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Optimization, Option Disclosure, and Problem Redefinition: Derivative Moral Obligations of Engineers and the Case of the Composite-Material Bicycle

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Description

This article describes the moral obligation of engineers and how it is related to design, manufacturing and responsible conduct of research; specifically composite material used in bicycle frame design.

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Introduction

In April 1995, I conducted an informal survey of then current Stanford engineering students and practicing engineers. One of my objectives was to get a sense of the expectations and experiences of both groups regarding the prevalence and diversity of ethical issues in engineering. To that end, one survey questionnaire item directed at practicing engineers asked, "Have you ever been faced with an ethical issue in the course of your engineering practice?" Respondents answering in the affirmative were invited to "please describe briefly what kind of issue it was." The unexceptional nature of this question and request notwithstanding, one practicing engineer was moved to compose and attach to his completed questionnaire an ethically rich, autobiographical case study. After relating this case, I will analyze the ethical issues it raises and draw several conclusions of a more general nature. To preserve confidentiality and increase candor, the names of the engineer-respondent and the other *dramatis personae* of the case, individual and corporate, have been altered.

Narrative

In the 1980s, bicycle journalists and corporate marketing departments campaigned for the development of strong, lightweight bicycles made of new, exotic, composite materials. Responding to this market pull, in 1989, Zephyr, a leading U.S. bicycle manufacturer, contracted for consulting services with an independent engineer, Smith, who claimed he had a workable method of designing and manufacturing composite-material bicycle frames.

When Smith was unable on his own to convince Zephyr of the workability of his approach, he engaged the services of my engineer-respondent, Brown, as a secondary consultant. Brown was engaged by Smith to "validate his methodology

and technical approach," i.e., to confirm the workability of his plan for designing and manufacturing such bicycle frames. To promote his ideas, Smith subsequently organized a meeting among himself, Brown, and Zephyr's technical staff, whose members "knew little of composite structures" other than that, at the behest of the marketing division, "they wanted one in their product line." During Smith's presentation at the meeting, it became "quite obvious" to Brown that the proposed solution "created far more new problems than it attempted to solve." At one point in the meeting Smith asked Brown to "validate or endorse his structural concept," one which "appeared workable by surface cosmetic and general conceptual standards, but did not have the underlying reinforcement fibers oriented to react to any of the critical load conditions this bicycle frame would see in use." In response, Brown "suggest[ed]" that he "apparently did not have the same insight and awareness of the problem as [Smith] and that [Smith's] understanding of the dynamics and intricacies of his concept surpassed his [Brown's] own." Brown "offered to refrain from commenting" until he "understood the process as well as its author."

Later in the meeting, Jones, the bicycle manufacturer's director of R & D, asked Brown "point blank" whether or not he thought Smith's was a workable approach. Brown answered that his "direct relationship" to Zephyr was only through Smith and that Brown's company "would work with [Smith] to address issues which were important to the client's [Zephyr's] requirements."

The limitations of Smith's design and manufacturing concept became clearer to Zephyr as time passed. Eventually a representative of the company approached Brown without Smith's knowledge and confided that Zephyr wished to "begin a direct relationship" with Brown's company and "bypass" Smith altogether.

Brown's reaction was to "simply state" that he would "continue to provide our services to [Smith] as we had agreed so long as that relationship existed with the client [Zephyr]; and that if ever that relationship should terminate equitably and the consultant [Smith] be compensated for bringing our company to the problem, we would then[,] with [Smith's] knowledge and consent[,] negotiate a direct contract with the bicycle company for the services sought." Eventually, Zephyr terminated its relationship with Smith. When Smith informed Brown that he was now free to begin a direct relationship with the bicycle company, Brown negotiated a new agreement with Zephyr. The result was "a $720,000 drafted contract that included royalties on each composite bicycle sold... This was a very good deal for us, and as it turned out for the client as well."

