synergistic potential. Problems which are defined to lie clearly within the intellectual sphere of a single discipline and bureaucratic or methodological evaluation of solutions represent conditions highly unlikely to produce polydisciplinary synergy, while problems defined through polydisciplinary interaction and standards of evaluation which demand supportable explanations of phenomenon or demonstrable product effectiveness are more conducive to synergy.

Social Settings Affect Synergy.

Regardless of the nature of the research problem and the standards of evaluation used, the social setting in which the team works also heavily influences a team's synergistic potential. We earlier argued that considerable polydisciplinary interaction was necessary for the generation of research products which were both interactive and innovative. Such interaction assumes that the members of a given team are both capable of frequently contacting others and interested in doing so. Social factors which limit capability include:

(1) Physical isolation;
(2) Socially restricted communication channels;
(3) Differences in professional orientation and knowledge.

Many polydisciplinary "teams" operate under physical conditions which permit only infrequent face-to-face contact. When representatives from different institutions work together on a problem, time and resource constraints frequently restrict communications to issues of general planning and strategy and to exchange of data and progress reports. Access to someone else's results without the opportunity to discuss how and why those results were generated decreases the probability that those results will stimulate one's own thinking. A question which might be asked of a co-worker from another discipline if he were just across the hall might easily be dismissed if the co-worker must be reached by phone. The day-to-day sharing of problems and ideas which allows some insight into the perspective taken by another discipline cannot be replicated by even the most intense study of another's final report.

Just as physical distance may impede interaction, so may socially restricted communication structures. These social restrictions may be explicit, as when a team leader demands that all problem-relevant communications be channelled through him, or they may be implicit. Status differences between team members, for example, may result in a variety of such implicit restrictions. People are more likely to approach status equals with new ideas than they are to approach either status superiors or status inferiors. Poor ideas contributed by high-status individuals may frequently be widely circulated, while the good ideas of low-status people are not discussed at all. In any setting these social restrictions are as "real" as physical constraints in that they may virtually eliminate any possibility of communication between some team members.

Although the effect of social restrictions is not always immediately perceivable (team members may not even view themselves as constrained), the effect on a team's performance may be quite pronounced. For example, if communications are centralized, or funneled through one investigator who acts as an integrator, much of the content may be lost through multiple translations of the message. In addition, team members are likely to communicate only that content which they believe the integrator might consider to be worthwhile or important, with the net effect of reducing the number of ideas which are circulated through the team. If the integrator is an economist, for example, a sociologist might communicate ideas regarding only differences in the buying behavior of different social classes, omitting any mention of the relation of social class to other behaviors of more interest to sociologists.

Interaction among disciplinary representatives may also be impeded through a simple lack of understanding. An idea formulated in the context of one scientific paradigm might seem meaningless to a listener who views the world through the perspective of another paradigm. A problem considered important for study by one discipline may well be considered resolved by another. Representatives of even such closely related disciplines as physics and chemistry will frequently experience these kinds of problems.

This problem may be solved in two ways. First, a polydisciplinary team may be composed of generalists who, although experts in their own disciplines, have cultivated some basic knowledge of other disciplines as well. Second, one or more generalists may act as translators for communication between disciplinary specialists. Failure to resolve the problem will frequently result in team members attempting to communicate only on those issues which they believe will be clearly understandable to others, resulting in a "lowest common denominator" effect. An example of this would be a physicist and biologist working jointly on a problem with each person offering only those ideas from his own discipline which he could assume were already familiar to the other person. The problem solution offered by such a team would thus represent less than either team member could have produced by working alone.

In addition to constraining the amount and content of communications, social factors also affect the <u>motivation</u> to exchange ideas. Talking freely about one's work with someone from a different academic background can be a frustrating experience. Unless one is totally convinced that such conversation is likely to be useful and informative, the probability of such exchanges taking place is low.

The most natural way in which to learn of the utility of interdisciplinary communication is to engage in it. Social arrangements which make such communications difficult initially are likely to affect motivation to engage ideas later when the initial constraints have been relaxed. We therefore believe that if a polydisciplinary team is to have any real chance of producing synergistic outcomes the initial physical location and social structure of a team must be such as to maximize the potential for communication across disciplines.

Even if the potential for communication exists, however, other social factors may impede the motivation to take advantage of opportunities. These factors include:

(1) bureaucratic organization of work;
(2) internal reward systems emphasizing individual achievement;
(3) status inconsistency;
(4) status ambiguity.

In any situation where work is bureaucratically organized (i.e., specific tasks are assigned to specific individuals with time and cost criteria used to evaluate success) individuals are motivated to focus their energies on their own work assignments and ignore what others are doing. Even if work is sequentially organized (i.e., one person's output serves as input for another), chances are good that a given individual will remain unconcerned with utilization of his work product once it is completed.

To maximize the likelihood of interaction work should be interactive whenever possible and specific task assignments should reflect a shared understanding of how the given task fits with other work. These conditions are likely to deepen each scientist's understanding of the role of other disciplines on the project and increase the likelihood that he will consult with others if his own work produces an unanticipated result.

Rewarding specific individuals for specific results may have much the same effect as bureaucratically organizing work. Each person focuses on his own task and will be motivated to consult others only insofar as it may be directly beneficial to himself. Even if some effort is made to orient the individual worker toward the group product, the worker will likely continue to focus only on those activities which directly reward him.

