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Developing Problem Solving Leadership: A Cognitive Approach*

KATHRYN W. JABLOKOW
Engineering Division, Penn State Great Valley, 30 E. Swedesford Road, Malvern, PA 19355 USA
E-mail: KWL3@psu.edu

The difficulty and complexity of today's problems, in their catalytic progression, mandate the need for engineers who are both advanced problem solvers and leaders within their profession. Their knowledge and skill must extend beyond the traditional technical subjects to an understanding of problem solvers themselves, alone and in teams, and to the facilitation of those teams—a task that demands even more insight and practical expertise. This paper describes a cognitive framework for problem solving (founded on Kirton's Adaption–Innovation theory) that supports this view, and the new curriculum based upon that framework that was initiated and developed at Penn State University to help address these needs. The curriculum is composed of a core module of three courses that focus on fundamental concepts and principles of problem solving, progressing from the individual problem solver to problem solving teams and culminating in problem solving leadership. Several supporting courses are also offered or are under development (including courses on invention and problem solving ethics), and additional enhancements (including on-line delivery) are underway. The design, implementation, and evaluation of this program are discussed here, as well as our exploration and testing of the underlying theory based on the assessment of students' problem solving styles.

Keywords: problem solving; leadership; creativity; diversity; cognitive style; engineering education

INTRODUCTION

IN TODAY'S FAST-PACED GLOBAL ECONOMY, with the scope, difficulty, and complexity of problems increasing rapidly within a constantly changing socio-technical landscape, the critical need for engineers who are highly effective problem solvers (both alone and in teams) and responsible leaders has never been more apparent [1–10]. With a backdrop of some confusion (and little consensus) surrounding loosely used concepts like 'creativity' and 'innovation' [1, 2, 11–17], it is imperative that a sound approach is adopted to meet this need, one which will require engineering educators to dig more deeply and rigorously into, what are for them, 'non-traditional' disciplines (e.g., business, psychology, and even biology) and to pay more (and closer) attention to the individual differences of their students [4, 18–21]. As the National Academy of Engineering's Committee on the Engineer of 2020 noted [3, p. 52]:

> Our aspiration is to shape the engineering curriculum for 2020 so as to be responsive to the disparate learning styles of different student populations and attractive for all those seeking a full and well-rounded education that prepares a person for a creative and productive life and positions of leadership.

At the Pennsylvania State University's Great Valley School for Graduate Professional Studies (Penn State Great Valley), we have developed a new program of courses based on well-established theory and sound practice that is dedicated to educating engineers (among others) about problem solving, creativity, and leadership in a way that is both rigorous and practical. This approach enables us to sort out frequently confounded concepts (like those terms, 'creativity' and 'innovation', for example) and put them into proper perspective, so we can focus on problem solving practices that are truly effective (and understand the underlying reasons why they are). This paper discusses the cognitive framework behind the curriculum in some detail, as well as the development, implementation, and assessment of the curriculum, problem solving profiles of students in the program, lessons learned, challenges faced, and future program extensions.

PROBLEM SOLVING LEADERSHIP

Technological change (indeed, all change) is catalytic in its progression, building on itself (even its failures) and precipitating more change of varying size, scope, style, and impact as time (and problem solving) progresses [1]. This catalytic nature of change gives us (its agents) an enormous advantage, allowing us, with each achievement, to reach a better position to solve more at an even higher level. However, this progression also opens up a vast and growing number of increasingly difficult and complex problems, especially within

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large communities of problem solvers (consider, for example, our current concerns with energy, the environment, and healthcare). This perplexing and somewhat paradoxical situation is due in large part to our own success; we have created many of these problems *as a result of* our growing numbers and expanding needs. In addition, these problems all carry decreasing timelines for expected answers and increasing demands for immediately perfect solutions. The end result: our current success is the base of our future problems.

No one problem solver can possibly manage such problems or demands, in such progression, alone. In order to solve these problems effectively (indeed, to solve them at all), we must collaborate with other problem solvers, and we must do so wisely and well if we are to succeed. In order to collaborate, we must first understand the key differences and similarities that exist between us, both as individuals and as groups. Otherwise, our ability to match our problem solving resources (i.e., ourselves) to the problems we face will be compromised, preventing us from solving all the very problems for which our teams are formed. Facilitating this matching of people to problems and managing the gaps between them is the essence of *problem solving leadership*. In other words, being a problem solving leader means knowing how to manage effectively a diversity of problem solvers working on a diversity of problems using a diversity of approaches—surely, this demands an understanding of all three.

Managing a diversity of problem solvers and their various approaches to problem solving begins with an understanding of others; understanding other problem solvers requires an understanding of self (as a problem solver) and one's own preferred approach. As Beveridge notes [22, p. 2]:

> It is not necessary to be a mechanic in order to drive a car, nor trained in cognitive psychology (study of the thinking process) or philosophy in order to think or reason. But there are times when the car will not go and times when the usual thought processes do not solve a problem and then it is useful to have a working knowledge of the machinery one is using.

In other words, even those who desire to be only competent in their problem solving need to know something about how the brain works as it problem solves in order (for example) to know what to do when stuck or how to approach a problem when some preferred way of solving it is no longer effective. Taking the argument further: if we want to be *expert* problem solvers (as opposed to merely competent), then we need to know even more about how the brain operates, as well as how the problem solving performance of other problem solvers compares with our own. And if we want to be *leaders* in problem solving, then we must know at least as much (or more) than our fellow team members about how to manage different problem solvers (including ourselves), making them and us more effective by optimizing individual and group performance with respect to the problem at hand. In conclusion, the technical content involved in the solution of many engineering problems is no longer enough, even just to 'get by'; we also need knowledge and practice in the domain of the 'human engine' (i.e., the brain) in order to solve today's complex problems successfully.

This position is not new, and it is gaining ground, as the increasing attention to problem solving (and its leadership) within engineering (and other) curricula attests [8, 23–42]. Of these efforts, most (if not all) take an *explicit* approach [28], designing skill modules, courses, and programs that address problem solving directly, rather than as a by-product or sidelight of other more traditional coursework. Two particularly noteworthy examples are the well-established Problem Solving Program at McMaster University [33] and the new Center for the Study of Problem Solving at the University of Missouri [8]. In the first case, Chemical Engineering faculty at McMaster University have spent over 25 years developing, delivering, and testing an instructional program that focuses on process skills, including those related to problem solving (alone and in teams), self-assessment, lifelong learning, and change management; this program has received international recognition, and its components and materials have been studied and adopted by numerous companies and other university departments. In the second case, Education faculty at the University of Missouri are developing a new Center that will focus on both 'everyday' and professional problem solving research in STEM disciplines, with the ultimate aim of helping all university students become better problem solvers.

Similarly, at Penn State Great Valley, we are addressing the need for more effective collaborative problem solving in engineering through a coordinated program of courses dedicated explicitly to that purpose. Our first step was to identify a cognitive framework that could support the desired progression from the individual problem solver to the problem solving team to problem solving leadership. Given this framework, it was our pedagogical aim to design a curriculum that teaches engineers (and others) how to be more effective problem solving leaders, i.e., to be effective problem solvers themselves (alone and in teams) and to be able to facilitate the problem solving of diverse others—even when they (the 'leaders') are not the leading experts in the technical domain of the problem.

In describing our efforts to date, we begin (in the next section) with a broad (yet fairly detailed) summary and discussion of the cognitive framework we have adopted. We present the problem solving curriculum we have developed around this framework in the section, 'The Penn State Problem Solving Program'**. Next,** we describe the use and impact of problem solving (cognitive) style—a key variable—within the program, including the assessment of students' cognitive styles using the

Kirton Adaption–Innovation Inventory (KAI), instructional design based on these data, and some implications of our findings as we test the underlying theory. We go on to discuss the current implementation of the program at Penn State, and present some of the challenges that we faced in creating it. We then discuss the assessment of the program, including its impact in industry and on scholarly research. Finally, we provide a general summary and some conclusions about our work, as well as several proposed extensions to it.

A COGNITIVE FRAMEWORK FOR PROBLEM SOLVING

The cognitive framework for problem solving embraced here was introduced by Kirton [2, 43], a British industrial psychologist who has spent nearly four decades developing both its theoretical foundations and its practical application across disciplines (including, e.g., management, education, and science). In this section, we will explore a condensed summary of Kirton's framework for problem solving, incorporating the work of others whose contributions add support as well as depth and breadth to Kirton's original views. We begin by recalling the greater context for problem solving and change in today's world, driven by the challenge and complexity of our current problems, the catalytic nature of change, and the implicit need for collaboration. In responding to all of these, our understanding must begin with the cognitive processes of individuals—where *all* problem solving begins.