After developing "a workable manufacturing plan for composite bicycles," but prior to deciding on a composite frame design, Brown felt it was important to see if the strength and stiffness of the *existing* 4.5 lb. production frame could be duplicated at a lighter weight. He asked Jones if he would agree to some finite-element computer runs aimed at optimizing the structure of the existing metal frame. Jones told Brown "in no uncertain terms, 'Do not do that!'." Since, however, Brown believed that doing so was "a vitally important step," he decided to optimize the structure at his own company's expense. What he determined was that the weight of the existing aluminum frame could be reduced with no loss of stiffness or strength from 4.5 to 3.1 pounds, within 2 ounces of the target weight of the projected composite-material frame.

With over $300,000 of the contract's $720,000 still unspent, Brown called Edwards, the president of Zephyr, and informed him that "'the cost to reduce the weight of his existing aluminum frame to 3.1 pounds was going to be about $6.35 per bicycle with no additional investment in facilities or personnel[,] compared to building a new facility, hiring and training a second production staff at an initial cost of $2.6 million[,] and a unit cost of $97.00.'" Edwards decided that "his marketing staff's insistence on having a carbon-fiber bicycle frame had more to do with incorporating the 'buzz-word technology *du jour*' than [with] relying on fundamental applied engineering to achieve the desired weight reduction deemed necessary to maintain market share." He therefore asked Brown to complete any task in progress and "bring the composite bicycle program to a close." The improved aluminum-frame bicycle was a successful part of Zephyr's product line from 1992 through 1996.

Edwards' decision to terminate the composite bicycle program "meant the loss of the remaining $300,000 on the contract" and that Brown's company's "was going [to] have a lot of unbillable time for a few months." It also saved Zephyr "a great deal of money!" To Brown, it also demonstrated that while "ethics have a price,...integrity has a reward." For, he revealed, "[t]he referral business from this experience has returned the lost revenue several times over." However, according to Brown, "money itself is not the best reward. That comes from within and if you understand that, you probably have good ethics anyway. If you don't understand that, you probably didn't understand [the] choices made in this case history either!"

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Analysis of Ethical Issues

Ethical issues are raised by the actions of various parties in this case, including Jones and perhaps Smith. In what follows, however, we shall focus our discussion on ethical issues raised by actions of Brown, or by actions of others that targeted Brown. Noteworthy ethical issues reared their heads at five junctures in this case: (1) when Smith asked Brown to endorse his method and approach at the meeting with Zephyr's technical staff; (2) when Jones asked Brown at the meeting whether he thought Smith's design and manufacturing concept was workable; (3) when Zephyr sought to bypass Smith and proposed to begin a direct relationship with Brown and his company; (4) when Brown was instructed by Jones not to optimize the structure of the existing metal frame; and, finally, (5) when Brown determined that an aluminum-frame bike could be designed that was as strong and almost as light as the desired composite-material bicycle. Let us look individually at each of these episodes.

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Episode 1 - Smith Asks Brown to Endorse his Plan

When, at the meeting with Zephyr's technical staff, Smith asked Brown to "validate his [Smith's] methodology and technical approach," Brown felt himself embroiled in what he termed a "multi-faceted...ethical quandary." On the one hand, since he had been introduced to Zephyr as an invitee of Smith, Brown felt "ethically bound not to undermine [Smith's] business with this client." On the other hand, since he also felt "bound to contribute both experience and technical expertise with integrity to my company and its reputation," Brown felt he "could not endorse the technically flawed program which was the subject of the meeting" without harming his own company and its employees. As noted earlier, his response was "to suggest that I apparently did not have the same insight and awareness of the problem as the consultant and that his understanding of the dynamics and intricacies of his concept surpassed my own. I offered to refrain from commenting until I understood the process as well as its author."

Brown's conduct was for the most part laudable, even, as we shall see below, exemplary. However, two aspects of his behavior in this first episode merit examination. First, as the above quote indicates, in his response to Smith's endorsement request at the meeting Brown dissembled and prevaricated. One reason he did so was because he adhered to a "simple business ethic." Under it, he believed himself "ethically bound" not to do anything that would undermine Smith's reputation with *his* client, Zephyr. Brown seems to have regarded that obligation as *absolutely* rather than *prima facie* binding. He realized that acceptance of Smith's approach "could cost the bicycle company many hundreds of thousands of dollars before they understood its weaknesses." That he feigned ignorance and was evasive even under that realization suggests that he felt the obligation not to undermine his client's was categorical.

