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Designing a Serious Game to Map the 'Process Genome' of Hospitals

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Abstract

Better understanding the processes within a hospital and integrating this understanding into a virtual model capable of allowing dynamic simulations, would have value for multiple healthcare stakeholders. We outline one potential user model able to generate such a 'genome mapping.' We describe an innovation platform, with knowledge sourced from both in-house subject matter experts, client and customer subject matter experts as well as third party suppliers, customers, end-users and non-client subject matter experts delivering inputs through crowdsourcing. We conceptualize the innovation platform and its crowdsourcing within a 'serious game.' In this view, the business model is built around a technical solution (the visualization of the hospital), and encompasses local and remote additions to populate the visualization, suggest refinements, conduct what-if changes, learn from, etc. the continually updated technical solution. Local additions and refinements are motivated through extrinsic incentives and are achieved by front-line delivery staff complemented by appropriate technical managers. Remote additions and refinements are motivated chiefly through intrinsic incentives when contributed by users, end-users and clinicians, but are motivated by extrinsic need for credentialing, interoperability certification and training when contributed by medical device and infrastructure suppliers.

Background

In the United States, the HiTECH Act was passed in order to stimulate the adoption of a minimal level of health information technology (IT) centered around electronic health record functionality in an effort to improve healthcare quality and reduce health care costs. In other industries, process reengineering coupled with intelligent use of technology is a cornerstone of business improvement. Yet similar investments in medical technology interoperability, process technology and process engineering have lagged this push into electronic health records.

A precondition for such reengineering would be a better understanding of hospital processes. In this debate, we use the term ‘process genome’ to indicate the superset of hospital processes, and to allude to the decoding that is needed. The successful mapping of the process genome, coupled with its simulation and visualization within a technical solution, would allow its developers and users to improve processes within a hospital. In consequence, hospital staff would gain training and experimentation opportunities in safe but realistic virtual environments, device manufacturer clients would be able to gain credentialing of an interoperable device in a setting in which interoperability drives safety, costs and outcome, and suppliers would be better able to interface with hospital analog and digital processes. We also saw payors gain financially through potential safety and quality enhancements and by avoidingiatrogenic costs.

To achieve such benefits, a user model needs to be proposed and needs to account for the intrinsic and extrinsic motivations of users, the sources and uses of such process information must be described, and a technical solution needs to be sketched. Finally the business and clinical value which can be derived from such a solution needs to be articulated. We describe how similar industries have used similar technical and business model solutions to address analogous business performance problems or challenges. We extend this and specialize in the business value accruing to hospitals, their stakeholders, their end-users, and their suppliers.

In this Debate we outline our thinking on one such user solution, technical solution, and possible business value. We have chosen to sketch the design of an innovation platform whose technical solution possesses a number of technical attributes, and whose user solution centers on the crowdsourcing of knowledge inputs within a serious game. Other designs are certainly possible, and our intent is to contribute one such design and thereby stimulate technology, business process and business model innovations in the healthcare IT space.

Technical design

We discuss in three sequential steps the user model (options and our preferences), attributes of a technical solution, and how business and clinical value could be created as a result. We conclude the Discussion section by asking and answering why such models have not already been built.

1 User model

The user model spans two critical design dimensions: first, the sources of the expertise domain that need to be on hand during the application design phase and the scenario design phase, and second the orientation of the solution itself in terms of a formal simulation versus a less formal serious game (Table 1).

<<Insert Table 1 about here>>

The latter denotes a game designed for a serious primary purpose rather than for an entertainment primary purpose.[1] Note that the options in the table below are not necessarily mutually exclusive over the full application. We elaborate on these options for the user models below, before highlighting our preferred scenario.

1.1 Experts in a simulation model

The most traditional approach is to have subject matter domain experts help design, provide inputs into and (help to) run a formal simulation model of the healthcare process of interest. The advantages of this are the familiarity of this approach, the ease with which it can be designed and the simplicity of extracting domain experts' point of view using similar constructs and concepts. In healthcare, even in the most complex intensive care settings such as coronary care pathways, Curry, Nembhard and Bradley of Yale have consistently argued for the value of exploring qualitative factors and sourcing improvement ideas from multiple healthcare professional sources.[2]

General management academic studies of the success of multisided platforms using domain experts are clear on the advantages. Boudreau found that as the number of application software producers increased on a particular platform, the number of software varieties rose,[3] while Lakhani et al find similar positive results in big data biomedicine.[4]

Terwiesch and Xu showed how such open (albeit, with qualified domain-expertise) innovation can deliver an enormous benefit by increasing the total expertise available to solve a problem, incenting superior solution efforts, and penetrating further into rugged solution landscapes with more creative trial and error experimentation.[5] Austin, Devin and Sullivan argue that 'accidental innovation' has strong beneficial effects, overcoming the decrease in variation experienced by incumbents as they mature.[6]

Unfortunately, we judge this option to have only limited utility in generating usable data, and we see only limited crossover between domain expertise and simulation expertise. That is, the more in-depth the simulation, the less likely that clinical domain expertise will be fungible to the functions of refining and interacting with the simulation. Despite these misgivings, a number of extant examples exist, mostly in the basic life sciences. For instance, Su Labs (Scripps) has developed the BioGPS simulation model for annotation of genes by biology experts.[7] Results to date have captured thousands of gene-disease pairs.