Key variables of cognitive diversity

All humans solve problems, and at the core of every individual's problem solving efforts (according to Kirton) are four principal elements or key variables: *opportunity, motive, level*, and *style*. While these elements are common to all humans, small but significant variations in them help define the differences in our problem solving efforts. As for opportunity, the environment is its general source, however a particular opportunity may come to our attention (as Kirton notes, opportunities may be revealed, sought, or made [2, p. 7]). Without opportunity, no problem solving can occur; when it exists, opportunity must be perceived by the individual (perhaps from among many opportunities), who must then manage and exploit it successfully—or recover from bad decisions.

Next, motive is needed to drive our problem solving efforts; it is the means by which we channel energy in a particular direction, at the necessary intensity, for the required duration, in order to solve a given problem. Motive is also the underlying process that enables us to filter through all the possible problems (opportunities) available and helps us choose those that we wish to address (and in which order) [13]. Having chosen an opportunity (problem) upon which to act, we plan, find, and implement a solution. To do so, we need two cognitive facilities: level (capacity) and style. We know a good deal about cognitive level, which refers to an individual's inherent potential capacity (such as intelligence or talent) and manifest capacity (such as technical competence or managerial skill). Cognitive style, on the other hand, describes the *manner* in which we solve problems [2, 20, 30, 44]; more precisely, cognitive style is the 'strategic, stable, characteristic, preferred way in which people respond to and seek to bring about change' [2, p. 43], including the solution of problems. Kirton's particular contribution here is to make clear (backed with evidence) that cognitive style is *independent* from cognitive level [2]; knowing something about an individual's style tells us nothing about that person's level, and vice versa, although the two are often confounded in practice [44, 45].

From this discussion, note that our definition of problem solving is very broad; in essence, it is the act of bridging a gap (of cognition and resource) between 'what you have' and 'what you want or need', with variations in how (and where—as in 'which discipline') that occurs encompassed in the four key variables described above. On this point, our approach differs from some others, where problem solving (as opposed to, say, 'exercise solving' [33, 34]) is constrained to include only those situations 'that the problem solver has not encountered before' and/or in which 'the procedure to be used is unclear' [33, p. 75]. The general definition for problem solving we have adopted, which subsumes these cases, is not new or unusual; it forms the basis for many problem solving process models in use today [34, 46] and can be found in the classic works of Wallas [47], Guilford [48], and Gagné [49], among others [e.g., 26, 27].

The concepts and definitions presented above all feed into a number of key assumptions. First, by virtue of adopting a broad functional model for human cognition, we can link creativity, problem solving, and decision making together: the brain uses the same fundamental cognitive process for all of them. Since all humans utilize this process, we can assume that all humans are creative and solve problems—with differences in their problem solving and creativity explained through variations in level, style, motive, and (perception and selection of) opportunity [2, 13]. Among these variations (i.e., this diversity), no style, level, or motive is better than any other *in general*, only more or less effective (appropriate and efficient) for finding the required solution to a *specific* problem and implementing it. Every style and level has advantages and disadvantages, in which the style and level of *the problem*, not one's preference, is the key [2, 17]. This is a vital element of Kirton's theory that moves us from allowing popular trends (e.g., 'Innovate or die!') to determine the so-called 'best' approach to problem solving, to the more reasonable approach of determining what the problem actually requires for its resolution—regardless of what the trends say. In actual practice, a team member may not fit the current trend, but he or she may be most helpful (given that person's particular level and style) with the present problem, at the present stage!

With these principal elements and assumptions in place, we now have a model of cognitive diversity at the individual level, which (while basic) is rigorous and useful. In summary: all humans are creative and solve problems, at different levels and with different styles, driven by different motives, and exposed to different opportunities (which they also view differently). In problem solving, we must–at a minimum–manage this individual diversity in order to manage change; to manage wider change, we must manage wider social diversity (i.e., that of the group) as well.

Style and structure

Next, we explore the concept of cognitive diversity (and its relationship to problem solving) from another perspective, with a particular focus on cognitive style. Personality can be defined generally as the sum of all the stable cognitive influences on and the stable patterns of behavior; it is a structure, as are all its elements (e.g., attitude, motive, potential level, style, etc.) [2, 50, 51]. Differences in personality result from variations in these patterns, to which we, as humans, are particularly well attuned ('I can readily tell that you are not like me, even if I cannot explain why!'). According to Kirton, one of the main patterns that differentiates us from each other is the characteristic way (as distinct from characteristic level) in which we, as individuals, manage structure.

In general, cognitive style (like cognitive level) has multiple dimensions, which can be assessed by many different means. To assess cognitive style, Kirton developed and validated the Kirton Adaption–Innovation Inventory (KAI), a straightforward psychometric assessment that does its job neatly and compactly [2, 43]. As measured by KAI, cognitive style differences lie on a bipolar continuum that ranges from strong Adaption on one end to strong Innovation on the other. In general, individuals who are more Adaptive prefer to solve problems using more structure, and with more of this (cognitive) structure consensually agreed. In contrast, more Innovative individuals prefer to use (be confined by) less structure when solving their problems and are less concerned with gaining consensus around the (cognitive) structure they use. Note that individuals are most accurately described as 'more/less Adaptive' or 'more/less Innovative' in keeping with this continuous range of styles, although the terms 'Adaptor' and 'Innovator' are sometimes (but cautiously) used for linguistic convenience.

In general, more Adaptive individuals prefer to approach problems from within the given frame of reference (or paradigm—a conceptual structure) and strive to produce solutions that are more immediately efficient, sound, and reliable. They are especially good at refining the current standards, rules, and procedures in order to make them operate as effectively as possible. The value of these individuals is obvious: they provide the consistency, stability, and efficiency necessary to keep a system running smoothly in the long term. Their advantage lies in their preference for finding ways to enable and create change *within* a structure, making best use of its defining properties and resources; they also change the structure *as an outcome* of solving a problem. Their disadvantage is their tendency to stay with a (even the main) structure 'too long'—i.e., after its usefulness has played out [2].

The more Innovative person, on the other hand, tends to detach a given problem from its customary frame of reference, searching for 'unusual' solutions in unexpected places [2]. These individuals are particularly good at bending the current rules and procedures in order to move a system into different (often riskier) territory. The value of the more Innovative is also clear: they provide more radical shifts in structure when these are required. They may, from time to time, alter elements of (even) the main structure in order to solve the problem—a riskier approach. Their advantage lies in their preference for manipulating boundaries and juxtaposing views that may not be obvious to their more Adaptive counterparts. Their disadvantage is their tendency to leave a structure 'too soon'—i.e., when it is still enabling and delivering value. For additional descriptions of commonly observed traits of individuals with different Adaption-Innovation (A–I) cognitive styles, see Kirton [2, 43, 52] as well as Buffinton [24], Lopez-Mesa and Thompson [53], and Jablokow [1, 54].

The paradox of structure

Within these variations of style and their corresponding impact on problem solving, we can see a paradox: the style (preference for structure) that enables problem solving in one instance may hinder it in another [1, 2, 30]. For example: while Leonardo da Vinci devised many 'futuristic' designs that spanned and combined a wide variety of disciplines, he frequently left projects unfinished due to his apparent lack of focus [55]. In contrast, Thomas Edison—who was very focused—found it difficult to shift away from a particular design solution, even when superior alternatives existed [56]. When applied to structure in general (whether it be technical, social, conceptual, etc.), Kirton refers to this phenomenon as the *Paradox of Structure* [2, pp. 126–134]; that is: *every* structure, by its very nature (including one's own brain), is both enabling and limiting at the same time. In fact, a structure limits (i.e., focuses our efforts) *in order* to enable, but it must enable *more* than it limits, or the structure cannot function well. The limits must be focused, sharp, and stable enough to enable 'now', yet flexible enough to change when currently-required enabling is blocked. The trick is to find a good balance in each circumstance, i.e., we must find ways to maximize the enabling factors and minimize those that limit in order to reach ground where there is payoff for all.

One difficulty is that the proponents of any structure will play down its limiting side and play up its enabling side, whatever that structure might be. Here we must take care: within much of the literature devoted to 'creativity', breaking down or shedding structure (i.e., Kirton's Innovation) is considered better (i.e., 'less structure is more creative')—which, from a cognitive perspective, blatantly confounds level and style by falsely assuming that structure only limits. The careful distinction between level and style (and its practical implications) is a key element of Kirton's theory that makes sure we see Adaption–Innovation as a continuum, not a dichotomy.

As noted previously, no particular style (level, motive, etc.) is better than any other *in general*; only in the face of a *particular* problem might one be more effective (by being more appropriate) than another. As engineers, we know the truth of this from practical experience: there are times when maintaining or fine-tuning the current structure (product, idea, design) is the best solution, while at other times, the current structure must be rebuilt or replaced in order to succeed. In complex problem solving, both approaches are needed *overall*, at different times, and applied toward different parts of the 'larger' problem. There is more than one style of creativity and problem solving, and within that diversity, more Adaptive and more Innovative approaches are equal in intrinsic value, with their complementary contributions wrapped around the management of structure.