But however he construed his "simple business ethic," Brown was not obliged to refrain from critical comments on Smith's method and approach by the Code of Ethics for Engineers" of the National Society for Professional Engineers (NSPE). While this code does state that engineers "shall not attempt to injure, maliciously or falsely, directly or indirectly, the professional reputation, prospects, practice, or employment of other engineers, nor untruthfully criticize other engineers' work" (Section III.8), it does not hold that engineers are obliged not to criticize their professional colleagues, only that such criticism as is made of their work by fellow engineers be truthful, non-malicious, and not intended to injure. The ethic embodied in the NSPE code of ethics appears, in this instance at least, to be more nuanced and conditional than Brown's seemingly categorical "simple business ethic."

If Zephyr had not eventually come to recognize the flaws in Smith's plan and had proceeded on the basis of that proposal, the company might not only have wasted much money but have reached a point at which it was on the verge of manufacturing and distributing structurally flawed bicycles. Whether Brown's adherence to his "simple business ethic" would have impelled him to continue to dissemble or be evasive if Zephyr was poised to make a decision that could have resulted in the delivery of a product that might jeopardize its users' physical safety is in principle unknowable. Fortunately, Brown's initial lack of candor was sufficiently upstream in the product development process that it did not contribute to creating an unreasonable risk of unjustifiable harm to members of the public.* However, his choice to remain publicly noncommittal, even though Zephyr stood to lose a lot of money investigating ideas of Smith that Brown knew to be structurally flawed, is

troubling from the point of view of respecting Zephyr's protectable financial interests and revealing about the strength of Brown's perceived obligation not to undermine his client's professional reputation. This first episode had a second ethically problematic aspect, one which contributed to the first. By his own admission, during Smith's presentation at the meeting with Zephyr it "became obvious" to Brown that Smith's "proposed solution created far more new problems than it attempted to solve." Nevertheless, Brown's decision to become a consultant for Smith and apparent willingness to attend the meeting with Zephyr in the role of endorser of Smith's method and approach *before checking on their validity and viability* invites criticism. Brown seems blameworthy for not investigating the workability of Smith's plan before agreeing to put himself in a situation where he would be subject to strong pressure to dissemble or prevaricate. For, it may be argued, he knew or should have known that he would be expected to support his client's proposal at the meeting. Moreover, given his "simple business ethic," he should have realized that, independent of its merit, he would be extremely reluctant if not unwilling to say anything that would invalidate or cast doubt upon his client's program and thereby his reputation. In effect, Brown seems to have inadvertently put himself in a position in which he was confronted by a classical conflict of interest. For respecting the legitimate financial interest of his indirect client, Zephyr, and the safety interest of the bicycle riding public could easily come into conflict with protecting the professional reputational interest of his direct client, Smith. It turns out, however, that the above depiction of events in and around this first episode, an account based upon Brown's initial written case study and on the 1995 class session, is too thin and tidy. It does not do justice to the complexities and dynamics of the sociotechnical engineering situation Brown actually faced. While consistent with Brown's original written case study and initial class discussion, the above account and analysis rest upon several important explicit and implicit assumptions. For example, they assume that Brown was unaware of drawbacks of Smith's concept prior to the meeting with Zephyr and that Brown knew or should have known that he would be expected to endorse or validate Smith's plan at the meeting. Upon further inquiry, both assumptions prove to have been invalid. Let us briefly consider each in turn.

