Suboptimization of Motivation Approaches in Engineering Education

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Abstract

Engineers of the 21st century will be called upon to work and learn in ways their predecessors never experienced. They will face novel, ambiguous, complex problems that will require adaptability, innovation, and leadership. To meet the challenges their students will face in the future, engineering universities need new approaches and structures to motivate their future graduates. The use of extrinsic (rather than intrinsic) motivation to prod student learning is virtually ubiquitous in engineering universities. This paper provides an overview of research that has been done on performance and motivation, and develops a model of student motivation based on that literature. The main contribution of this paper is a theoretical model of the relationship between types of motivation and performance. It proposes that attempts to optimize student learning has resulted in sub-optimization due to local optima and unexplored search spaces. It proposes a re-structuring of engineering education to meet the challenges of preparing 21st century engineers.

Introduction

The National Science Board found that companies of the future will "want engineers with passion, … an ability to innovate, …, an ability to adapt to changing conditions, and an eagerness for lifelong learning. This is a different kind of engineer from the norm that is being produced now" [1].

Rather than being passionate and driven by curiosity and a desire to learn, too many engineering students are passive, dependent learners, whose main question seems to be "Will this be on the test?" Research suggests that the roots of this problem lie in the kind of motivation used to prod student learning, which, in turn, springs from the very structure of university education.

Examinations, tests, and grades are a nearly ubiquitous feature of the student experience. Nearly every course requires a grade, and the method of determination of those grades described in painstaking detail is a common feature of course syllabi. Underlying this taken-for-granted feature of university courses is a basic assumption about how to prod students to learn: that extrinsic motivators, like grades and homework points are the most (or only) effective means of provoking learning, and especially for provoking the *type of* *learning* needed by tomorrow's engineering graduates. While some controversy still exists, there appears to be a growing consensus that, for the type of conditions faced by university students, this basic assumption is not supported. Research in extrinsic and intrinsic approaches to learning suggests that the current emphasis on extrinsic motivation actually sub-optimizes student learning, and may even be the cause of the deficiencies ascribed to engineering education.

Intrinsic and Extrinsic Motivation

Intrinsic motivation is at play when one engages in activities because one finds them interesting, challenging, involving, and satisfying. Intrinsic motivation has been linked to higher performance in learning, academic performance, and even well-being [2]. It has also been predictive of creativity for R&D professionals [3].

Extrinsic motivation, on the other hand, drives behavior when one engages in tasks NOT because one finds them inherently captivating, but because of factors like the promise of rewards or threats of punishments, dictates from superiors, surveillance, and competition. As a result the "goals" of tasks undertaken due to extrinsic motivation tend to be related to the factors mentioned (e.g., attaining a reward, staying out of trouble) rather than related to the mastery of a skill or finding the answer to a puzzling question.

The most troubling effect of extrinsic motivators is that, in certain situations, they can reduce the degree of intrinsic motivation experienced by participants. While more comprehensive studies need to be completed in this area, theory suggests that the lack of interest in academic topics engendered by grading may contribute to a lack of long-term interest in the topic [4]. For engineering graduates this may reduce the ability to engage in life-long learning.

Research [5, 6, 7] has shown that, even when there is preexisting strong interest in an activity, extrinsic rewards can reduce that interest when the rewards are experienced as controlling. Ryan and Deci [8] write that "[p]erformance contingent" rewards, like an "A" for doing well on a test, are usually experienced as particularly controlling, "so there is a strong tendency for these rewards to undermine intrinsic motivation." As Ryan and Deci further illustrate (pg. 39), grades, in particular, are often experienced as controlling:

> "Evaluations and the contingent administration of grades are perhaps the controlling methods of motivation that are most prominently used is (sic) schools, and evidence suggests that they can be highly detrimental to both self-motivation and the quality of learning. … [A] study by Harackiewicz et al. (1984) [9] showed that when participants were told that their performance would be evaluated and they were then given positive evaluations after they finished the task, they displayed significantly less intrinsic motivation than did others who were not told that they would be

> evaluated but got the same positive feedback. Smith (1975) [10] reported similar results."

It has been shown that controlling, extrinsic motivators reduce students' ability to solve complex problems that require flexible thinking [11, 12]. Grades, in particular, have been shown to focus some students' attention on the acquisition of the grade rather than mastery of the topic [13] , which can result in shallow, mechanistic learning or "cheating". This may lead engineering students to focus on the application of "plug and chug" equations rather than a deeper understanding of the underlying concepts and principles that is intended.