We can find many historical examples of the catalytic nature of change and the Paradox of Structure in science, engineering, management, and other disciplines [1, 2, 12, 57]. Classic case studies include the Copernican Revolution [58, 59], the development of the Periodic System of the Elements [60], and the invention of the telephone [61], among others. In each case, it is evident that multiple problem solvers were necessary to resolve these complex problems—individuals with different levels, styles, motives, views of change, and perceptions of opportunity. And so we generalize: a diversity of problem solvers using a diversity of approaches is needed to solve a diversity of problems (as we have noted before, we *must* collaborate in order to survive). What is equally obvious is that these diversities of problems and people need to be managed and facilitated; they do not generally 'take care of themselves'. If the current, required diversity is not managed well, it will reduce (not enhance) the team's problem solving effectiveness. The question is: how do we take the essence of this multi-faceted diversity of problems, people, and processes, which we have tried to capture here using a few key variables and principles, and apply it to collaborations in a systematic and practical way? How can we come to some understanding of the implications of cognitive diversity (and the beginnings of its management) in a group setting?

Cognitive diversity in teams: Problem A and Problem B

And so we come to teams: in problem solving, we must manage our own individual diversity to manage our personal impact on change; we must manage the diversity of teams to manage wider change. Kirton describes this practical challenge in a simple, yet elegant way [2, p. 5, also p. 205]: every time a person shares a problem with another person (i.e., in *every* collaboration), each person automatically acquires *two* problems. The first is Problem A—the original problem around which the team was formed (even if it is a team of only two), and the second is Problem B—the problem of managing each other's differences (i.e., managing the collective diversity). In the end, Problem A should take up more of the collective energy than Problem B, or the team will eventually fail. We are repeatedly faced with this situation and must ultimately make a choice in each case: do we collaborate or clash?

Problem B can take many forms, for the potential differences between two individuals (much less, two groups) in level, style, motive, and perceptions of opportunity are countless. In addition to these person-to-person variations (which can create considerable friction between team members), the problem of managing the differences between our problem solving resources and the requirements of Problem A is an additional challenge—in essence, another form of Problem B. We can come to a better understanding of Problem B and its resolution by considering the notion of cognitive gap.

Cognitive gap

Strictly speaking, *cognitive gap* is defined as all cognitive differences between a lone individual and the problem, or between each individual in a team and the problem plus each individual and every other member of that team [2, Ch. 10]. Put very simply, there are two forms of cognitive gap: Person–Person and Person–Problem [45], where 'Person' can refer to an individual or a group (see Fig. 1). Kirton focuses mainly on cognitive gaps in style, but also includes gaps of level, motive, etc.—in fact, any cognitive difference that has an influence on problem solving effectiveness.

The presence of cognitive gap is another example of the Paradox of Structure: cognitive gaps (a psychological structure) both enable and limit the solution of problems. Some cognitive gaps are necessary and desirable, e.g., the diversity of ability and/or preferred approach among problem solvers in a team (or between several teams) needed to meet the requirements of a particular Problem A [2, 45]. However, those same gaps can limit

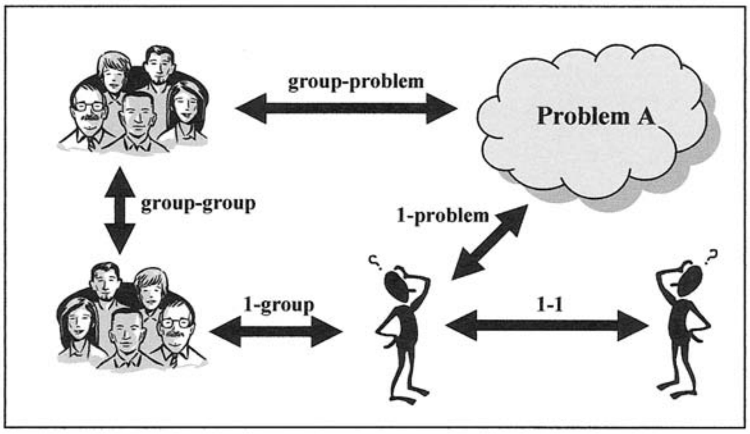

Fig. 1. Forms of cognitive gap

through their potential to create Problem Bs within or between those teams, i.e., the difficulties that may arise between problem solvers who view Problem A and its solution differently. In short, as Driver [62] and others have observed, both too little and too much diversity can be detrimental for effective group performance [63, 64].

Note then, that underlying each arrow in Fig. 1 is a potential Problem B. Jablokow and Booth [45] explored the impact of cognitive gaps (of level and style) in the context of high performance product development organizations, noting their paradoxical dual role; in that context, cognitive gaps are a result of the diversity necessary to develop new products and bring them to market efficiently, but they may (simultaneously) create disruptions in communication and threaten the good will required for collaboration. In the end, understanding and clarifying the distinction between level and style appears to be one of the most effective ways to manage such a situation [2, 45].

How else can such gaps be managed? Kirton suggests that the best way to handle them is through a process that depends initially on insight. Specifically, when an individual learns about cognitive differences, their source, their value, and their limitations, then relationships with others (including those they consider problematic) can be understood better. Another person is not necessarily being 'difficult' or 'hostile'—he or she is just different, and that difference may be exactly what is needed to resolve the current Problem A (i.e., a human 'toolkit' of different facilities). Now we have a situation that can be interpreted as a mutual problem to be solved, rather than a battle. Training and education may not remove the gaps (style preference is fixed, for example, while level can be increased), but coping behavior (i.e., learned behavior that differs from preferred style) and insight may be used to good effect. Other ways of closing gaps (in general) include changing the requirements of Problem A, delegating to others, reorganizing roles in a team, and bridging—a social role in which a problem solver works to span a gap by bringing those on either side of it into closer accord [2, p. 247].

The progression of change

With some key concepts laid down relating to the cognitive diversity of individuals and the impact of that diversity in teams, we are coming closer to answering our ultimate question: with all of the complexities inherent in the problem solving efforts of human beings, how can we *lead* problem solving and change most effectively? What we can see so far is that the management of cognitive gap supports the management of diversity, which underlies the management of change and problem solving. Facilitating this process lies at the heart of problem solving leadership.

There are many models of change and even more scholars discussing its management [e.g., 65–70]. These contributions come from diverse fields (although many are rooted in business) and address the notion of change in the form and function of ideas, artifacts, and organizations. A fundamental weakness of some [e.g., 69, 70] is their tendency to see growth solely as an outcome of Innovation (i.e., 'revolution', 'breakthrough thinking'), and catastrophe as an inevitable result of excess Adaption (i.e., 'evolution', 'incremental change'). They fail to note in addition (and to balance their evaluation) the high death toll experienced by many Innovative ventures (e.g., start-up companies) and the critical growth found in many Adaptive efforts (e.g., precision technologies).

In contrast, Kirton and others [e.g., 12, 67, 68, 71] suggest that there are dangers throughout the change process, with more danger likely at *both* extreme ends, just as biology would suggest: we are most secure when we are in our prime (as long as we are healthy and well-adjusted). Consider, for example, an infant—born in a highly flexible state (a 'blank slate' of promised potential) but also extremely weak (helpless, in fact). As we age, our physical and mental abilities grow, reaching a 'prime time' (middle age) during which we are highly productive. As we age further, we begin to lose our physical abilities, but this loss is balanced by gains in knowledge, wisdom, and insight, and for a time, we can maintain our productivity. Eventually, however, both our physical and mental abilities wane (in old age), and we become as vulnerable as an infant once again.

Looking back, then: where are the points of greatest weakness—for both individuals and organizations? The answer: at the two extremes—first, in flexible ('Innovative') infancy, and second, in well-defined ('Adaptive') old age. Note that for organizations, we can also have excessive Adaption early on (which fails to keep up with changing social needs from the start), as well as late regeneration (infusions of Innovation), even in old age. Many a company, a hundred years old, has been set on a new path by its management for several more decades—and successfully, as long as they did not lose touch with needed Adaption (as Marconi failed to do [2, p. 181]).

Now we see a more balanced view emerging: for optimum problem solving and growth, we must shift—repeatedly, and irrespective of how long we have been going—to more (or less) Adaption or Innovation and more (or less) domain knowledge and expertise (i.e., various forms of level), depending on or in anticipation of the changing situation (not just the age of the enterprise); all this rather than dramatic shifts between (say) highly Innovative and highly Adaptive extremes. Given that all organisms, ideas, and artifacts follow a natural progression from vulnerable, flexible start (armed with few resources) through a vigorous prime (with all-round ability) to a gradual decline (balanced by accumulated experience and skill, at least for a while), how should we measure success? Kirton's recommendation is to consider how much each form of the system (team, organization, etc.) delivers while it lasts, within each and any phase of progress [2]. There are multiple factors involved (style, level, motive, etc.), with no one of them solving all problems, although any one of them may need to take the lead in a particular setting at a particular time.