First, Brown had several meetings with Smith about his proposed solution idea well before the meeting with Zephyr's staff. At them Brown had "expressed his concern [to Smith] that for fundamental reasons his solution did not appear to be workable." (CS97) Indeed, prior to their meeting with Zephyr, Brown had already presented Smith "with several optional approaches to [solving] Zephyr's problem which did

address the unworkable aspects of his initial concepts." (CS97) What Brown realized at the meeting with Zephyr was not what he already knew -- that Smith's approach was structurally flawed -- but that Smith's concept "created far more new problems than it attempted to solve." But since Brown had conveyed his concerns to Smith before the meeting with Zephyr, Brown's obligation not to undermine his client's reputation and credibility was significantly diluted if not completely dissolved by Smith's public request for validation from the very person who had previously told him in private that his proposed solution idea was structurally flawed.

Second, far from understanding that he was attending the meeting with Zephyr to endorse or validate Smith's ideas, Brown was in fact "surprised" (CS97) that Smith called upon him during this meeting to validate what Brown regarded as "a very creative, clever, but highly unworkable solution." (C97) Given its early stage of development, he regarded Smith's solution idea as distinctly "premature" for endorsement or adoption. (CS97) Brown was taken aback by Smith's request to validate because he saw his role entering the meeting as that of a consulting engineer with expertise in composite-material structures who had been by a client and invited by him to participate in a three-way meeting the purpose of which, he assumed, was to jointly "explore problems" with Smith's embryonic ideas. That he was taken aback by Smith's endorsement request is clear from Brown's statement that "What I don't know to this day is whether [Smith] felt that he was under pressure to perform on this contract and needed to produce a positive response in the manufacturer as to his performance. Those are things I don't know, but they could easily have been motivational factors that would have influenced why he *put us on the spot*." (C97) (emphasis added)

In light of this less tidy situation, review of moral judgments about Brown's conduct based on the simpler account initially offered is in order. First, was Brown's initial dissembling and evasiveness morally blameworthy? While he did dissemble and prevaricate, Brown "respected, and had confidence in, Zephyr's ability to discover the potentials and pitfalls of Smith's concept." (WC97) He felt it would "serve no purpose to deny Smith an opportunity to present and defend his recommendations to Zephyr," especially since Brown's "assessment of the situation and personal dynamics [at the meeting] was that Zepyhr's funding commitments would only be toward engineering [and] technology validation at this time and that production funding would be based on demonstrated merit." (WC97) Whether this more complex state of affairs suffices to absolve Brown of any moral blame for his feigned

ignorance depends on whether his confidence was well grounded that Zephyr would in fact discover by itself the pitfalls of Smith's concept. On the one hand, if Brown had good reason to think that Zephyr would probably discover these pitfalls on its own before losing significant money, then his evasive behavior would seem to be ethically defensible. On the other hand, to the extent that he lacked good reason to think that Zephyr would discover the flaws before spending a significant amount of money on Smith's unworkable ideas, then his lack of candor would be ethically problematic, especially if, as argued above, Smith's knowing endorsement request of Brown at the meeting with Zephyr released Brown from any moral obligation he had to avoid doing anything that might damage his client's professional reputation.

Second, what of Brown's "apparent willingness to attend the meeting with Zephyr in the de facto role of endorser of Smith's method and approach *before checking on their validity and viability*"? It now appears that, on the contrary, Brown clearly recognized and explicitly told Smith prior to their meeting with Zephyr of serious flaws in Smith's method and approach and did *not* accept before the meeting the role of blithe endorser or rubber-stamp validator of Smith's flawed solution idea. This revised depiction of the reality of Brown's state of knowledge and role understanding absolves him of any charge that he was negligent in being willing to attend the Zephyr meeting as endorser without first checking out the validity of Smith's ideas. As Brown put it, his notion of the purpose of the meeting was that it was to be devoted to jointly "exploring problems" with Smith's ideas, not to "foisting [flawed] solutions" on a skeptical manufacturer by allowing his expertise in composite structures to be exploited by his client. (C97)