Consider the case of a writer on an advertising agency team whose goal is to create a multimedia ad campaign for a product. Although his superiors may continually stress the need for a successful team effort (ads which sell the product), the writer knows that his personal livelihood depends primarily on the quality of his copy. Even if the advertising campaign as a whole fails, he might be promoted on the basis of a clever limerick or jingle.

To the extent that an individual scientist's career may be advanced more easily through his individual effort on a polydisciplinary team than through his identification with the team product we expect him to behave very much like the copywriter and focus primarily on his own tasks. We of course recognize that many scientists may interact with others for no greater reason than to satisfy their curiosity, but at the same time we suggest that relying on such motivations to produce synergy is overly optimistic. A team reward structure in which individuals are rewarded primarily through their association with a high quality team product is more likely to be conducive to synergy.

Settings which produce social strain or tension will lower motivation for communication. Among the conditions most likely to produce such strain are conditions of status inconsistency and status ambiguity. Briefly, status inconsistency exists on a polydisciplinary team when the <u>internal</u> prestige of a given team member significantly differs from his prestige in the greater world of science.* For example, a Nobel Prize winner who occupied a peripheral position on a team of less generally prestigeful scientists might feel status inconsistent.

Status ambiguity occurs when individuals are unsure of their position within the team. If two individuals who were initially defined as status equals are suddenly differentiated (e.g., one suddenly controls resources needed by the other), both may suddenly become unsure of their position.

Both status inconsistency and status ambiguity will produce subjective stress or strain for the individuals involved, and these people may be expected to seek ways in which to reduce such feelings. One simple mechanism is to withdraw from the tension-producing setting insofar as it is possible. We might therefore expect a scientist who feels stress from either of these two sources to minimize his participation in a polydisciplinary team. He may do this both by refusing to initiate non-essential interactions and by discouraging others from initiating towards him. In addition, if such interactions are initiated the underlying stress may tend to magnify the social impact of disagreements and misunderstandings, producing feelings of animosity which might otherwise not exist, and further reducing motivation to continue any exchange of ideas.

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*For a more complete discussion of the concepts of status inconsistency and status ambiguity see "Interdisciplinary Research Teams as Status Systems", Kruse et al., 1975.

Conclusions

We believe that if intellectual synergy is to be a realistic goal of polydisciplinary research, more energy must be devoted to the creation of appropriate social conditions than is the case at present. The current structure of science is unlikely to frequently result in specific team settings which encourage the necessary interaction vital to true polydisciplinary innovation. Therefore, either the structure of science must itself be altered, or effort must be made at the research team level to create a more appropriate environment.

Communication between team members should be facilitated both through physical proximity and the availability of some team member(s) who can effectively translate ideas from one discipline into the language of another. The team must also be organized in such a way as to minimize the costs of polydisciplinary cooperation, through mechanisms which reduce tensions associated with feelings of status inconsistency, status ambiguity, and reward inequity. In sum, the team organization must maximize both the feasibility and desirability of communications between team members.

Research settings displaying the features we have outlined are currently few in number. As we suggested, polydisciplinary research is somewhat unnatural within the scientific community in that science offers the greatest rewards to those who pursue specific disciplinary pursuits. Honors and prizes go to scientists who contribute to specific disciplinary knowledge, and training emphasizes monodisciplinary specialization; publication policies of prestigious journals are biased against reports of findings which do not fit an existing disciplinary perspective.

In addition, disciplines are _status ordered_, meaning it is much more prestigeful to be affiliated with some disciplines than with others. To be a chemist, for example, is more prestigeful than to be a political scientist. Available evidence suggests that these prestige differences frequently reflect differential expectations of performance such that members of the more prestigeful disciplines are actually considered to be generally more competent than members of less prestigeful disciplines. The net effect of this differential prestige in polydisciplinary settings is an unequal voice for some disciplines both in defining problems and suggesting solutions, resulting in a monodisciplinary orientation.

Funding agencies also engage in practices which discourage a synergistic orientation. Considerable support is given to studies which propose to do little else than summarize existing knowledge with respect to some problem of interest. Client-defined problems, particularly those defined by federal agencies, tend to be vaguely formulated or stated in futuristic terms, suggesting no criteria for evaluation of solutions. Perhaps because of this, bureaucratic criteria of evaluation are applied to research efforts, resulting in an emphasis on time and money expenditures rather than problem solving.

We have defined as synergistic those problem solutions generated by a polydisciplinary team which are both interactive and innovative. A solution is interactive if it contains elements from more than one discipline, and innovative if it contains new elements foreign to all disciplines. We believe that polydisciplinary teams are most likely to generate synergistic problem solutions when the utility of such solutions is perceivable to team members, and when team members maximize attempts to exchange ideas and information during the problem solving process.

Unfortunately, the potential for synergy is never easily realized. As we have demonstrated, innovative work is a possible but not necessary consequence of the collaboration of good minds. Collaborative efforts require interaction, and the same types of social factors which inhibit the frequency and quality of interaction in other social settings operate in scientific research efforts as well. We believe that an understanding of the potential disruptive effects of these factors is an important step in fulfilling the promise of synergy.