The pendulum of change vs. the spiral of change

Following this argument leads us to consider several different trajectories of change, characterized by two familiar shapes: the pendulum and the spiral. The *pendulum of change* represents change managed poorly, in which groups oscillate between unbalanced extremes [2, p. 217, also pp. 281–288]. Such a pendulum can be set in motion when groups 'suddenly' realize that the approaches and solutions that have made them successful in the past no longer work effectively—whether those approaches and solutions are more Adaptive or more Innovative in nature, or of a particular balance of levels among (e.g.) engineering, finance, and marketing, or even within the same department, between (say) research and development. Left unchecked, each swing of the pendulum will eventually lead a group (or organization) into inevitable dysfunction and potential decline. Fortunately, the successive swings of the pendulum of change can be avoided through effective leadership and proactive planning. From the perspective of Problems A and B, problem solving leaders need knowledge of Problem A so as to lead the team toward it, as well as knowledge of Problem B—so they can lead the team away from it!

The hopeful alternative to the pendulum is the *spiral of change* [2, pp. 288–292], in which groups and organizations manage change well by cycling through stages of growth that build upon each other in an expanding path of progress, adjusting style and level (and all else) just enough, soon enough, to stay on an effective problem solving track [1, 72]. These cycles or stages of growth can be characterized by different styles and levels, among other variables (e.g., attitudes, beliefs, personal needs). As noted previously, we can see such catalytic spirals of change in various case studies from the history of science and technology [1]. In such cases, the spirals of change were not deliberately designed, in the sense that the protagonists behaved as they behaved unconsciously, knowing (in some cases) that they were different from each other, but not knowing explicitly why they were different or how those differences could be managed best. But *we* are in a different and advanced position: by virtue of the framework we have for understanding the human brain and its problem solving processes, we have the opportunity to anticipate, plan, and manage change proactively to a much greater extent than ever before, if we will accept the challenge. This, of course, begs the question: but how is it done?

The management of diversity and change

Framed in the Paradox of Structure, Kirton describes the *management of change* (done well) as 'managing structure, by adjustment and readjustment, so as to set just sufficient limits that will achieve maximum enabling' [2, p. 287]. How can we make this information useful in an immediate and practical way? As one strategy, consider the following: when teams are first formed, a good deal of time is spent assembling the best possible combination of people in style, talent, knowledge, motivation, etc., for the *current* problem in its *current* form. But any team, by virtue of its own success in solving the original problem, creates new conditions, and these new conditions can create needs that the present team is not well equipped to handle.

In essence, every large and complex problem (at least) is 'a moving target' [2, pp. 290–292], and we must learn how best to track it. One solution is to identify competent, experienced people who, although currently at a disadvantage and seemingly out of favor in the present environment, will be needed at the appropriate time and stage to adjust and help control the change trajectory (avoiding the pendulum of change, seeking a spiral) in due course. In other words: identify what will be needed when the current phase of problem solving has changed the operating conditions and what will be needed in the next phase of problem solving; it helps if the entire team shares in these insights and assists in the process. So, to manage change widely and well, a team needs to manage diversity (both of problems and its own internal array) equally widely, wisely, and well [2].

Agents of change

Within this model of change and its management, it is also useful to note Kirton's revision of the concept of 'agents of change' [2, pp. 229–232]. Just as every person is creative and solves problems (at different levels and in different styles), so *every* person is an agent of change—also with different levels and styles. There are no generalized 'resistors to change', no universal 'agents *against* change'. (Even dinosaurs kept changing—just not fast enough in the right direction, although we do have birds with us yet.) Given that all life keeps changing, people still differ in how much they are creative and in what way; they also differ in the extent to which they are agents of change in a *particular* situation and how effective they are at it (then and there). No one accepts all change, and no one rejects all change; we each accept some changes and reject others—the question is, which ones and (in each particular case) why?

Kirton's framework suggests that changes are most likely to be acceptable to an individual if they fit that person's cognitive profile (preferred style, current level, present attitudes, etc.). That is, a person will most readily accept those changes that he or she understands and with which he or she agrees, all done with a speed that person considers appropriate. As Kelly observes, no healthy individual can accept change that is so large and/or so challenging as to threaten that person's understanding of self and reality [51].

With respect to structure, a proposed change is more likely to be accepted by someone if it lies within a degree of structure that matches that person's preferred cognitive style, and it is more likely to be rejected by him if it does not. For example: more Adaptive solutions, ideas, or products may be dismissed by the more Innovative as 'mere' tinkering or 'hardly creative' (confounding style and level), while more Innovative solutions may be viewed warily by the more Adaptive as being overly risky, peripheral to the problem, or just plain 'silly'. These different perceptions of change are yet another representation of cognitive gap, which, when understood and appreciated, can lead to valuable insights that aid in its management (i.e., a shift from 'how irritating you are' to 'how useful you might be if only I could collaborate with you better').

Problem solving leadership

In essence, all the elements described above represent the knowledge required by a problem solving leader in order to manage successfully the efforts of a problem solving team. They also represent the knowledge required by each member of that team in order to help a leader be successful; there are no ideal leaders who can 'do it all'. In the past, considerable time was spent in the search for such an 'ideal leader'—a notion we reject. This past leader was selected (or took command) because it was deemed (especially by the leader) that he or she had outstanding knowledge of the problem area (what we might call the 'technical content'). This leader was expected, with whatever resources of people and materials were available, to dominate the problem solving process, leading and commanding while others 'followed' (i.e., did the work).

In our framework, a leader is the (any) person holding the *role* in leadership that will facilitate the team in solving a particular problem, over a specific time, with the currently available resources, within the available team. We seek to be pragmatic rather than aim for an unattainable ideal. As such, today's problem solving leader needs a new array of attributes to be successful and remain acceptable; these are composed of two general parts. First, he (or she) still needs knowledge of the original problem (Problem A)—not in order to dominate it completely, but enough to be able to 'hold his own' as an expert in an appropriate team. This is now a more modest requirement, but it is only half of what is needed. The other half is an understanding of the problem solving process and the problem solver (i.e., knowledge related to Problem B). This combination will allow a leader to help the team direct their combined energy efficiently towards the collective solving of Problem A, with as little hindrance from any potential Problem Bs as possible [2, pp. 308–313; 21]. So, it is the *team* that solves the problem, under knowledgeable leadership, given that 'knowledgeable' has been redefined. The leader is now a conductor of the orchestra, interacting with each player, rather than the lead player on every instrument.

THE PENN STATE PROBLEM SOLVING PROGRAM

As mentioned in the major section above, 'Problem Solving Leadership', Penn State is one of a growing number of universities creating specialized courses and programs to develop problem solving leadership in engineering students. Such courses might well be placed within the core of any engineering program (undergraduate or graduate), or they might be integrated through the creation of specialized tracks, minors, or skill modules. At Penn State Great Valley, we have chosen to begin with our Systems Engineering and Information Science degrees, as both place special emphasis on the management of complex socio-technical systems, but other degree programs would have been equally suitable. In describing the details of the Penn State Problem Solving Program, we begin

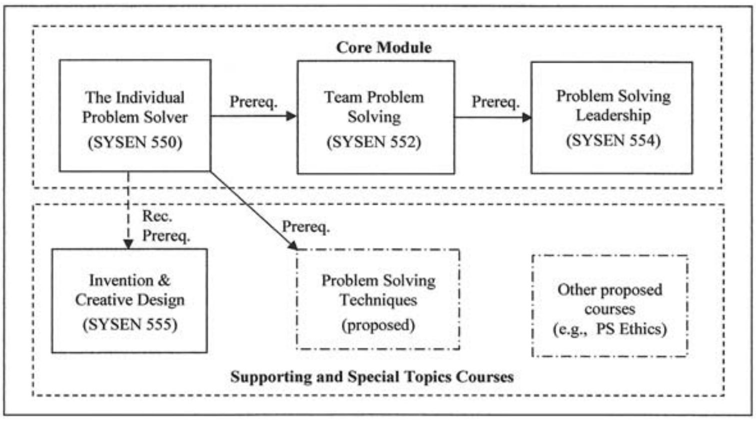

Fig. 2. Progression of courses within the Penn State Problem Solving Program.

with its specific progression of courses and their corresponding key concepts.