This first episode suggests a general lesson for engineering ethical theory, practice, and pedagogy. Subtle, elusive, context-specific factors can be vital to sound prospective ethical decision-making and fair retrospective ethical judgment-making. For example, the temporal juncture at which a triangular episode such as that described above occurs in a dynamic, evolving engineering process can bear on the question of whether an agent's act of omission or commission is reasonably regarded as creating an unreasonable risk of harm to protectable public or private interests. A secondary consulting engineer's state of knowledge about the viability of a client's proposal and her or his reasonable expectations regarding the role he or she is expected to play in a three-way meeting about that proposal can also matter ethically, for example to judgments of professional responsibility or negligence. The same is true of a secondary consultant's reasonable notion of the purpose and

agenda of a meeting called by her or his client that includes important representatives of the client's client. All three contextual factors merit scrutiny in reaching equitable conclusions about a secondary consultant's conduct and judgments, phenomena that may, as in the present case, seem ethically indefensible at first glance. Role assumptions and perceived purposes may be illusory because of deception by the original consultant or because the latter deliberately or inadvertently under specifies roles or meeting purpose and agenda to his own engineering consultant. As this case shows, if left unclarified, manipulated or misconstrued role expectations or assumptions of meeting purpose and agenda may put a secondary engineering consultant in a delicate ethical position requiring difficult ethical choices.

If there is a specific moral to be derived from this first episode it is that engineers and other secondary technical consultants should be exceedingly careful before allowing their potent expertise to be deployed in third-party situations where important decisions may be made on the basis of their actions of commission or omission. A secondary technical consultant should make a reasonable prior effort to determine to the best of her or his ability what her or his role is and what the purpose and agenda of such a meeting is to which he or she will bring expertise able to decisively affect a participant party's protectable interests. If prudence is a virtue for engineers and other technical experts, then reasonable exercise of caution prior to the commencement of such situations is ethically obligatory for such professionals, the more so to the extent that decisive decision-making is possible and noteworthy safety or financial considerations are at stake.

Moreover, given the pragmatic difficulties of exercising such caution beforehand, the question may be raised whether a secondary engineering consultant with potentially decisive technical expertise should *ever* permit it to be deployed in a three-party meeting situation called by her or his client if that person has not previously *earned* the engineer's trust, something which would at least justify assumptions that proffered notions of role and agenda are reliable and not likely to create ethical minefields.

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Episode 2 - Jones asks Brown to Evaluate Smith's Approach

Later on in the meeting, Jones, Zephyr's director of R & D, asked Brown "point blank" whether or not he thought Smith's was a workable approach, "a yes/no alternative that forced a major breach of ethics with either answer, since I believed it was an unsound and unworkable concept." Brown presumably means that had he answered "yes, it's a sound and workable approach," that would have eventually harmed his and his own company's reputation with Zephyr, with a "long-time [composite-materials] supplier [of Brown's] who sat in on the meeting," and with any other knowledgeable parties who learned of what would be a dishonest endorsement. The harm done to his company's reputation would also indirectly harm important economic interests of Brown's own employees. On the other hand, had he answered "no, it's an unsound and unworkable concept," that "would have destroyed [Smith's] business relationship with his client." In the event, Brown gave an answer that he believed "maintained everyone's integrity": viz., "to confirm that my direct relationship to the bicycle company was through [Smith] and that we [Brown's company] would work with the consultant to address issue[s] which were important to the client's requirements."

Beyond indicating that "maintaining everyone's integrity" was Brown's top priority at this juncture, his answer was arguably defensible. For, to an experienced listener, his refusal to answer Jones' question substantively, unequivocally, and without hesitation could not but heighten Zephyr's doubts about Smith's approach and make it more cautious about adopting it -- and Brown probably realized that. If Brown had no misgivings about the plan, Smith would not have wanted him to hide that fact and take refuge as he did in a chain-of-command formalism. In this sense, Brown's reply, although neutral on the surface, invited the interpretation that he regarded the plan as problematic, something which, whether or not intended as such, probably served as a valuable yellow flag to Zephyr. Therefore, Brown's reply here to Jones' question was effectively less evasive and more cautionary than his earlier response to Smith's request.