A conceptually related model is ResearchGate, in which research-active scientists can “Smartsource” projects and scientific questions and quickly collaborate with other experts.[8] Despite the obviousness of this concept, and the many alternative and competing approaches that could deliver on the same objectives, the ResearchGate site is growing rapidly.

1.2 Experts playing a serious game

As opposed to the first option above, in this approach, domain expertise is married to a less formal serious game. The advantages are that the informal and gaming setting potentially incentivizes more experts to use the modeling system more often, more conscientiously, more interactively due to the appeal to intrinsic personal and social motivation. Disadvantages of this option include all those mentioned in the first option above, plus additional ones. Designing and developing attractive gameplay layers additional development costs onto the project, while the degree to which clinical domain experts are interested in, willing or able to use gamer skills is not currently well-understood.

For these reasons, we saw only rare examples in this category, and these were not commercialized.   One model uses experts and leverages Tetris and Invaders style games to support annotation of domain-specific terms in a taxonomy study.[9] It is noteworthy to consider that this crowdsourcing evaluation, or 'game with a purpose' required formalization as a competition with prizes, but drew computational linguist participants from the same department or on-campus institute as the game developers. The degree to which this constitutes truly voluntary crowdsourcing is doubtful.

Another early but not particularly compelling example is the CABERNET game for normalizing definitions of phenotypes by consensus.[10] In this crowd sourced expertise, game scores reflect the degree to which histology classifications by a participant matches those of other users. It is not clear to us how this procedure avoids selecting for a type of 'group think' that minimizes variance on the extensive margin (by deterring those users from further game participation, whose answers lie too far from those of the 'mainstream'.)

These models appear much more applicable to situations in which process conformance is more important than process re-engineering, or situations in which a process is already very well understood. Such innovation contests are sprouting up all around us. We also noted the example of InnoCentive which claims a success rate of 50%+ in posted problems requiring a solution from expert users. Key successes have included a discovered biomarker for ALS progression, and a discovered solution to simplifying and reducing the costs of the production process for TB therapy.

1.3 Crowdsourcing non-experts for a simulation

This option was judged by us to be the least feasible, and potentially an invalid one. On the one hand, it is theoretically possible that more data could be surfaced by the much larger number of non-domain experts relative to domain experts. However, the quantity/quality trade-off remains a serious consideration. The general online public lacks domain *and* simulation expertise in many settings in which such crowdsourcing might be a potential solution. Furthermore, the act of interacting with a simulation seems inappropriate for persistent motivation since such simulations lack gaming incentives.

Probably the most compelling example we could find is the use by theBlu of a successful immersive ocean simulation, where amateur artists can create their own fish and marine ecosystems.[11] Incentives appear to be a mixture of intrinsic motivations: self-actualization, hobbyist aspirations and also the fact that 25% of proceeds go towards ocean-helping non-profit organizations.

Even in this example, it is difficult to see how the data owner and developer of the simulation actually benefits *directly* from the participation of users in the simulation. As the business model states “you’re buying computer animals to protect the real thing”. Possibly as a result, the verisimilitude of the simulation aspects contributed by lay participants has been criticized as well.[12]

1.4 Crowdsourcing non-experts in a serious game

When crowdsourcing domain experts as end users for datamining purposes is valuable but possibly not readily available or affordable, then efficient crowdsourcing of online gamer expertise is an alternative goal. We saw the feasibility of this as hinging on supply-side and demand-side factors: if domain knowledge experts are scarce or if the task doesn’t require specialized knowledge and if the IP protectability of the sourced information is not an issue.

The chief advantages of this user model are that there will be more inputted data to mine, and that we can provide incentives for gamers in common gaming areas of expertise. The main disadvantage is that this user-friendly design as a game clearly occasions far more design difficulty in translating domain-specific processes into gaming paradigms. This is of course not insuperable and merely one input in the overall cost-benefit equation.

Several compelling examples include puzzle games (foldit, phylo) used to fold proteins, or track diseases according to genome configurations.[13] In our opinion, these games are not very well designed from a gameplay point of view, since primacy appears to have been given to the domain constraints. It is also possible that the domain constraints bind and prevent more interesting game play. More advanced examples include those of telepathology which turns diagnosis of malaria etc. into a crowd sourced game.[14] This is successful in terms of accuracy: within 1.25% of correct diagnosis rate by experts.[15]

When the actual simulation is hidden, and all the user can see is the gameplay interface, then kaggle.com has essentially created a serious game. In models looking at predicting readmissions, a large part the data on which submitted algorithms are judged is kept secret and hidden from participants who see only a small training set.[16] Users, who tend not to be healthcare experts as much as computer scientists or programmers with neural network skills, are only able to see how their latest efforts rank them on the leaderboard. Some participants have submitted hundreds of entries cumulatively in an endeavor to fine-tune their algorithms on the hidden data.