Progression of courses and concepts

In designing a curriculum to follow the progression of topics within the framework described above, we have developed a core module of three courses, which cover fundamental concepts, applications, and case studies of problem solving as they move from the individual problem solver, to collaborative (team) problem solving, to problem solving leadership (see Fig. 2, with prerequisites indicated by arrows). In addition to these core courses, several supporting and special topics courses are also offered or are under development. Because the courses were originally introduced as part of Penn State's Systems Engineering degree, they all use the Systems Engineering prefix (SYSEN). Within the core module, the progression of concepts through the sequence of courses is summarized in Table 1. In reviewing the path through this core module from beginning to end, we will now discuss each course briefly in terms of its general objectives, overarching themes, personal insights, fundamental aims, key elements of theory, practical entry points, and expected skill outcomes.

SYSEN 550: Creativity and problem solving I (The individual problem solver)

The fundamental objective of this first course is to help students become better and more effective problem solvers through a basic, yet rigorous, understanding of the cognitive processes involved in problem solving and creative activity. To meet this objective, key elements of the problem solving framework are examined (using Kirton's Cognitive Function Schema as a guiding map [2, pp. 36–37]), along with general and domain-specific models of the problem solving process, a range of problem solving techniques, and illustrative examples of these topics in a variety of contexts, including science, engineering, and management.

In addition, each student examines his or her own problem solving profile, an activity that includes evaluations of cognitive level, cognitive style (using KAI), process expertise, and knowledge of problem solving techniques. Our aims for these activities are threefold: to demonstrate the validity and usefulness of the cognitive framework and its underlying theory through personal application; to provide students with an assessment of their relative, changing, strengths and weaknesses (as determined by each problem) within the domain of problem solving; and to give students a sound basis for understanding and appreciating the diverse problem solving abilities and styles of others.

The overarching theme of the course is the individual problem solver, with personal insights related primarily to individual awareness of one's unique problem solving profile (style, level, motives, perceptions of opportunity, etc.) and its implications. Our fundamental aim is precision of terms and concepts in order to lay a foundation of

Table 1. Progression of concepts within the core module

	SYSEN 550 ⟶	SYSEN 552 ⟶	SYSEN 554 ⟶
Overarching theme	Individual problem solver	Problem solving teams	Problem solving leadership
Personal insights	Me, alone	Me, working with others	Me, facilitating others
Fundamental aim	Rigorous foundation	Efficient relationships	Effective achievement
Key elements of theory	Cognitive diversity; Paradox of structure	Cognitive gap; Progression of change	Management of diversity; Management of change
Practical entry points	Individual traits; Case studies	Problems A and B; Case studies	Pendulum of change vs Spiral of change; Case studies

common facilitating language and perspective for use across the program. The main elements of theory include the key elements and assumptions of problem solving that support the cognitive diversity framework, as well as the Paradox of Structure—all of which remain critical throughout the module. As practical entry points, the description of specific individual traits associated with different cognitive styles and levels, coupled with detailed case studies (e.g., the Copernican Revolution; Kirton's study of Management Initiative, see [2, pp. 9–25] for a summary), provide a practical perspective on the Paradox of Structure and set the individual traits into an established pattern.

SYSEN 552: Creativity and problem solving II (Team problem solving)

This second course builds on an understanding of the individual problem solver to address the dynamics of problem solving teams as its overarching theme. Here, we seek to provide awareness and insight about 'me, working with others—especially those not like me' (problem solving still begins with the individual). At the core of the material is the concept of cognitive gap (in all its forms) and its basic management. Modeling the progression of change is also a key element, appearing in a number of case studies (e.g., the development of the periodic system, the discovery of the structure of DNA, the invention of the jet engine). Other topics include coping behavior, agents of change, the problem as a moving target, and responses to change (acceptance/resistance). As practical entry points, we explore the identification and handling of Problems A and B (i.e., 'the management of my diversity relative to yours, with the diversity and complexity of the original problem at the back of everything, all the time'). Our fundamental aim in this course is efficient relationships, laying an intra-team foundation that builds on the common language and outlook established in the first course of the module.

Upon completing this course, students have a fundamental understanding of cognitive diversity within groups and how it can be leveraged to make problem solving more effective. Practical discussions focus on the skills necessary to analyze the cognitive resources of a problem solving group, break down complex problems based on cognitive variables, and match cognitive resources appropriately with required tasks. Students explore the impact of different cognitive profiles on problem solving from multiple perspectives, including group efficiency, personal communication, and the quality of group outcomes. Strategies and tactics for improving the problem solving performance of groups of all sizes are presented and applied using real-world case studies.

SYSEN 554: Problem solving leadership

This third course builds on an understanding of the individual problem solver and problem solving teams (and the individual's role within them) to focus on leadership and the problem solving leader. The core of the course material contains all the key concepts covered in the two course prerequisites, plus essential elements of socio-technical systems theory and the advanced modeling and tracking of complex problem and product diversity. Now we consider these concepts from the perspective of leadership—what problem solving leaders need to know, why they need to know it, and what they can do with this knowledge. In this course, students pay more attention to the problem solving environment, i.e., the consideration of organizational climate and professional culture [2, 52, 59, 73, 74], as opposed to national culture (e.g., [75, 76]).

The overarching theme of this capstone course in problem solving leadership is 'grand' management, including leadership as a social role within the group—focusing on the responsibilities in managing self and others (balanced by potential rewards). The main elements of theory are the management of (cognitive) diversity and (as the foundation for) the management of change. Practical entry points include the Pendulum of Change vs. the Spiral of Change, linked with the dangers of success, such as 'spin-off problems' [2, p. 12]. Additional case studies, including the management (or mismanagement) of technological change at companies like Xerox, Motorola, and Ford [71, 77] provide illustrative examples of these concepts. Our fundamental aim in this course is effective achievement, i.e., facilitating the solution of complex real-world problems by making the best use of every member of the team.

Certain components of this course are carried out in *action learning* mode, that is, with students actively participating in the collection, processing, and presentation of course material. This action learning approach is also extended to a major course project, in which students design and implement problem solving 'interventions' within the workplace or community over the course of the semester. Upon completing this course, students have an advanced understanding of cognitive diversity within groups and how it can be leveraged to make problem solving more effective. Expected skill outcomes for this course include the ability to design and carry out practical applications of problem solving theory, the ability to integrate knowledge of cognitive diversity into real-world settings, and the ability to optimize personal leadership roles within problem solving groups.

Additional themes within the core module

In addition to separate specific themes for each course, there are at least three common themes featured throughout the core module: first, there is the perceived nature of the problem (opportunity), interacting with motive, level, and (preferred) style. Second, there is the search for excellence in leadership (to which everyone, to a greater or lesser degree, contributes) and the search for expertise (to which each person contributes, to the extent he or she has it, as and when needed). Both of these attributes are preferred to the search for 'ideal leaders' and 'ultimate experts'—since neither exists. And finally, there is the need for everyone to learn about *all* of the above, always and constantly; the more demands we make upon our problem solving 'engine' (the brain), the more we need to know about it and the processes it uses.

SYSEN 555: Invention and creative design

Inspired by the work of Gorman, et al., at the University of Virginia [78], the aim of this first special topics course is to explore invention and design as essential examples of problem solving. Rhodes' framework of '4P's' [79]—Person, Process, Product, and Press (Environment)—is used to provide an underlying structure for the course, with each element investigated in some detail, both separately and in combination. Kirton's work is integrated in support of this structure, providing added depth through an understanding of the different ways in which inventors approach their work, the underlying reasons for those differences, and the corresponding impact on the products that result. Adaption–Innovation theory (and its application to technology, in particular) is also used to shed light on the development of inventions, i.e., the progression of successes and failures, over time, that build on the different styles and levels of the inventors involved. (Note that the structure and content of this course as described previously in [80] have been revised extensively; further details will be provided in a separate publication.)

Upon completing SYSEN 555, students have a sound understanding of inventors as problem solvers, key factors that influence their behavior, models of and theories related to the invention process, issues related to the development of new technologies and their impact on society, the state of the art in invention research, and the U.S. patent system (including patents as technical literature). Other topics include the Theory of Inventive Problem Solving (TRIZ) [81], social aspects of invention, and the management of invention.

Proposed new courses

As shown in Fig. 2, a new course focused on problem solving techniques has been proposed to support the curriculum; it is currently under development. This course will help students assemble an extended practical 'toolbox' of problem solving techniques that might be used in various stages of a problem solving process (including invention or design, for example). Emphasis will be placed on choosing the right technique for the problem at hand in terms of both level (e.g., degree of complexity, field of expertise) and style (e.g., more Adaptive vs. more Innovative) based on classification schemes such as those suggested by Lopez-Mesa and Thompson [53]. Students will also focus on practicing and facilitating these techniques (alone and in teams) in the context of real-world problems in order to improve their effectiveness.