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Episode 3 - Zephyr Seeks to Establish a Direct Relationship with Brown

The limitations of Smith's design and manufacturing concept "became more evident to the client [Zephyr] as these issues were brought forward." Zephyr eventually approached Brown without the knowledge of Smith and confided that it wished to begin a relationship with Brown's company and bypass Smith altogether.

However, to his substantial moral credit, Brown felt it would have been unjust to Smith to commence such a relationship since it would have deprived of business the very engineer who had brought him to this opportunity in the first place. He stated that he would countenance such a relationship only after Zephyr terminated its relationship with Smith. Further, Brown waited until Smith informed him that his relationship with Zephyr had been terminated before entering into a direct relationship with the company. Finally, because Smith had already done work that "saved [Brown's company] five or six months of energy and effort," (C97) Brown promised Smith a portion of the royalties he ultimately earned from sales of the bicycle he designed for Zephyr: "I just felt that there was some reward due and that he [Smith] should not be cast out with the bath water." (CS97) Brown's admirable sense of propriety and concern for fairness to Smith may have enhanced his credibility in Zephyr's eyes as someone who in his business relationships is not completely driven by short-term profit maximization. This should and hopefully did have an edifying effect on Zephyr regarding making future overtures to consultants of consultants while the former are still under contract to their respective clients.

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Episode 4 - To Optimize or Not to Optimize

When Brown entered into a contract with Zephyr, the "original problem statement" was "to design a composite frame that was equal in strength and equal in stiffness to the existing [tubular metallic] frame." (CS95) After developing a working manufacturing plan for composite bicycles, Brown made an important decision.

Because the composite analysis was so much more complex and therefore more costly, "we suggested that we make certain that the frame [Zephyr] had given us as a baseline was in fact as good as it could be before we departed [from it] and tried to make that same frame out of some advanced material."(CS95) But, to his surprise, when he asked Jones for permission to optimize the existing frame, he was told not to do so, something Brown felt was "a very shocking thing for him to say until I [learned] subsequently that [Jones] was its designer," (CS95) and that his "design ego" was the main factor driving his prohibition. (CS97)

Brown could easily have taken that "no" for a definitive answer and acted accordingly. However, he "decided to go off the customer's book and if we found something that was of note on our own invested nickel, then we would bring it to the customer's attention." (CS95) In the event, what he found was that the design of the existing tubular metallic frame was "nowhere near where it should have been to be the appropriate baseline to solve the [composite] problem." (CS95) The stated reason why Brown undertook to optimize the frame on his own time and resources was that he regarded optimization of the existing frame as "an essential, sound engineering practice." (CS95) As he put it, "if you're going to design an experiment and the objective is to make something the best you can, and you have a baseline to start with as your point of reference, your control, if you will, and you find that there's something wrong with that control that's going to throw off the whole experimental base that you're trying to accomplish, ...so we wanted to make certain that the control was in fact as refined as it could possibly be so that all of the rest of the work that we had to accomplish would be based on the best answer [for] their existing technology." (CS95)

Given the terms of his contract, optimization was not only not legally binding on Brown, he was expressly told not to do it. Nevertheless, I contend that in this case optimization was not only morally permissible but morally obligatory for Brown. His obligation to optimize did not stem from the fact that optimization is an element of good engineering practice as such. After all, not everything that is "good engineering practice" is morally obligatory for engineers, e.g., bench-marking, careful record keeping, and fastidious literature searches. Rather it stemmed from two other considerations.

First, engineers have a general moral obligation to act so as to serve the legitimate interests of their clients or employers as well as they can. For the design engineer, this general obligation ramifies into a more specific obligation to design the best

product or process that meets the given specifications under the specified constraints. This, Brown reasonably believed, required optimization of the existing frame. For to proceed without optimization would be akin to a surgeon performing an important, innovative operation on a patient after having acquiesced to the order of a member of the patient's family, unbeknownst to the patient, not to carry out an exploratory diagnostic procedure which could significantly enhance the prospects for a successful surgical outcome. The specific obligation to optimize derives at two removes from the engineer's general obligation to serve the legitimate interests of the employer or client to the best of her or his ability.