Research has shown that even reading with the expectation of being graded, when compared to reading for the purpose of simply learning, tends to create reduced long-term retention of facts as well as reduced ability to develop conceptual understanding of material under study [14, 15].

Kerr [16] commented on the "displacement" of student goals from learning to grades when he wrote:

> "If it is assumed that a primary goal of a university is to transfer knowledge from teacher to student, then grades become identifiable as a means toward that goal, serving as motivational, control, and feedback devices to expedite the knowledge transfer. Instead, however, the grades themselves have become much more important for entrance to graduate school, successful employment, tuition refunds, and parental respect, than the knowledge or lack of knowledge they are supposed to signify. It therefore should come as no surprise that we find fraternity files for examinations, term paper writing services, and plagiarism. Such activities constitute a personally rational response to a reward system which pays off for grades rather than knowledge."

The use of extrinsic motivators, particularly grades, is ubiquitous throughout universities, even though their negative effects on student learning and interest have been documented through hundreds of studies. One of the main findings, confirming Kerr's comment on "displacement" via Cognitive Evaluation Theory [17 – 22] , is that extrinsic motivators like grades tend to reduce interest and enjoyment by shifting perceptions of control toward external, rather than internal forces.

While the laboratory and experimental research supporting this is compelling, there is also anecdotal support that students intrinsic motivation to learn has been reduced in the form of typical complaints that faculty raise when discussing student learning. Comments like "they are only interested in what is on the test" or "you have to make it worth points for them to engage" are far too common among faculty.

Grading also may have an effect on the instructors. By leading instructors to rely on the application of extrinsic motivators to learn, faculty may fail to reflect on their own approaches to teaching and building supportive relationships with students that foster deeper learning [8] (p. 40).

Potential long-term erosion of intrinsic motivation by extrinsic motivators is supported by a meta-analysis that [8] (p. 29) indicates that these effects are persistent. This effect suggests that a "recovery period" may be necessary for individuals to regain their sense of autonomy after experiencing controlling incidents.

A Mathematical Model of Motivation and Performance

The desired characteristics of future engineers - passionate, driven by curiosity, able to innovate and adapt, and eager for lifelong learning – describe individuals who are intrinsically motivated. The passive, dependent learners that engineering faculty see who are more interested in "getting a good grade" than mastering the art and science of engineering, are symptomatic of reliance on extrinsic motivation. While there is a clear call to change engineering education, there has not been a corresponding call to reduce extrinsic motivation in university programs. This raises the question, "What prevents universities from moving to a more intrinsically motivational system?" While there are many answers to this question from many perspectives, this paper focuses on a potential systemic cause. It proposes a relationship between performance and intrinsic/extrinsic motivation that makes the present system seem to work, when viewed from the perspective of the individual professor. This paper presents a theoretical model of the effects of form of motivation on performance. It provides a graphical overview, which suggests that an inclination to move toward extrinsic motivation is a result of attempts to optimize performance when faculty members act as a group. The model suggests that, since individual faculty members do not have a systems perspective on the effects of motivation, they sub-optimize student motivation by not exploring a portion of the search space.

The available literature suggests several general relationships that are the hypothetical basis of this analysis.

1. Individuals motivated purely by intrinsic motivation produce higher levels of learning (e.g., conceptual learning, rather than shallow learning) than those who are purely extrinsically motivated.
2. When mixed motivation occurs (both intrinsic and extrinsic) the extrinsic motivators reduce the performance effect due to intrinsic motivation.
3. When there is a series of motivations, a reduction due to previous extrinsic motivation appears in consequent periods

Generating an equation to quantify these relationships suggests:

$$Perf \equiv \left\{ \frac{(n_{\text{int}})(k_{\text{int}})(c_{ext})^{n_{ext}} + (n_{ext})(k_{ext}) - \sum_{i=1,3}\left[f(n_{ext,t-i})^{i}(k_{ext}) \right]}{\left[n_{\text{int}} + n_{ext} \right]} \right\}$$

Where:

Perf = the learning performance of an individual at the end of a given period

n_{int} = number of instances of intrinsic motivation in a given period

n_{ext} = number of instances of extrinsic motivation in a given period

k_{int} = Intrinsic motivation performance constant. Since there is no experimental data for this number a value of 3 was chosen as a hypothetical figure.

k_{ext} = Extrinsic motivation performance constant. Since there is no experimental data for this number a value of 1 was chosen as a hypothetical figure.

c_{ext} = Extrinsic motivation erosion constant. This reflects the erosion of intrinsic motivation by extrinsic motivation in any given period. A hypothetical value of 0.333 was chosen for this constant. Since the erosion of intrinsic motivation by extrinsic motivators is relatively strong, it is hypothesized that number of extrinsic motivators has an exponential effect on reducing intrinsic motivation.

f = Lagged carryover effect of extrinsic motivations. A hypothetical value of 0.2 was chosen for this effect. It is hypothesized that a portion of the performance increase created by extrinsic motivation in previous periods will be removed from later periods.

i = periods of motivation. Since there is no available data, a reduction in performance is hypothesized to last 3 periods. In reality it is likely that this number varies greatly depending on individuals and circumstances.

$t - i$ thus signifies the individual's history of motivation, $(n_{ext,t-i})$ is the number of instances of extrinsic motivation in the previous period when n=1, the one before that when n=2, etc.

The first set of factors in the numerator signifies the performance due to intrinsic motivation, reduced by a factor related to the number of extrinsic motivation instances in the current period. If this is the only period and there are no instances of extrinsic motivation the performance value is 3, given the hypothesized values.

The second set of factors in the numerator signifies the performance due to extrinsic motivation.

The third set of factors in the numerator signifies the lagged reduction in performance due to instances of extrinsic motivation in previous periods.

The equation is normalized by the number of instances of motivation (sum of intrinsic and extrinsic) that occurs in any given period. It is assumed that the same number of instances occurs in a given period. So, for example, a student may be taking several courses during a semester, and each course has a similar number of graded or ungraded items that occur during a portion of that semester.

Method and Analysis

A spreadsheet was used to calculate values of performance for various cases. As an initial measure, the value of performance was calculated for one period with five instances of motivation. This is analogous to a single student being exposed to five instances of motivation during a single period. (See Figure 1.) At the left side of the figure, the student is exposed to five instances that are purely extrinsically motivated, such as five quizzes in courses in which he/she is not interested in the subject. At the right side of the figure, the student is exposed to five purely intrinsically motivated instances during the same period, such as a Ham Radio club or experiential design team, which he/she has a great deal of interest in. In the middle of the figure, there is a mixture of intrinsic and extrinsic motivation. So, for the case where there is one intrinsic and four extrinsic instances of motivation, the increase in performance due to intrinsic motivation is reduced due to the focus on achieving the rewards of the instances of extrinsic motivation. As a result, overall performance is decreased. To give an example, a student who has four quizzes in one week is likely to be less interested in an experiential design team during that week, and would therefore lose the opportunity for learning that would come from engaging in that activity. For this case, there are no lagged effects, since this assumes only one period.