One other traditional example of a crowdsourcing success is General Electric, who designed its Eco-Innovation Platform to offer financing to small potential innovators and to harvest entrepreneurial energy and ideas from those external sources, and its Healthymagination

Challenge to identify and accelerate ideas that advance earlier breast cancer detection and diagnostics.[17]

Finally, we saw some crowdfunding business models as having commonalities with this option of crowdsourcing non-experts in a serious game. For example, in the healthcare space, Medstartr.com solicits relatively small contributions to emerging technologies or business models in a setting that could be described as a serious game.[18]

Participation allows earlier or cheaper access to some technologies or data (e.g. the DocGraph project allows sponsors to get preferential access to a social graph of referral patterns), or to have their backing listed on the project website non-anonymously for intrinsic motivations or reputation enhancement, or receive an identifying small gift celebrating the backer's promise of support. We saw the game aspect of this in the countdown to a deadline, the use of a specific funding monetary target, and the interaction possibility between backers, and between project staff and backers.

1.5 Operationalizing the crowdsourcing non-experts in a serious game

In this Debate, we articulate a preference for the dominant use of non-experts in a serious game as the user model. We saw several avenues for gamer crowdsourcing to break down complex domain-specific process models into simpler game-based processes and gather data from "expert" gamers for each subset. For one process model, we would seek to develop games to bridge small gaps. Following this, we would abstract each step to be tractable to gamer expertise (Tetris, Doom, fast-forward Game Of Life, ...) and yet still be a relevant domain task.

Subsequently, we would break down functions, operationalization, and goals further as necessary in order to get the simplest gameplay mechanisms with the most suitable abstractions (i.e., easiest to evaluate and needs least translation by a subject matter expert). Finally, we would then tabulate the statistically strongest pathways from data output, from simple process to combined processes, distilling the crowdsourced solutions.

In terms of functions, we saw the following operationalizations and game goals as potentially very relevant for hospital processes. Note that we conceive of different hospital functionalities as data layers within the technical solution, and imagine that filters isolate or highlight portions of each function. For network infrastructure we conceived of information flow, terminal placement (including mobile devices /paths), cable/wireless node placement, firewall /security setup (data layer in cyberspace sim, can be swapped out / merged with physical structure) as the relevant functions of interest. The two game goals for crowdsourced non-experts would be to maximize information relevance and accessibility.

For staffing, we saw the assignation of staff routes and tasks (data layer over physical structure) with maximization of staff visibility / availability / efficiency as the game goals. For physical infrastructure, floor plans and interior layout (walls, corridors, equipment, electrical outlets, plumbing) would be the operationalizations of interest with reduction in cost / travel time / risk the game performance goals.

For communicable disease control we assumed that hygienic measure placements and quarantine regulations would be the parameters of greatest interest, and the obvious performance objective to halt the spread of an outbreak of communicable disease. Other more sophisticated measures could include the balance between the costs and benefits of immunization and the risks of achieving higher than needed herd immunity in terms of negative feedback on the immunization decisions of individuals.

For functions such as patient admission and patient triage in emergency room settings, the key processes to manage are patient care and movement and triage policies (i.e. thresholds). Here the game goal is more complicated, reflecting both emergency department performance as well as inpatient referrals downstream, each of which has different financial implications. A further complexity is the interdependence of different regional emergency departments in the production of 'ambulance diversion' hours, since one hospital's diversion is another's encounter and vice versa.

Finally, we saw useful partial or complete aggregation of game functions such as the pairwise combination of process models involving staff routes and patient movement or triage, and the total combination of process models in assessing operational risk and higher level performance analyses such as cash flow analyses, patient quality of care and safety overall.

2 Technical solution

Given our design bias towards a serious game with crowdsourced domain and non-domain experts, we now describe our technical solution. We inventoried 5 attributes of the desired technical solution that we claim are of highest value in meeting the objectives of both mapping and decoding of hospital process 'genome' as well as constructing and managing a 3rd party innovation platform for incremental innovations in device and care delivery space. These technical attributes include *Artificial Intelligence*, *Dimensional Repurposing*, *Object Malleability*, *Multiplayer Simulation* and *Anatomy Infrastructure and Functionality*. Each of these attributes map to the hospital setting as described below:

2.1 Artificial Intelligence

This is something of a catch-all / umbrella term, but for our purposes it represents computational methods that model or interface with human cognition and behavior (Table 2). Computational human cognitive modeling is based on theories and results from neuroscience, cognitive science, and psychology. External (social and behavioral) models are necessary for artificial patient and staff simulations, but these are greatly enhanced in realism by solid cognitive, and particularly emotional, internal models. Beyond that, the behavior and inferred cognitive models of human users can be aided by including an artificial evaluative assistant, which can not only track progress but also analyze errors and offer solutions or hints.

<<Insert Table 2 about here>>

2.2 Dimensional Repurposing

The visualization of data and processes is in some regard limited by the user's experiential limits of three spatial visual dimensions (possibly augmented by audio etc.). However, the spatial dimensions themselves do not have to represent length, width and height (Table 3).

<<Insert Table 3 about here>>

For instance, a flat map representation might repurpose height to visualize a timeline. Conversely, other aspects of visualization can be repurposed to represent spatial dimensions; e,g., color representing the length of a cable connection in a sprawling system.