Second, this derivative obligation was strengthened by the fact that Brown's task called for him to go beyond what Walter Vincenti, extending Thomas Kuhn and Edward Constant, calls "normal [engineering] design" and to enter the realm of "radical [engineering] design." One enters this realm when the "configuration", the "operational principle", or, as in this case, the structural material of an item of technology constitutes a marked departure from the reigning, well understood normal design paradigm. The obligation to assure that the baseline frame was optimal in design stems from the fact that "composites are unique" and "tricky"

(CS95) and sometimes behave in ways that are not yet adequately understood. Moreover, composites, although very strong and very stiff, are "very brittle and don't give much external evidence of internal failure."

(CS97) Therefore, optimizing the structure of the old frame in terms of strength and stiffness would provide a baseline to refer to when evaluating the behavior of the composite frame under critical load conditions.

Without this baseline, it would have been impossible for Brown to know whether he was designing the best product for his client, hence was serving the client's interests to the best of his ability. For without optimization, the new composite frame might have been lighter than the existing frame but, unbeknownst to the designer, not appreciably lighter (and possibly less reliable) than the optimized, more cost-effective, tubular metal frame. In his determination to carry out the "essential, sound engineering practice" of optimization, even at his own expense, Brown exhibited exemplary moral character and good engineering judgment.

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Episode 5 - Option Disclosure and Problem Redefinition

As a result of his optimization study, Brown determined that for an incremental manufacturing cost burden of $6.20/bicycle and with a change in only a couple of materials used in making the bicycle, the existing metal frame could be reduced in weight by a third, bringing it within about 2 oz. of the target weight of the projected composite-material bicycle. Moreover, this could be done "without adding about $2 million in capital equipment, without adding a total secondary staff of people who [would have] had to learn new skills...not totally available in the ...marketplace, apply these new skills to the new equipment, go through the learning curve headaches, and come up with an optimally designed and manufactured corporate product." (CS95)

Given all this, Brown felt obligated to disclose this new option to Zephyr. Why? As he put it, "it is my job to provide [the people employing us] with full and complete information so that the conditions under which they employ us are honest and viable...[B]y withholding information that's essential to their decision-making process, I'm not being honest and complete in the service I provide...It's simply our job to present alternatives that are either known in advance or that come up in the course of our investigation."(CS95)

Brown's remarks here conflate two kinds of consideration: (1) considerations of moral character and (2) considerations of the employer's best interests, here in making sound decisions. The obligation to disclose the alternative production option stems not just or primarily from the fact that honesty is a virtue, but from the fact that option disclosure was necessary if the client's decision making was to be made sound by being informed rather than remain vulnerable by being uninformed. For the company's production decision about whether to proceed with development of a composite bicycle to be informed, it had to be based on knowledge of the range of options available to it, including the improved non-composite option. If a consulting engineer has a moral obligation to serve her or his client's or employer's legitimate interests to the best of her or his ability, and if making important decisions on an informed basis is a legitimate client or employer interest, and if a consultant acquires information bearing substantially on her or his client's ability to make such decisions on such a basis, then option disclosure here was morally obligatory for

Brown. He so regarded optimization and option disclosure and acted accordingly. For example, beyond optimizing the existing frame at his own company's expense, Brown participated in conference calls with the president of Zephyr and his director of R&D, during which he informed the president that he had been told not to optimize but that he considered doing so essential, for reasons of "product liability, consumer issues, [and] safety issues." (CS97)

But for Brown, serving the best interests of the client went beyond *optimization* and *option disclosure*. It also encompassed *problem redefinition*. Instead of just "make us a carbon-fiber bicycle," Brown helped Zephyr see that its goal was "[to make the] best possible product, given all possible perspectives of the problem." (CS95) This in turn involved helping the client see that "the real problem" was "to build a lightweight bicycle frame that was equivalent in strength to their existing frame," CS95) whether made out of a fiber-reinforced composite material or out of a less exotic metallic material.