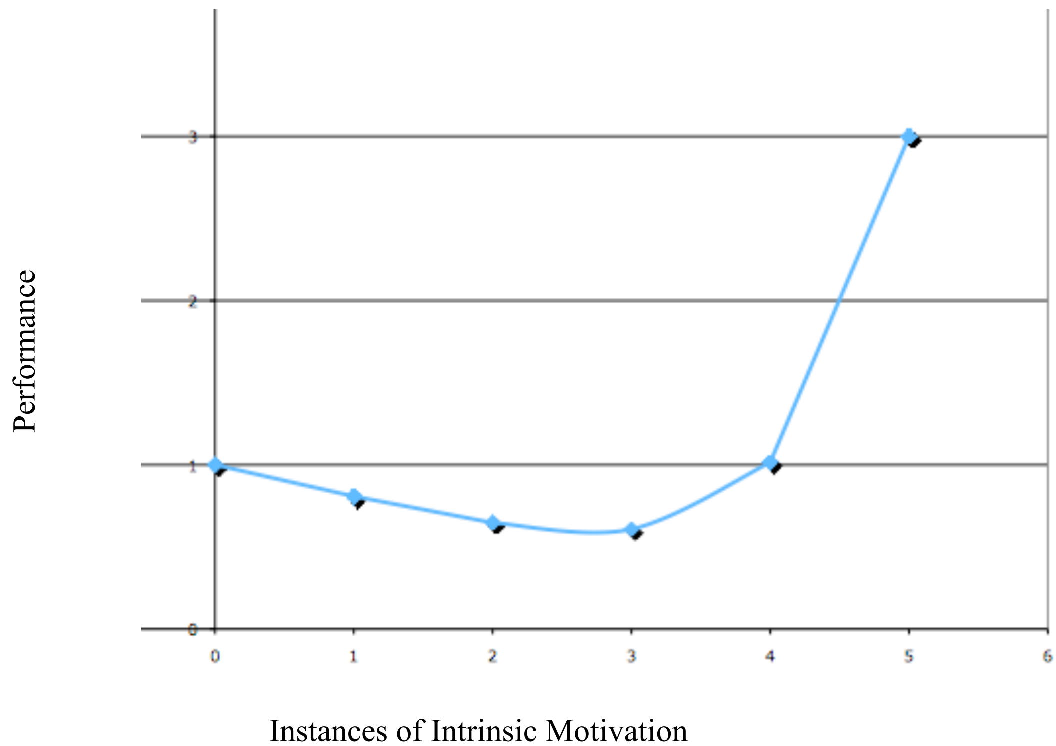

Figure 1 – Performance vs. instances of intrinsic motivation (five instances)

For this case, the minima is near the middle of the graph. However, increasing the number of instances of evaluation to fifteen (by, for example, adding courses, homework, or other activities into the student experience during a period) moves the minima toward the right (Figure 2). This suggests that when an individual instructor is “blindly” exploring the search space (by trying out different extrinsic or intrinsic motivators to provoke student learning) in most of the cases he or she will find that what “works” is a move toward greater extrinsic motivators. Reducing a reliance on grades or points will, in most cases, produce lower levels of performance. This provides an explanation for statements that faculty sometimes make along the lines of “students won’t do anything unless it has points attached” or “the only way to make them work is to give them a graded incentive”. Based on the form of the curve this appears to be true, but the result is suboptimal learning by the students since increasing extrinsic motivation moves student performance toward a local optima rather than the global optima available through intrinsic motivation.