2.3 Object Malleability

Objects (physical or otherwise) in a visualization model have particular properties that can change if looked at from a grouped perspective (Table 4). Ten objects representing a single person each may not be able to break down a wall individually, but a single gang of ten might have that capacity. Another example: several temporal events grouped together might be automatically represented as a timeline "meta-object".

<<Insert Table 4 about here>>

One way to track objects, groups, and meta-objects is by an interaction matrix, where each object has a known, arbitrarily detailed set of interactions with every other object, group, or meta-object in the model. The matrix expands as more groups are created, etc.

2.4 Multiplayer Simulation

Multiplayer game-based systems can harness the power of human competition as well as collaborative information pooling. A common and simple way to incentivize progress is to create a leaderboard where competitive players' relative success is displayed; another is to establish achievement metrics that players can aim towards. Multiplayer capability also facilitates the crowdsourcing aspect of our proposed solution, for subject matter experts and gamers alike (Table 5).

<<Insert Table 5 about here>>

To devise a game wherein general gamers can help optimize a domain-specific solution, two conditions must be true to some extent. First, the tasks for the gamers must be suitable for the gamers to leverage their expertise (as pattern matching, good reflexes, etc.). Second, and more difficult, the tasks or combinations thereof must have meaningful effects (directly mapped or analogical) for the domain and the problem at hand.

2.5 Anatomy Infrastructure and Functionality

The main advantage of our proposed technical solution is in its data modeling (Table 6). Domain-independent static and dynamic data visualization are standard in the system, and are customizable per user via several tools: aggregation, integration, data layers and filtering, etc. Lastly, the system offers a comprehensive logging and playback capability. This allows data mining for several purposes both within the game (playback of scenarios and save/branch points), and otherwise (predictive modeling of user behavior).

<<Insert Table 6 about here>>

In this Debate we have deliberately not described in any detail a technical architecture consistent with these technical attributes.

3. Relevance and Value to Business Problem

The attributes of the technical solution and user model combination described earlier have clear implications for business value in multiple segments of the business value chain. Generically, in the market for the factor of production, hospitals' use of advanced technology has reputational advantages that attract specialist labor such as clinicians and trainees. While till now this has manifested itself predominantly for direct clinical technology (e.g. DaVinci surgical robots for robot-assisted hysterectomies or prostatectomies, sought after by the respective specialist physicians).

In the output market for hospitals' services, the use of advanced technology contributes to advantages that can differentiate hospitals' positions in the space of public or payor perceptions. Transformation and production within the hospital is aided by the use of such technology, where internal health information technology is the obvious example. Increasingly we see information streams as examples of other technologies that assist process transformation within hospitals.

The use of remote benchmarking by Objective Health by McKinsey[19] and the use of external proprietary data on patients by ClearIQ by Transunion Healthcare[20] are more recent examples. Suppliers contributing to the transformative processes occurring within hospitals and derive separate, additional value from being able to extract business intelligence on the use and improvement of durable supplies. Within this context, each of the technical attributes of the proposed solution has distinctive uses and sources of value to different stakeholders within and without hospitals.

3.1 Artificial Intelligence

The sub-attribute of cognitive modeling, incorporating in addition emotional, behavioral and social factors can add value in the following example settings (Table 7).

<<Insert Table 7 about here>>

Separately, the use of a user-facing Evaluative Assistant within the technical solution can guide game users toward set of policies based on values, track progress within game, and analyze errors and offer solutions or hints based on others' gameplay.

3.2 Dimensional Repurposing

The sub-attributes of the combination of spatial and hybrid dimensions, and reverse spatial dimensional repurposing, can both improve value as shown below (Table 8).

<<Insert Table 8 about here>>

3.3 Object Malleability

The sub-attribute of allowing grouping and meta-objects has the following advantages, as does the sub-attribute of tracking objects, groups and meta-objects using an interaction matrix (Table 9).

<<Insert Table 9 about here>>

3.4 Multiplayer Simulation

The sub-attribute of facilitating collaboration across multiple internal player-based roles and data sources also has the value in different settings. The closely related sub-attribute of enabling collaboration across wider internal and external stakeholders and formally crowd-sourcing inputs has similar value across those settings (Table 10).

<<Insert Table 10 about here>>

The sub-attribute of leveraging natural competitive instincts and allowing competition through leaderboards as well as allowing for intrinsic motivations and self-actualization offers value in these contexts.

Finally, the sub-attribute of facilitating competition on a red team versus blue team basis in which all participants are playing on the same team against a virtual opponent, or in which teams of participants play on 'different sides' also offers business value.

3.5 Anatomy Infrastructure and Functionality

The sub-attribute of 3 dimensional models, layering and filtering, displaying state changes, and the flexibility of allowing dynamic visualization of data independent of domain offers specific advantages as shown in the table below (Table 11). The sub-attribute of simulation logging allows for playback functionality and predictive modeling, both of which offer value in the following example settings

<<Insert Table 11 about here>>

4. Why have such models not emerged yet?

Why is the information underlying this business still valuable and why hasn't this been done before? Most fundamentally, we argue in this Debate that there is a disconnect between the current investment in health information technology and health technology in health care. This disconnect arises and is strengthened by the following persisting factors.