A second new course related to problem solving ethics is also under consideration. Here, in addition to general organizing principles (e.g., utilitarianism) and specific techniques (e.g., line-drawing) for framing and analyzing problems with ethical dimensions, the ethics of membership within a problem solving team will also be explored. For the latter, students will learn to offer those facets of their total diversity that are required by the team 'now', holding back what is not wanted and changing what is offered (or held back) in accord with the (changing) problem at hand. We aim to teach these 'means' as ethics for the management of diversity for the common good—in short, offering one's diversity to promote Problem A rather than raise a Problem B (even unwittingly).

USE AND IMPACT OF PROBLEM SOLVING STYLE WITHIN THE PROGRAM

As mentioned above, students begin the Problem Solving Program (in SYSEN 550) with an examination of their individual problem solving profiles, including assessments of manifest cognitive level, process expertise, knowledge of problem solving techniques, and cognitive style. The results of these assessments are used to demonstrate the practicality and validity of the underlying cognitive framework through personal application by the students in their own lives; the data are also used throughout the curriculum in the design of classroom activities, homework assignments, and course projects, as well as in partnering and team construction.

Because cognitive style is so frequently misunderstood and so often confounded with level, we place slightly more emphasis on its exposition within the program; based on its rigorous design and testing, we use KAI for its assessment. In this section, we begin with some general background information on KAI, followed by a brief discussion of its administration and the feedback process. Next, we describe a few specific classroom activities within the Problem Solving Program that utilize KAI results in their design. Finally, we present some of the KAI data collected for students of the program and discuss the implications of our findings.

The Kirton Adaption–Innovation Inventory (KAI)

The Kirton Adaption–Innovation Inventory (KAI) was introduced in 1976 [43] and measures preferred problem solving (i.e., cognitive) style. Respondents answer a list of 33 questions that focus on how easy or difficult it is for a person to behave consistently, over a long period of time, in particular ways; each answer is assigned a value using a 5-point scale. The inventory is designed for adults with work experience, but it has been used with bright children as young as 13 with good results. KAI is easy to understand and can typically be completed in less than 15 minutes.

Felder [20] notes that any psychometric instrument used in the classroom (whether for research or personal development) should be reliable and well-validated; KAI meets these criteria. Initial validation of KAI was based on six general population samples across 10 countries (including the U.S.) with a total of approximately 3000 subjects; the internal reliabilities range between 0.84 and 0.89, with a mode of 0.87 [2]. Additional supporting data (derived from the KAI Manual) relating to the instrument's development, validation, and testing may be found in Appendix 6 of [2]; in addition, over 300 archival papers and more than 90 graduate theses have been published in support of the underlying theory and the inventory.

As shown in Fig. 3, a person's KAI score will fall within a range of 32 to 160 (theoretical mean: 96), with a score of 32 representing the theoretical limit of highest Adaption, and a score of 160 representing the theoretical limit of highest Innovation. In practice, scores typically fall between 45 and 145. For large general populations, the distribution of KAI scores forms a normal curve with an observed mean close to 95 (± 0.5) and a standard deviation of (circa) 17 for all samples [2, Appendix 6, Table A]. In terms of gender differences, women are (on average) about one third of a standard deviation (i.e., 6 to 7 points) more Adaptive than men, with females' KAI scores normally distributed around a mean of 91, and males' KAI scores normally distributed around a mean of 98. To date, no culture differences have been found in the large sample studies [e.g., 73, 82]. Smaller, stable groups can be predictably different from general populations, depending on their problem solving orientation, and may exhibit skewed distributions about different means; the observed mean for engineers (in general, across genders) is 96.8 (N = 800). Additional statistics for these and other sample populations may also be found in [2, Appendix 6].

KAI administration and feedback

A qualified facilitator who has received the appropriate formal certification and training administers and scores KAI. This certification process is tightly controlled to preserve the integrity of the instrument and prevent its misuse. The inventories are not self-scorable, and on-line forms are not currently available, although an electronic version of KAI is under development. A number of faculty members at Penn State Great Valley have been certificated to administer and score KAI.

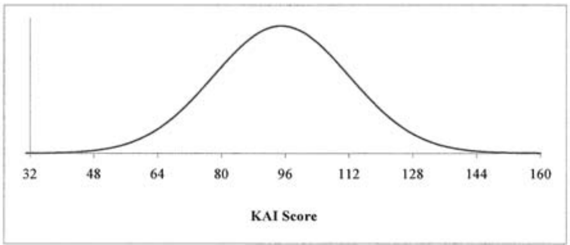

Fig. 3. The Adaption–Innovation (A–I) continuum with typical KAI distribution for a large, general population.

In the context of the Penn State Problem Solving curriculum, KAI is administered during the first class session of the first course in the core module (SYSEN 550) following a brief introductory lecture that includes simple working definitions for cognitive style and cognitive level. Students are assured of the confidentiality of their individual responses, although they are told that group data (such as ranges and means) may be presented or reported with assurance of anonymity. Confidential personal feedback is provided (in writing) to each student; no responses are revealed to any other individual without explicit permission, but students are encouraged to discuss their scores with others in the classroom. Our experience shows that students are generally eager to share their scores (and their corresponding insights), as long as a safe and non-judgmental environment has been established in the classroom and once they clearly understand the value of all cognitive styles.

Specific classroom activities based on KAI

In SYSEN 550, a full class session is devoted to personal feedback on KAI half-way through the course. This feedback is provided to help students gain personal insight about their respective problem solving styles and to demonstrate the predictive potential of the inventory (and the theory behind it). Within that feedback session, one exercise is particularly powerful for highlighting the differences between styles. Students are placed in homogeneous groups with respect to style (i.e., within any group, the KAI scores fall as much as possible within a range of 10 points) and are then asked to discuss and report on the advantages and disadvantages of 'being who they are', recording their results on flipchart paper. Because of the groups' respective homogeneity, students feel comfortable and 'at home' in them; as a result, coping behavior is minimized, and the characteristic differences that exist *between* styles become more obvious. These differences are revealed both in the processes of the different groups (e.g., more Adaptive groups spend more time establishing consensus; more Innovative groups have more difficulty staying on task) and in their final flipchart reports (e.g., more Adaptive groups tend to have neater and more detailed presentations than the more Innovative groups). The overall outcome is a simple but compelling demonstration of individual differences and their value; similar results have been reported (with managers in practice) by Hammerschmidt [83].

In the remaining two courses of the core module, individual KAI scores are used to enrich the learning experience and facilitate the design of class exercises and homework assignments in a number of ways. At this stage, students are prepared to consider the effects of 'power groups' on organizational climate and culture; these can

Table 2. Key statistics for KAI scores of all students (total sample and sorted by gender)

Student sample	Size (N)	Range	Mean	Std dev.
All students	209	53–143	97.9	18.4
Male students only	145	53–143	98.8	17.4
Female students only	64	61–136	95.9	20.5

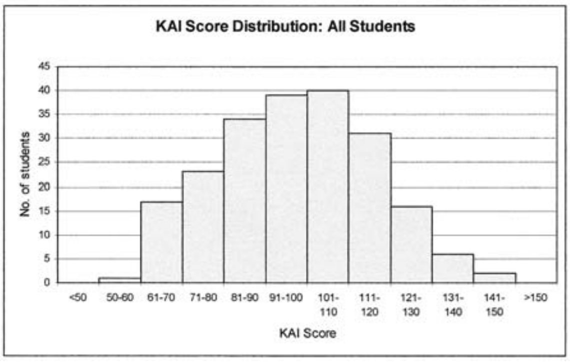

Fig. 4. KAI score distribution for total sample.

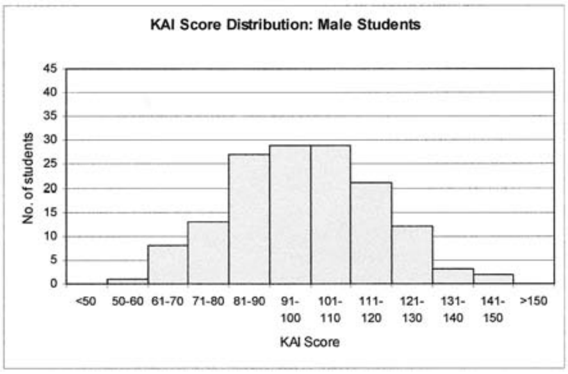

Fig. 5. KAI score distribution for male students only.

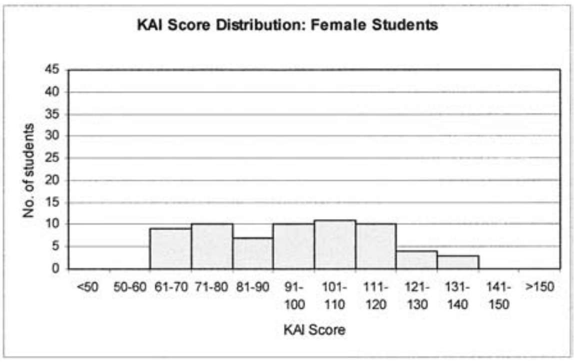

Fig. 6. KAI score distributions for female students only.

include the impact of current trends or a group's influence on professional standards and beliefs, as well as differences in culture between business units faced with the demand for safety and those with a greater need for risk.