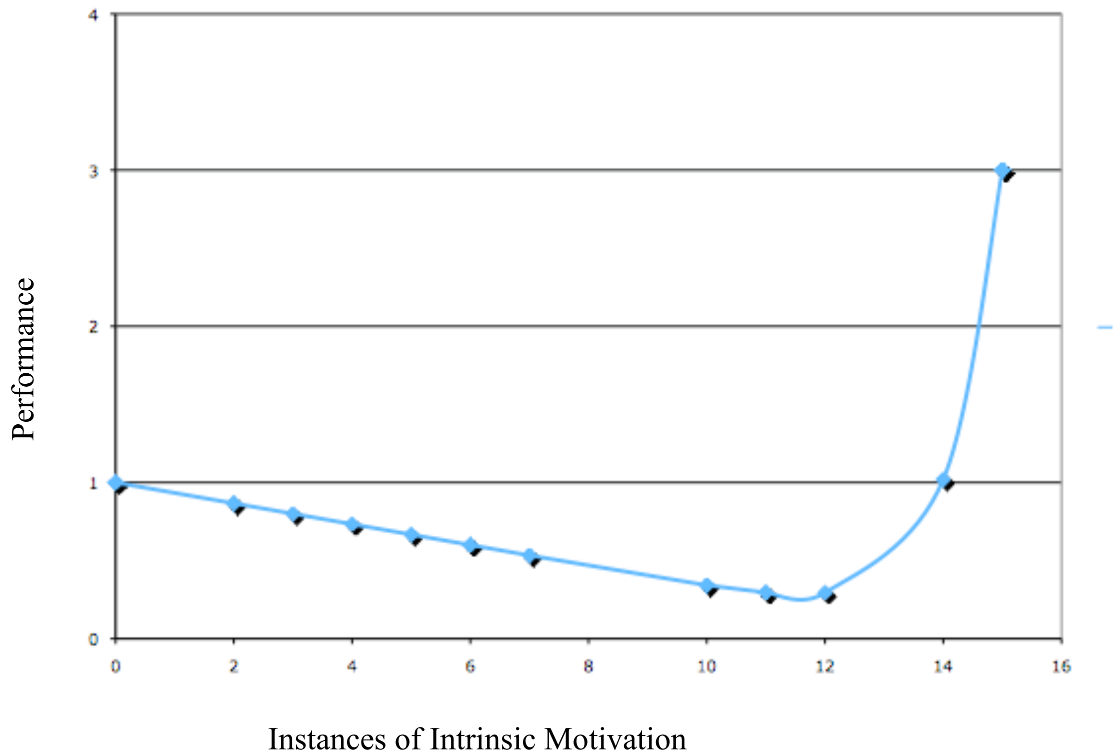

Figure 2 – Performance vs. instances of intrinsic motivation (fifteen instances)

To further illustrate these effects a three-dimensional graph was plotted incorporating multiple instances (Figure 3) during a single period. As suggested by the previous graphs, as the number of instances of motivation increases, overall performance decreases when the student experience involves a mixture of intrinsic and extrinsic motivation instances. A large portion of the horizontal plane is tilted toward purely extrinsic motivation, suggesting that a faculty member working to improve student performance without a systemic view would tend toward a greater reliance on extrinsic motivation.

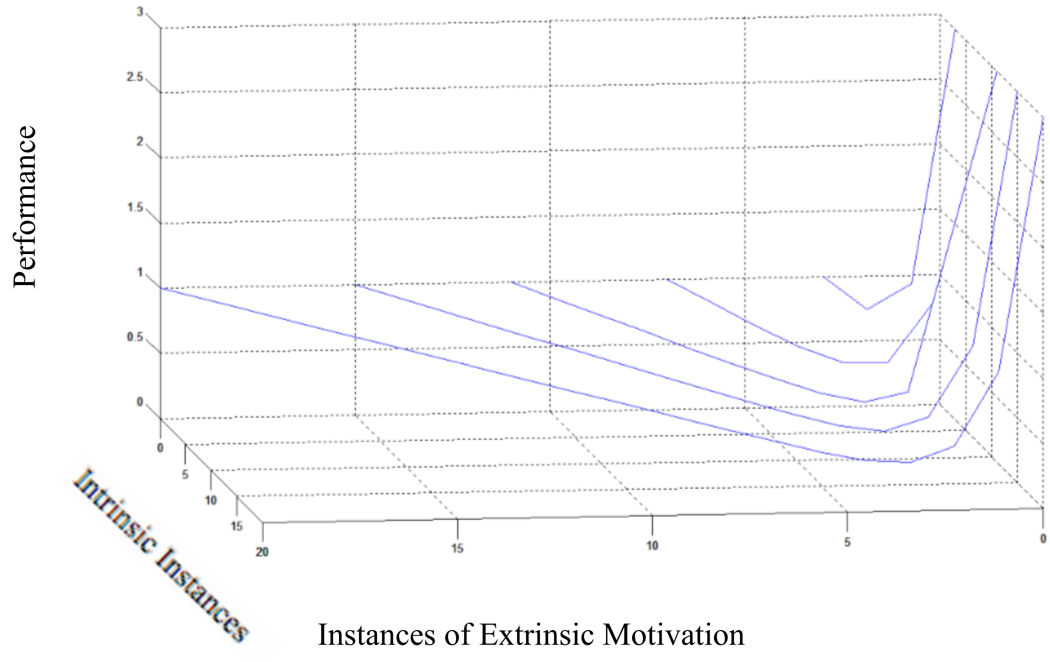

Figure 3 – Performance vs. instances of motivation (several instances)

To this point the analysis has involved only one period, that is, the lagging effects of extrinsic motivation that act to reduce subsequent levels of intrinsic motivation have not been considered. To consider these effects, a simulation was run where an individual received a set of instances of motivation during one period, another set during a second period, another during a third, etc. Since there are many possible paths to take (e.g., an individual may have varying numbers of instances of intrinsic or extrinsic motivators from one period to the next) a random number generator function on a spreadsheet was used to create a subset of the potential range of steps that were possible. Figure 4 shows the results on performance after five periods with fifteen instances of motivation per each period. There is a range of values at each instance because of the variety of paths (i.e., different combinations of intrinsic and extrinsic motivation during each period) that could be taken. The addition of lagged effects tends to reduce overall performance across the board, but the general shape of the graph remains about the same.