Strategically, we believe that the current government-mandated focus on health IT adoption has 'crowded out' attention at senior management of hospitals for other strategic objectives such as innovation in sourcing, use and interoperability of medical technology. Based on our own interactions with hospitals in the throes of adopting EPIC, Cerner or other systems, bandwidth at the COO level seems tapped out dealing with these major implementations of these contracts in the tens to hundreds of million dollar range.

Linked to this crowding out is, we believe, an attenuation of business logic. For most firms, information technology investments are driven from a business objective (e.g. efficiency, quality, reputation, transformation, keeping up with the 'pack') which drives a technology adoption strategy, conditioned on achieving a particular ROI and meeting the business case. Yet in the last half a dozen years, the increasing bubble in health IT solutions seems to have led to health IT investments being justified separately from business logic. Adoption is driven directly by Federal stimulus and federal short-term financial incentives. Solutions are successful to the extent they meet Federal criteria, as opposed to more business-specific goals. When such specific goals exist (e.g. improve patient safety through CPOE systems), it is not really clear that this use case is not yet supported by robust data.

We believe that an additional and previously under-appreciated reason for the disconnect between technology investment and goals has to do with the field of medical informatics, which has been dominated by professionals with deep implementation skills but generally not strategic skills. Apart from this, the business and quantitative training necessary for medical informatics specialists to understand business needs and strategies is generally frankly lacking.

Worse, the mindset and training developed from historical systems and legacy applications biases current medical informatics attitudes away from modern information technology capabilities around portability, connectivity, searchability, and the structured vs. unstructured data trade-off. Coupled with this skills issue is a fondness for public good uses of medical data, and public health applications of hospital investments in medical technology of any sort. It is clear that these uses may not synch well with actual workflow in a hospital, nor with the focus on a business case for hospitals.

Related to the old-fashioned mindsets that abound among medical informaticians are old-fashioned attitudes about technology architecture (e.g. big, owned, proprietary, not interoperable, not cloud-based, not SaaS based) that dominate health IT architecting. Suppliers are content to build and supply solutions that cement this stand-alone philosophy, by either designing solutions that don't easily work together with other IT systems, or by charging separately for interoperability which further limits network economies. While these criticisms apply most directly to health IT, similar attitudes and design philosophies are evident in how hospitals and clinicians think of other medical technologies.

Moreover, beyond simply medical informatics workforce weaknesses, the healthcare workforce more broadly has limitations in terms of the critical thinking, the critical skills necessary to build use cases, assess user experience, improve workflow and performance, and undertake data mining activities to better understand their organization's needs. These limitations are pervasive throughout the technology ecosystem within a hospital from data capture, to productivity and workflow management, and to the users of secondary data in business strategy and operational roles.

Most importantly, we are continually struck by how little experience senior hospital or clinical leaders have with technology or alternative business models in healthcare. Outside healthcare, a typical technology implementation follows a process of defining the current business processes and supporting technology. Then, driven by functional silo or overall business strategy, a description of the new business process that the organization wants to achieve is crafted. Downstream of these decisions, the technology group uses the use case to drive development of new technology solutions.

In consequence, while reengineering coupled with intelligent use of technology is a cornerstone of business improvement in other industries, healthcare proceeds in a different manner. In healthcare on the other hand, this robust change process does not occur. Clinical purpose is unclear, and fought over between organizational units (e.g. should we become a minimally invasive shop or stick with older techniques) and between service lines and the corner suites. A similar lack of consensus characterizes the path that transformation should take. Into this vacuum (and enabled by the lack of independent technology skills among leadership), a CIO or CTO can develop their own concept for what business process the organization should use (e.g. the vendor's canned CPOE sets, or best practice sets from an elite provider organization). The work product stemming from this benign neglect could be great (but without clinical buy-in, genuine adoption is fraught with risks) or poor (feeding into a generalized rejection of technology as a solution to implement new business processes.

Between these two extremes, a slightly more standardized, slightly newer way of 'automating' the cow path of existing processes is the likely result. This characterization of clinical and medical (mostly health IT) technology adoption differs from the more well-understood supporting systems that run back office applications in finance and accounting. In contrast to the lack of consensus above, shared services use cases tend to be well-agreed on and uncontroversial adopted. Of course, excellence in these systems is unlikely to lead to market performance.

In conclusion, if hospitals were better at harvesting their own transactional and clinical data, extracting descriptions of workflows and constructing and refining operational models, and better at sharing and benchmarking this data with each other, then this information would be far less valuable and far more commonly available. We do not believe hospitals are near this stage of information gathering and analysis. Given their role as owners and generators of such data, effectively acting as gatekeepers to the potential flow of information from clinical workflows in their facilities, other ‘consumers’ of such data are also unable to obtain this except through complicated partnerships and small-scale collaborations.

Summary

We see the preceding sections driving a new business development opportunity in which information on medical technology use and clinical workflows and their intersection is crowdsourced cheaply and at large scale from a combination of non-domain experts and actual clinicians and nursing staff through a serious game. We are agnostic in this Debate as to whether a hospital can and should develop this model as a proprietary solution, or whether a third party should or could play this role.

Our approach suggests that such an open innovation platform could allow a third party to “crowdsource” suggestions and feedback on device position, workflows, display colors, alarm sounds etc. Like in energy, electronics and gaming, the power of this new form of ideation-based “innovation platform” could accelerate advances in critical care therapeutic and diagnostic device innovation in ways the field of medicine has never seen.