To help set up these problems, students in SYSEN 552 are placed in heterogeneous style groups as they complete a 'desert survival' team exercise (as one example) in order to illustrate the benefits and challenges of working in diverse groups. These same groups are also assembled to work on homework assignments, with special emphasis on helping each other meet the requirements of each assignment by leveraging style differences. So, for example, students who are more Adaptive can assist their more Innovative peers when the assignment requires tighter structure (e.g., more detail and/or precision), while the more Innovative students can provide guidance when the solution of a problem requires (e.g.) the 'bending' of key assumptions. In SYSEN 554, students are regularly assigned different partners (using KAI scores) to assist them with their capstone projects; again, the emphasis is on understanding and appreciating the diverse views and preferences of others and on leveraging those differences to improve every individual's results.

Student KAI scores: analysis and implications

Over the last four years (2003–2007), we have collected KAI scores for all students attending the first course in the core module (SYSEN 550) and used these data to study the problem solving orientation of various student populations. In addition to helping us get a clearer picture of our students as problem solvers (which enables us to serve them better), we regularly integrate reports on our findings into the course content, so students can see the underlying theory in action and gain insights from its application. To date, we have collected and validated KAI scores for a total of 209 students. Table 2 shows key statistics relating to those scores (as a total sample and sorted by gender); Figs. 4, 5, and 6 show the corresponding distributions of scores within those samples.

A few simple observations can be made based on these data. First, overall, the range of scores was large (90 points within a sample of $N = 209$), indicating a wealth of cognitive style diversity within the total sample. As a benchmark, the just-noticeable-difference (JND) for two individuals (or between an individual and the mode of a group) is 10 points for KAI, with greater differences (particularly those of 20 points or more) considered large enough to require increasing care as the gap widens [2]. As a whole, this sample was slightly more innovative (mean of 97.9) than both the general U.S. population sample (mean of 95) and engineers in general (mean of 96.8), although these differences are very small and are unlikely to be noticed in either case; research suggests that the JND between the KAI means of two groups is 5 points [2].

In considering the sub-groups sorted by gender, the male students contained both the most Adaptive and the most Innovative students in the total sample (as expected from general population studies [2]), but the female student group also contained individuals with highly Adaptive and highly Innovative cognitive styles (within a total range of 75 points). While the male students reflected a distribution close to that of the general male population, the female students (on average) showed a slight skew towards Innovation when compared with the general female population (i.e., mean of 95.9 here compared with 91—a difference close to the group mean JND of 5 points). This result is similar to that obtained by McCarthy [84] for a group of 46 female engineers (mean of 102.5), although here the extent of the skew is not as great.

Such skews may be considered predictable if one considers the late appearance of women in the traditionally male-dominated field of engineering. Returning to our understanding of style as an indicator of preference for structure, previous research shows that those who 'break boundaries' (of any kind—conceptual, cultural, gender, etc.) are more likely to be more Innovative [2, Appendix 6, Table F; 85–87]; this is confirmed here to some degree. Possible implications of these results for engineering education are intriguing: for example, can we use this information to assist in the recruitment of women in engineering? In looking at the retention of female students, is there any correlation between style and the women who complete engineering programs as opposed to those who leave? This line of questioning opens up a number of potential areas for future inquiry, which we plan to pursue.

When grouped by academic major, the KAI data also reveal some interesting trends. As Table 3 shows, the means of the sorted sub-groups increase steadily as we move from Systems Engineering (mean of 94.8) to Software Engineering (mean of 97.4), Information Science (mean of 101.6), and Leadership Development (mean of 105.9), respectively. While the number of Leadership Development students is too small ($N = 8$) to reach any definite conclusions, the corresponding mean is in the expected place in the progressing pattern; it is also interesting to note that the range of scores was still quite large (72 points), even within this small sub-group.

The observed trend in means invites consideration. Research indicates that occupational groups (e.g., teachers, engineers, bankers, nurses) and functionally-specialized groups within a particular occupation (e.g., production, design, and R&D, within engineering) often have stable style distributions that are predictably different from those of the general population and each other (see [2, Appendix 6, Tables J–L], for supporting data collected by Kirton and others); the means of these groups correspond generally to the style 'nature' of the bulk of the problems they face. That is, groups that solve most of their problems within one major conceptual or organizational structure tend to be more Adaptive (regardless of the size and complexity of that structure), while groups that span several conceptual or organizational structures as they develop and implement solutions tend to be more Innovative.

Table 3. Key statistics for KAI scores of total sample, sorted by academic major

Major	Size (N)	Range	Mean	Std dev.
Systems engineering	66	53–138	94.8	20.3
Software engineering	45	62–143	97.4	15.6
Information science	71	65–136	101.6	17.2
Leadership development	8	69–141	105.9	24.5

Recalling that the JND in KAI group means is 5 points, we are lead to ponder how the problems faced by practitioners in the above-mentioned fields may differ. Are, for example, the problems faced by Systems Engineers generally more tightly focused than those faced by Information Scientists? Does the fact that the curriculum for the Information Science degree (as defined by Penn State) contains both Engineering and Management courses come into play? If they are stable, mean style differences between the practitioners of different disciplines (or sub-disciplines) could have interesting implications for recruitment to those various fields, as well as for the instructional design of other courses within their respective programs. These questions and areas of interest require further investigation and will form the backdrop for future research.

IMPLEMENTATION OF THE PROGRAM

Organizational context

Within the Penn State University campus system, the Great Valley School for Graduate Professional Studies (Penn State Great Valley) is a special mission campus focused on the delivery of high-quality graduate and continuing education for working professionals. Penn State Great Valley is the only all-graduate campus within the Penn State system, with approximately 1500 Master's level students enrolled each year, and it houses three major Divisions: Education, Engineering, and Management, plus an Office of Continuing and Professional Education. Within the Engineering Division, three degree programs are offered currently: Information Science, Software Engineering, and Systems Engineering.

As noted previously, the courses within the Problem Solving Program were introduced initially as part of the Systems Engineering degree and are listed under the Systems Engineering prefix (SYSEN); they are now offered more widely (see the next sub-section). As shown in Fig. 2, the three courses in the core module are taken in a fixed sequence with no other outside prerequisites. SYSEN 555 has no required prerequisites (although SYSEN 550 is recommended, as indicated), while the new Problem Solving Techniques course will have SYSEN 550 as its required prerequisite. Each course corresponds to 3 graduate credits, with classroom time of 42 hours distributed over a span of 14 weeks (3 class hours per week) or 7 weeks (6 class hours per week).

Integration into degree programs

The Problem Solving courses have been integrated into Penn State Great Valley's degree programs in a number of ways that span all three Divisions (Education, Engineering, and Management). In particular, SYSEN 550 is a required course within the 18-credit core curriculum of the Systems Engineering degree. Systems Engineering students must also choose six 3-credit courses within one of three elective tracks (Knowledge Management; Communications, Control, and Intelligence; and Engineering Leadership); SYSEN 552, 554, and 555 are all options within the Engineering Leadership track. Similarly, all four courses (SYSEN 550, 552, 554, and 555) are options within the Technical Leadership elective track of the Information Science degree.

Within the Management Division, SYSEN 550 and 554 have been incorporated into the Master of Leadership Development degree program as electives. In particular, SYSEN 550 is one of three Leadership Competencies electives focused on creativity, and SYSEN 554 is among the ten possible Leadership Context electives for the program. In addition, SYSEN 555 is an elective within the Graduate Certificate in the Essentials of Entrepreneurship. Finally, within the Education Division, all students are eligible to take the three courses from the core module as electives (as timing permits within each particular program).

The Penn State Problem Solving Certificate

A 12-credit Graduate Certificate in Problem Solving has been created for those students who would like to receive special recognition for their work in this domain or for those who do not wish to enroll in a full degree program. This certificate program may form the foundation for a Problem Solving Minor at Penn State in the future. The Problem Solving Certificate is currently composed of the three courses from the core module (SYSEN 550, 552, 554) plus the course on invention (SYSEN 555). When the proposed course on problem solving techniques has been created and is in place, students will have the option of choosing that course or SYSEN 555 to complete the certificate. As more problem solving courses are added to the program, choices within the certificate will continue to expand.