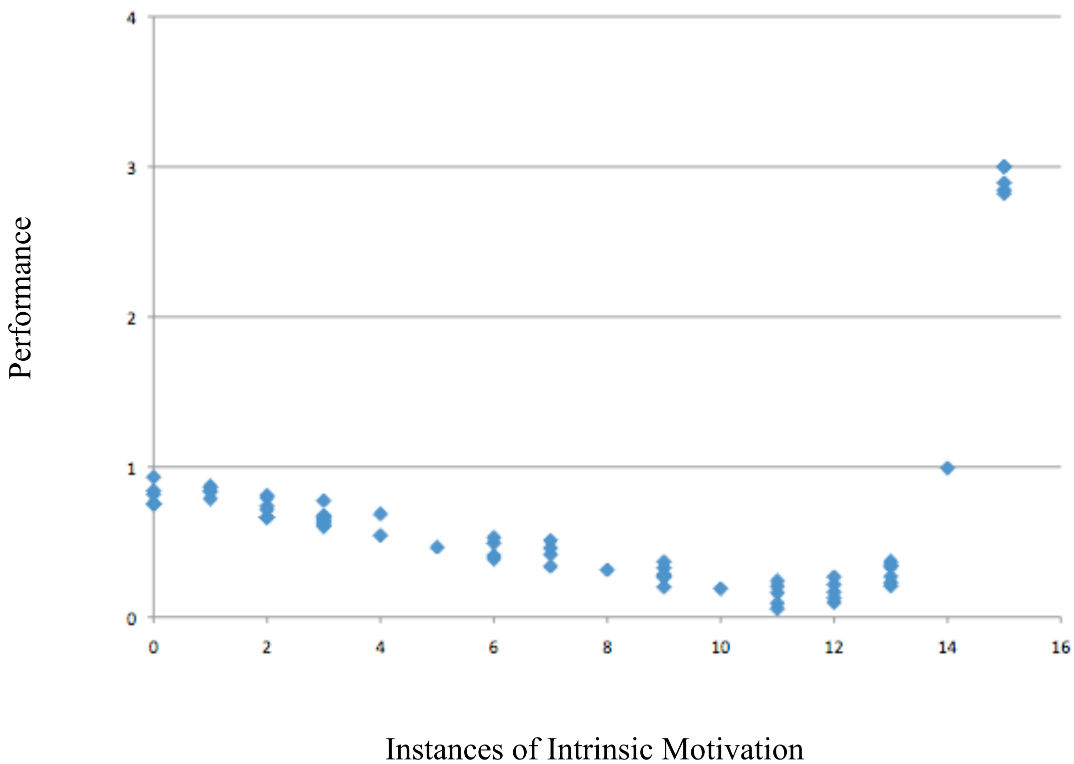

Figure 4 – Performance vs. instances of intrinsic motivation (5 periods, 15 instances)

To give a picture of the overall shape of the curve at the end of several periods, Figure 5 uses median values from a set of five randomly generated periods to generate a 3-D graph of performance for several sets of instances (from three to twenty). The data indicate an increased loss of performance due to lagging effects, particularly as the number of instances of motivation increase.