This information could be captured and processed, and repackaged for sale or rent to a variety of potential ‘consumers’ of such content ranging from hospitals, medical device and health information technology suppliers, infrastructure developers, nursing and clinician educators, and government quality regulators and stakeholders. We see this as an iterative process, where ‘consumers’ implicitly define questions to which answers are sought (but not explicitly, as in the form of a codified challenge) or domains in which suggestions, tips and ideas are welcome.

‘Suppliers’ of information, by what they supply in response to challenges in the simulation game as much as by what they don’t, reveal insights into (further) questions which should be posed.

To implement such a design, next steps would center around the quantification of supply and willingness to contribute, through surveys, questionnaires and specialist inputs. In parallel, we recommend the piloting and testing of a stripped down form of the innovation platform+serious game concept.

On the packaging end, we see three types of content that could come out of the transformation. ‘Consumers’ of such content span the value chain. For educational and training courses aimed at hospital clients, a leading example would be a simulated patient-staff interaction or device-staff interaction, which had previously been ‘played’ as a serious game by hundreds of distributed clinicians. A hospital client would download and play a logged exemplar game and solicit trainees’ inputs on what issues they see. Their answers would be tested for prioritization, quality and quantity against a master list of harvested best practice answers.

For device testing and interoperability credentialing, a second example of content would be a suite of logged public gameplay using existing different versions and different manufacturers of a particular device as played by different sets of users, complete with annotated user feedback and frank comments. Manufacturers and hospitals would then privately contrast the play achieved on other devices, and the interoperability problems noted, with the particular test device of interest. They would be able to ‘play’ their device in the same context, noting whether similar problems supervened.

A third example of content would be the dedicated creation of a putative new facility layout by a facility builder/designer, and testing this purpose made product in the serious game, harvesting user comments and feedback on how this incremental, decremental or major innovation was perceived by end-users. These clients, similar to the device testers above, could gain technical testing, validation and certification of individual device performance within a virtual environment mimicking their own specialized, idiosyncratic real world environment.

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Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Both authors are equally responsible for the paper. Both authors read and approved the final manuscript.

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Table 1 Design options for innovation platform

		Orientation of implementation as	
		Simulation	**Serious game**
Domain expertise sourced from	**Experts**	Option 1	Option 2
	Non-experts	Option 3	Option 4

Table 2 Artificial Intelligence attribute of technical solution

Subattribute	Previous Use Venue	Previous Use Value Added	Difficulty	Depend
a. Cognitive modeling (+emotional, behavioral, social)	Commercial airline pilot simulation (AdCogSys)	Reduced cost and time for development (sim, sped-up humanlike behavior)	4 to 8	5bd
b. Evaluative Assistant	Siri (Apple)	Adaptively uses information about an individual to help solve specific tasks	4 to 8	1a

Table 3 Dimensional Repurposing attribute of technical solution

Subattribute	Previous Use Venue	Previous Use Value Added	Difficulty	Depend
a. Spatial + Hybrid	Multiple (e.g., SmartMoney stock market map)	Ease of data visualization	1+	5abc
b. Reverse spatial	Visualized acoustic diagrams (EchoView; e.g., color represents target length)	Ease of data visualization	1+	5abc

Table 4 Object Malleability attribute of technical solution

Subattribute	Previous Use Venue	Previous Use Value Added	Difficulty	Depend
a. Grouping and Meta-objects	Interactive workflow construction and analysis (InforSense)	Data aggregation and integration facility	2 to 5	5abc
b. Interaction matrix (object v. object)	Physics simulations (NASA Ames)	Manageability of dynamic data	2 to 8	3a, 5abc

Table 5 Multiplayer Simulation attribute of technical solution

Subattribute	Previous Use Venue	Previous Use Value Added	Difficulty	Depend
a. Collaboration: multiple player-based data sources	Team-based case analysis (AMIT)	Pooling of information and conjecture	2 to 5 depending on number of users	5cd
b. Collaboration: crowd-sourcing	Funding (Kickstarter, medstrtr)	Multi-point (robust) dependency	2 to 8 depending on number of users	4a
c. Competition: leaderboards	Multiple (e.g., World of Warcraft, Kaggle)	Incentive for continued play and improvement	1 to 4	5d
d. Competition: red team v. blue team	Cyber defense sims (Breaking Point Systems)	Competition as model quality control	2+	5d

Table 6 Anatomy Infrastructure and Functionality attributes of technical solution

Subattribute	Previous Use Venue	Previous Use Value Added	Difficulty	Depend
a. Three dimensional models, static portion of data	Multiple (e.g., MineCraft)	Visual modeling basis	2 to 6	None
b. State changes, dynamic portion of data	Multiple (e.g., Sims)	Temporal modeling basis	2+	None
c. Layering and filtering	Map layering (ESRI ArcGIS ArcMap)	Rich geospatial representation	3 to 8	5ab
d. Simulation logging	Military scenario analysis (VT MAK)	Data capture and playback / branching fidelity	2 to 8 depending on granularity	5ab

Table 7 Business value of Artificial Intelligence attribute of technical solution

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
Patient-level, unit-level or hospital-level care simulations in response to simulated internal or external threats to performance. Training for more realistic interactions; disaster scenario modeling; interdependencies modeling.	Efficient resource management in high-risk, high-patient flow environments. Strategic planning use for 'what if' scenario testing.	Reputational advantages in marketing services to patients and clinicians. Objective quality and safety enhancements and improvements.	Realistic test environment in which not only technical inter-operability is simulated, but individual user and team behavior in the context in which device use is likely.