CHALLENGES IN CREATING THE PROGRAM

An early version of SYSEN 550 was developed and first offered in 1997 at Penn State Great Valley. While KAI was administered as part of the course, Kirton's cognitive framework was only a small portion of the course content. In fact, the course design was (unfortunately) not well-balanced in terms of style and favored an excess of 'Innovation' in its emphasis [88]. While this previous form of the course was popular initially, student interest declined over some years, and the course was nearly discontinued. Fortunately, further and deeper study of Kirton's work and other supporting research led to a complete reformulation of the course, as well as the design and introduction of the core module of the Problem Solving Program. The revised SYSEN 550 is now one of the Engineering Division's most popular courses, with two sections offered (and routinely filled) each year. The second section was added in 2004 to meet the increased demand for the course, corresponding to increased interest in the Technical and Engineering Leadership tracks of the Information Science and Systems Engineering degrees, respectively (which also include courses in Project Management and Ethics).

Other educators have discussed the initially skeptical response of some engineering students to what they consider to be 'soft' courses and topics [21, 30, 33]; we have had a similar experience, although not to a great degree. Student response to the Problem Solving courses is overwhelmingly positive (as expressed in the students' course evaluations), but there are occasionally a few students who have difficulty finding immediate relevance for the material in their lives. In response, we continue to work hard to build links between theory and practice throughout all the courses; one highly effective technique has been the use of former students as guest speakers, particularly in the first course (SYSEN 550). Their experiences and personal examples of applying this material at work and at home provide the best testimonials to its value and real-world applicability. In addition, the efforts of a specially formed Problem Solving Research Group (see section on The Penn State Problem Solving Research Group below) help connect theory with practice at an advanced level, the results of which are integrated into the course content as supporting examples.

With respect to faculty colleagues, most are supportive of our non-traditional (one might even say Innovative) approach, although there has been a sense of tolerance rather than 'welcome' from a few. However, over a relatively brief time, positive feedback from the students (and their assurance that the material is covered rigorously, practically, and at an advanced level) has been instrumental in gaining support across Divisions. In fact, a growing number of faculty members from Engineering and Management have recently sought KAI certification, so that they might use the inventory in their own research and potentially assist with the teaching of the curriculum as well.

ASSESSMENT OF THE PROGRAM

While we are still refining formal assessment mechanisms for this program (i.e., those that will help us determine whether or not our students are meeting our objectives of individual and group problem solving effectiveness and leadership), we can present some evidence now that points to the program's efficacy, value, and acceptance.

Student enrollment and course evaluations

First, as mentioned previously, the number of students enrolling in the Problem Solving courses is increasing, with an average of close to 60 students attending the first course (SYSEN 550) over each of the past two years; enrollment in other courses within the module is also increasing. Formal course evaluations across the core module show a very positive response from the students as well. To date, the mean rating for course quality is 6.3/7.0 for SYSEN 550, 6.4/7.0 for SYSEN 552, and 6.5/7.0 for SYSEN 554 (all compared with a Divisional average of 5.8/7.0). Student evaluations also confirm the applicability of the material to real-life situations, with related ratings of 6.5/7.0 for SYSEN 550, 6.6/7.0 for SYSEN 552, and 6.8/7.0 for SYSEN 554.

In addition to quantitative evaluations, students are asked for written feedback on the strengths and weaknesses of each course, as well as suggestions for how each course might be improved. As typical examples of positive responses, one student remarked: 'This course opened up a new window on how I can think about problem solving and creativity. I think every engineer should take this course to collaborate better in a group', while another noted: 'With KAI, I am able to see applications of this theory on a daily basis and be more efficient at my job.'

Corporate interest and student success

Many large firms have created in-house 'leadership development programs' for their most promising young employees. The Penn State Problem Solving Program is becoming increasingly popular among the students of these corporate programs, with some students even seeking KAI certification so they can administer the inventory within their organizations. There is also a growing surge of interest from local corporations for training programs related to problem solving and for research based on applications of problem solving theory.

Anecdotally, there have been a number of students who have been promoted or who have received awards within their corporations for interventions they initiated based on the material they learned in the Problem Solving core module and subsequently applied. In one example, a senior IT manager at a large healthcare firm was rewarded for integrating the problem solving efforts of two disparate teams and for tracking the progression of change within the corporation in revealing and insightful ways. In another case, a technical manager within a large power distribution company was recognized for facilitating his team's problem solving efforts during a crisis situation.

The Penn State Problem Solving Research Group

As an additional outcome of the program, the Penn State Problem Solving Research Group was formed to facilitate research projects (both basic and applied) with (and between) current and previous students of the program. The group meets monthly to engage in focused discussion related to specific projects and in open-ended dialogue about general topics of interest that relate to problem solving. There are currently over 20 members in this group; on-going projects include the investigation of shared understanding between problem solvers in globally distributed software development teams [89], the style assessment of inventions [90], the impact of cognitive style in adult education, the classification of problem solving techniques, and the visualization of problem solving paradigms.

SUMMARY AND CONCLUSIONS

A growing number of scholars are turning their attention to the education of engineers in the explicit understanding of problem solving as a cognitive process and the importance of its effective leadership in team contexts. As Moore and Voltmer note [6, p. 452]: 'In short, engineers are problem solvers and designers; *their education must prepare them for this role in an ever-changing world*' (their italics). The corporate community is in strong agreement, with problem solving and leadership identified as two of the most important non-technical skills required by engineering graduates today [7]. Delivering these two key themes in combination, i.e., problem solving leadership, is the main aim of the Penn State Problem Solving Program; facilitating the fit of people to problems and managing the gaps between them lie at its core.

Specifically, we have developed a new curriculum for problem solving that focuses on the development of these skills and mastery of the knowledge that underpins them in ways that are both rigorous and practical. At the heart of this curriculum is Kirton's Adaption–Innovation theory, which, in combination with the supporting research of other scholars, provides a powerful framework for understanding problem solvers—alone, in teams, and in leadership roles. This paper provides a broad but thorough description of that framework and its mapping onto a formal course structure in terms of overarching themes, fundamental aims, anticipated insights, key elements of theory, expected skill outcomes, and practical entry points.

The Penn State Problem Solving curriculum is composed of a core module of three courses, plus a growing number of supporting and special topics courses, including those devoted to the study of invention, problem solving techniques, and problem solving ethics, respectively. Existing courses have been integrated into degree programs across the three Divisions currently represented at Penn State Great Valley (i.e., Education, Engineering, and Management) in a variety of ways. Assessment of the program to date has yielded very positive results in terms of student satisfaction and perceived value, as well as corporate interest and the generation of new research.

We collected data on the cognitive styles (as measured by KAI) of all students who entered the program between 2003 and 2007. Analysis of those data shows that there is a wide range of cognitive style diversity within our student population, with some interesting trends identified among students enrolled in various degree programs (e.g., Systems Engineering vs. Information Science) and between genders; further investigation of these findings (and their implications) will be the subject of future research. KAI data are also used within the curriculum to demonstrate key points of theory and to facilitate the design of classroom activities and homework assignments, with the aim of providing students with additional insight and expertise in working with other diverse problem solvers.

A number of extensions and new applications are planned for the program. First, as mentioned earlier, several new courses have been proposed and/or are under development. In addition, Penn State has begun the conversion of the core module and, possibly, all its supporting elements (see Fig. 2), merged with the certification element for KAI (with Kirton's approval) into distance learning mode; the aim is to widen the recruitment for this popular (if demanding) module over the US, the UK, and elsewhere. In particular, the first two courses from the core module (SYSEN 550 and SYSEN 552) are scheduled for on-line delivery by 2009 (as part of the on-line delivery of the Systems Engineering degree). Inclusion of various portions of the Problem Solving curriculum in new degree programs (e.g., Engineering Management) is also under discussion, as well as the extension of the curriculum to students (both graduate and undergraduate) at other Penn State locations.

In conclusion, we note that the importance of problem solving and the need for effective problem solving leaders are not restricted to the engineering profession. As Karl Popper, the eminent philosopher, proposed: 'All life is problem solving' [91], and in this, we (and Kirton) agree. The core concepts of the curriculum we have discussed here are appropriate for any individual, in any discipline—as we have begun to demonstrate through their integration in non-engineering degree programs (i.e., those in Management and Education). Therein, we believe, lies its key contribution and its primary strength: as a rigorous, scholarly approach to understanding a fundamental human process which we all share, and which can lead us to more effective collaboration in an increasingly complex world.

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Kathryn W. Jablokow, Ph.D., is Associate Professor of Mechanical Engineering and Science, Technology, and Society at the Pennsylvania State University, where she founded and leads the Problem Solving Initiative at Penn State Great Valley. Dr. Jablokow teaches and conducts research in the areas of problem solving, invention, system dynamics and control, and engineering ethics. She is a senior member of IEEE and a member of ASEE, ASME, and Sigma Xi. Dr. Jablokow currently serves on the Executive Committee of ASME's Technology and Society Division.