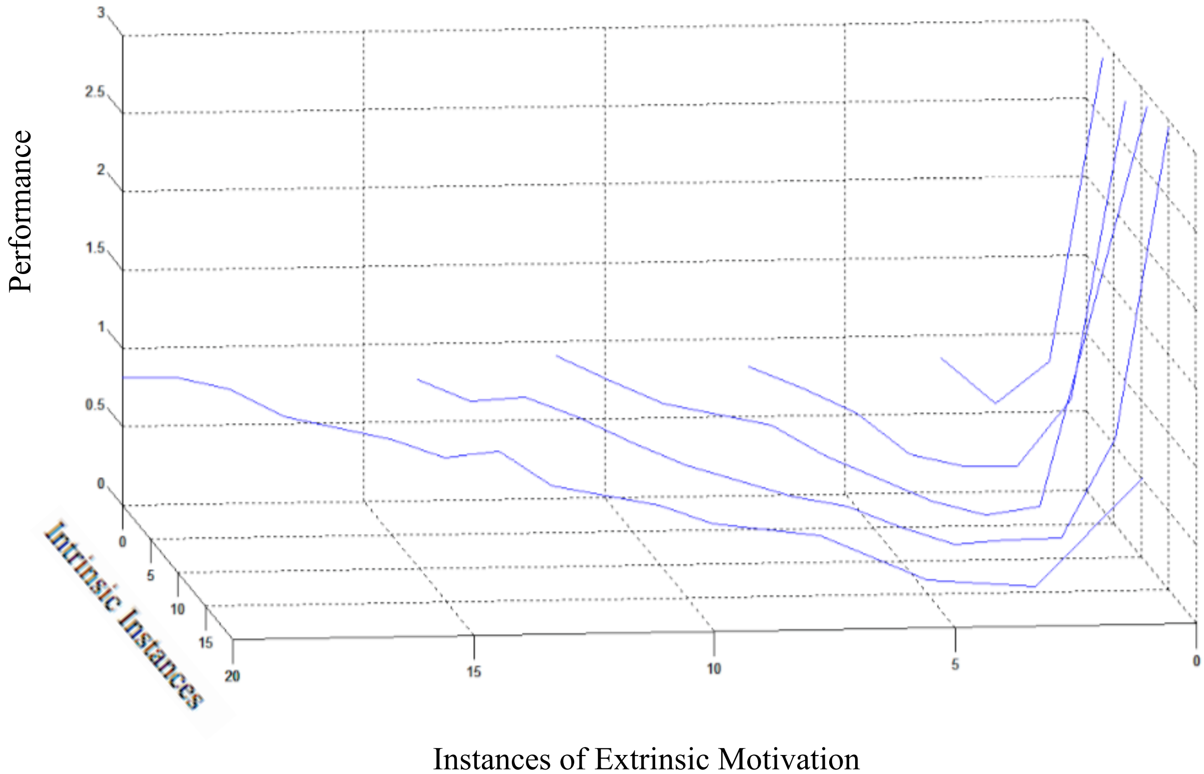

Figure 5 – Performance vs. instances of motivation (5 periods, several instances)

Summary and Conclusions

Extrinsic motivators are ubiquitous throughout university education, despite significant studies indicating that they have severe shortcomings, including reducing levels of interest and ability to engage in complex learning. Despite this, they continue to be used, and anecdotes by faculty attest to their effectiveness. While there are institutional and cultural reasons for the continued heavy use of extrinsic motivators in university education, this paper proposes that systemic effects also tend to perpetuate their use.

An equation was proposed that incorporates findings from research on the effects of intrinsic and extrinsic motivators. While the values of constants in the equation and the equation itself have not yet been supported by research data, the nature of the graphs generated by the equation do provide an explanation for the effects that are seen. The data suggest that extrinsic motivation continues to be used because it does improve performance. However, the data suggest that it results in a sub-optimization of performance because areas involving nearly purely intrinsic motivation are not explored. Because of the ubiquity of application of extrinsic motivators, purely intrinsic motivation of engineering students is even actively avoided. The data suggest that even if a small group or solitary faculty member were to cease to rely on extrinsic motivators the level of performance of students would likely drop, because of others' use of those motivators and lagged effects.

Research in student motivation and achievement suggests that a "better" approach to student learning would rely on intrinsic, rather than extrinsic, motivation. The hypothesized relationships illustrated in this paper suggest that a system-wide change in university motivational structure would be needed for a reliance on intrinsic motivation to be successful. Without such a broad change in the structure of a university, isolated moves away from extrinsic motivators would not be likely to have much effect.

A suggested approach to university restructuring that eliminates extrinsic motivators can be found in the book "Turning Learning Right Side Up" [23] . In such a structure students would not ask, "Will this be on the test?" because testing is used only to provide individual feedback about learning, and not as a reward. Similarly, "cheating" would be nonexistent, since there is no incentive to "cheat". Research suggests that approaches like this (or other unknown university structures based on intrinsic motivation) would have significant positive effects on student learning. However these approaches have only been used in a small group of K-12 schools (e.g., the Sudbury Valley School [24]). so the actual effects of a reliance on intrinsic motivation for engineering students are unknown. In effect, the "search space" for improving student performance remains unexplored in a key area where data suggest a global maximum might exist. Areas for potential research include verifying the structure of the equation, especially the erosion factors, as well as the "recovery period" that has been anecdotally described [25].

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