Table 8 Business value of Dimensional Repurposing attribute of technical solution

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
A relatively simple example is to incorporate performance objectives such as financial management into models. A simple example is to have model stack height represent some measure of investment capital allocated, costs incurred, or revenues generated.	For patient management, ability to pinpoint highest traffic choke points along care pathways such as ED to cath lab, OR to ICU, carparks to entry points. For physicians, ability to map 'hot spots' of hospital acquired infections within facilities.	For patients with multiple options for care in different ambulatory clinics, ability to view data on timeliness, time to next appointment across treatment site options. For nursing managers, ability to color code particular shifts of nurses as ones with higher preventable safety problems.	Ability to customize supplier-chosen attribute such as % staff in conformance with optimal device use (e.g. measured as proportion of staff times spent setting infusion pump within minimum and maximum time) and to quickly highlight and track this dimension across and within facility sites.
For better process control, allowing melding of spatial features and performance variables Network infrastructure and information flow where line color represents length of wiring, for example.	Capturing a time dimension (e.g. intervention timeliness, length of stay averages) using color added to spatial dimensions.	Capturing a complex measure of care coordination 'length' (e.g. number of handoffs) using color applied to a physical representation of a care pathway.	For a supplier whose device (e.g. an imaging tool) is impacted by throughput. Color coding throughput as a % of capacity and overlaying this on spatial representations of the imaging center within the facility, changing over times of the day and week.

Table 9 Business value of Dimensional Repurposing attribute of technical solution

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
Staff movement can be modeled either as groups of personnel together or as individuals separately. Similarly, physical facilities can be modeled as groups of rooms (i.e. Wards) or as individual objects (i.e. Rooms) in different data layers. Quality can be analysed across different staff grouping and routing strategies and mismatches identified.	Much sterilization of reusables proceeds in batch form. In such a visualization, all members of one cohort can be viewed as one meta-object. If needed, lower levels of aggregation can be visualized to identify surgical objects with longest cumulative cycle times or vintage.	Staff aggregates such as junior residents and vocational nurses can be modeled as interchangeable units of an aggregate. Alternatively, when required to be modeled as individuals with unique properties (e.g. cumulative on-time constrained by legal limits to shift time) this subsidiary view can be visualized.	Analogously, sets of devices powered using the same infrastructure can be modeled as one group and resulting individual performance inferred from simulated group performance.
Operational risk in terms of large-scale flu outbreaks requiring internal quarantining can be assessed by modeling the communicable disease area of effect.	The discharge process has taken on increasing importance given Medicare readmission rate penalties. Being able to track the connections between discharge planner, treating clinicians, pharmacy and outpatient schedulers via an interaction matrix would allow better discharge planning.	Right now, HCAHPS and other surveys link patient experience to 'nurse', 'doctors' and 'room' in a very generic sense. An interaction matrix-driven way of organizing the patient's exposures is to have a known and arbitrarily detailed set of interactions between patients and every other object or meta-object in the model.	There are clear advantages of defining interaction matrices for medical device objects, given their well-known proliferation in intensive care environments. Tracking these connections serves interoperability objectives, and by having existing schemata for the integration of such devices, would help to ensure plug-and-play objectives.

Table 10 Business value of Multiplayer Simulation attribute of technical solution

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
Equipment, staff and infrastructure data tagging to allow use in multiple models while protecting privacy, confidentiality (of users as well as underlying patients) and safeguarding business intelligence.	Quality and cost optimization via consensus on ICU design by stakeholders who directly use or interface the unit. Inputs from diverse staff roles (imaging specialists, janitorial staff) thus leveraged.	Addition of patient or patient advocate voice can enhance patient experience (and so improve HCAHPS scores tied to reimbursements). Addition of nurse and physician voice allows morale, burnout and churn improvements.	By incorporating continual user inputs on existing devices, manufacturer benefits from technical and subjective feedback with benefits to development and marketing.
Stepwise hospital process disaggregation into component tasks and then concatenation and evaluation during and after game play. A quality problem is analogized or directly and realistically modeled as a series of distinct tasks, objectives and constraints. By analyzing the game data logs, the most successful approaches are identified.	Admissions office seeking to redesign the forms, steps and process flows of patients, would seek to crowdsource these improvement suggestions from staff, clinicians and end-users with experience or ideas in this area.	In multi-hospital systems, the transplantation of best and better practices can be slow due to organizational inertia and poor intra-organizational learning. Facilitating crowdsourcing from different hospitals within the same system can overcome this learning deficit.	Currently, much surgical device development is done in concert with (and by) practicing surgeons. Deepening this model to collect user feedback systematically can serve as early alerts to adverse events (much as the Australian orthopedics registry spotted metal-on-metal problems before manufacturers here.
Given hierarchical units rolling up to higher level organizational units, a hospital is an obvious organization in which to motivate the achievement of institution-wide goals through friendly competition. Within a hospital, the achievement of HCAPHS-like patient experience survey results is a natural candidate for such leaderboard competition. Patient safety end goals and leading indicators, QI improvement suggestions, unit waste, absenteeism and presenteeism, provider	Within specialist units, greater homogeneity exists and thus more specialized objectives can be incented and competed on. Moving from leaderboard competition on hospital-acquired infections towards more nuanced measures reflecting decubitus ulcers, central line infections would harness the intrinsic motivations of specialist staff to ensure patient safety. Additionally allowing	Patient or patient relatives and friends represent potentially under-utilized sources of inputs that can be harnessed through natural competition. Making patients aware of their unit's participation in intra-organizational competitions can harness the end-user as a co-player. Numerous advantages here range from patient empowerment ("nothing without me", "nothing if not for me") to keeping it real ("is this really benefiting the patient") and surfacing previously unknown concerns or preferences (e.g. they may	Currently suppliers of specialist devices compete on abstract technical measures and cost-to-own models that may not reflect current and upcoming incentives faced by hospitals. If HCAPHS measures place importance on the quietness of the care environment, yet alarm fatigue plagues not only staff but also patients, then clearly suppliers are not perfectly aligned with hospital objectives. A generic part of hospital management processes is