This is a robust and ethically admirable notion of what it is for an engineer to serve the legitimate interests of one's client to the best of her or his ability. It enabled the client to choose between a new, expensive-to-manufacture, composite-material bicycle of uncertain structural reliability, and a redesigned, much-cheaper-to-produce, reliable metal-tube bicycle, as strong and almost as light as the composite. Had Brown's notion of serving the legitimate interests of a client as well as he could been subsumable under the simple 'uncritically-follow-the-client's-marching-orders' model, an expensive-to-manufacture and possibly sub-optimal carbon-fiber bicycle would have resulted and been the sole lightweight bicycle option available to Zephyr. Paradoxically, the general obligation of the engineer to serve the best interests of the client as well as he or she can here laid upon engineer Brown a derivative moral obligation to challenge and attempt to effect revision of the problem formulation originally given him by his client. Like the case of William LeMessurier and the Citicorp Building, the composite-material bicycle case suggests that fulfilling the consulting engineer's obligation to serve the interests of the client to the best of her or his ability is not always simply a matter of deploying state-of-the-art technical competence to achieve what is requested of one. Sometimes fulfilling that obligation requires having the courage of one's convictions, in this instance of undertaking to do exactly what one was told not to do, and of deftly exercising various diplomatic, organizational, and communications skills. In taking the path of option disclosure and undertaking the task of problem redefinition,

engineer Brown once again exhibited exemplary ethical conduct. It would have been easier for him to have kept knowledge of the new lightweight option to himself, or to have conveyed it only to Jones, with whom, for obvious reasons, it would probably have remained a closely held secret.

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Conclusion

Medical ethicists have begun to recognize that general human rights, like the rights to life and liberty, ramify in interesting ways in contemporary technological and professional-medical contexts, and that the resultant derivative moral rights sometimes require careful delimitation and qualification. Similarly, engineering ethicists should explore how general moral obligations of engineers give rise to more specific derivative moral obligations as a function of, among other things, the kind of engineering work being done and noteworthy features of the context in which that work unfolds. In the composite-bicycle case, general moral obligations of the engineer to serve the employer's or client's legitimate interests to the best of her or his ability, and to hold paramount the health, safety, and welfare of the public, gave rise to more specific, derivative moral obligations to optimize, disclose options, and attempt to effect problem reformulation. This ramification reflects the fact that non-normal engineering design work was being done involving the use of an advanced, not-well-understood material, the fact that the design work unfolded in a context in which substantial company money was at stake, and the fact that public safety was potentially at risk. Elaborating middle-level moral obligations of engineers as functions of the features of the total socio-technical contexts in question could help turn general formulations of engineers' moral obligations easily embraceable in the abstract into agendas of specific challenging tasks that engineers are morally obliged to fulfill in particular kinds of contexts.

Addressing intending engineers uneasy about the prospect of facing vexing ethical issues and making difficult ethical choices in their future practice, Brown concluded his written case study with a provocation: "My advice to you is to get out of engineering quickly and seek career opportunities in investment banking, stock brokerage, real estate, auto sales, or life insurance and financial planning." Brown here implicitly contrasts the listed fields and engineering. In the former, it is deemed

legitimate to persuade a customer that he or she needs something in fact not needed, this in order for the practitioner to make money. In contrast, for Brown it is sometimes ethically incumbent upon the engineer to attempt to persuade the client that something it thinks *is* needed is actually *not* needed, even if success in doing so means the engineer foregoes an opportunity to make money. This is a high standard of professional responsibility, one which Brown met and which future engineers must be prepared to meet if they aspire to call themselves true professionals. In light of this imperative, engineering educators have a derivative moral obligation of their own: to labor upstream with their students, such that, duly apprised of and equipped to grapple with the sometimes daunting ethical challenges of engineering practice, their career decisions will be more informed and truly voluntary. If, and perhaps only if, intending engineering professionals are so prepared, then radical downstream career changes, such as that urged by Brown, will become as unnecessary as they are upsetting.

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