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
own-vaccination are all reasonable corporate objectives to incent staff on.	competition based on leaderboards for solutions to posted problems (e.g. lung injury due to excessive ventilation pressures in respiratory distress patients) would harness specialist staff self-actualization motivations.	care less about abstract safety than visible cleanliness and quietness).	the balancing of overlapping and conflicting objectives in a balanced-score-card style approach. Making sure that suppliers and future procurement initiatives focus on competing on these dimensions is of clear value to hospitals and patients.
Similar to the above leaderboard advantages, hospitals have substantial discretion to create organizational units that could play internal red and blue teams. With appropriate safeguards, different services, different shifts or different units could directly compete in the simulation. Facing similar simulated challenges – e.g. a natural disaster with power and communications failures – these units could see which virtual ward fared better.	Sufficient published examples exist of best practices (e.g. the proven efficacy of chlorhexidine body washes in reducing hospital-acquired infections in the ICU) in the field. Allowing a hospital's ICU unit to play the part of a virtual opponent to a hypothetical best practice shop would ensure that performance thresholds aren't lowballed.	To some extent, communicable disease is a natural 'red' team, while patients and clinicians are the natural 'blue' team in such a model. Actively simulating an evolving ward-level infectious disease threat using modified real data could help to model different approaches to halting and controlling the spread of disease (e.g. incidence of hospital acquired infections) versus containment efforts (e.g. staff hand washing adherence).	Extending the infectious disease example to suppliers, a simulation gameplay can help suppliers of disinfectants spot ineffectiveness and inefficiencies in use (both under-use or over-use) based on patient flow and bedspace occupied.

Table 11 Business value of Anatomy Infrastructure/Functionality attribute of solution

Value added in example setting			
Hospital	**Hospital Functional Silo**	**Patient and End-user**	**Supplier, Manufacturer**
Hospitals may set internal service level standards for minimum service times and maximum wait times. To achieve these standards, modeling realistic staff and patient movement is required. Real-time modeling of such system attributes as patients are moved, for example, from wards to imaging facilities can balance both equipment throughput and patient wait times.	A simple example application is dynamic optimization of staff assignments to the emergency department due to temporary spikes in arrivals, or already present 'on diversion' status. Representing the dynamic impact of overflow and diversion on foregone revenues would be a realistic method to motivate short and longer-term changes in staffing and skill mixes.	Physicians in training are mandated to not be on duty for particular periods of time. Temporal abstraction of time-stamped data (e.g. doctor X entered a note in the system at time Y) and aggregating these time stamps into a more continuous measure of total time spent on duty would allow effective tracking of total shift hours worked, independent of self-reports or clock-in and clock-out times	Developers of closed loop medication control systems and electronic medical record developers have struggled to date to allow for time-indexing and thus the capability to calculate the cumulative dose of an administered drug over a day has often been lacking. Allowing temporal abstractions of dynamic data and simulating the impact of changes in staffing on the spacing of doses and cumulative dosage could prevent supra-therapeutic dosages.
The emergency department triage process is the confluence of important processes. Ambulance transfers, coronary care pathways, readmission/observations, inpatient admissions and treat-and-release phenomena originate here, and triage decisions affect all of these processes. Being able to simulate trainee nurses as they deal with simulated triage decisions and playing this back for real-time education would be one clear use.	Admission and registration points of contact are well-known choke points with long queue and service times. Simulating a run of patients and modeling different approaches to registering patients, then logging and playing back these different approaches for training purposes.	A clinician end-user will subconsciously undertake certain actions in a particular order or follow certain persistent behaviors for idiosyncratic reasons. Being able to monitor and analyze clinician gameplay may help to predict future real world user behavior. Changes in cognitive and technical abilities, changes in judgment or empathy as displayed in allow risk 'game' may signal serious issues.	Understanding how device manufacturers perceive priorities in high-intensity environments through logged gameplay