SUSTAINABLE INNOVATION
IN
EDUCATIONAL TECHNOLOGY

by

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ABSTRACT

This paper proposes to develop a framework for educational technology policy – ***sustainable innovation*** – to guide all aspects of decision-making. The concept of sustainable development, taken from environmental policy, serves as the overarching philosophy for this framework. The four analytical pillars of the framework use concepts from four major fields of technology and policy research: diffusion of innovations theory, operations research, risk assessment / failure analysis, and public goods economics. Sustainable innovation provides educational technology leaders with a comprehensive framework that can help reduce complexity, cope with technological change, integrate technology into educational practice, ameliorate system failures, and manage limited resources.

About this paper

Although written outside the context of a formal research project, some content relies on unfunded research conducted for the author's Master's thesis at the Technology and Policy Program at the Massachusetts Institute of Technology from 1994-96. Other concepts are abridged from established fields of research, and although not original, have not been systematically applied (to the knowledge of this author) to the field of educational technology. Written from the front lines of classroom, school, and district implementation, much of this paper represents a synthesis of accumulated learning and experience. Although an exhaustive literature review was not feasible, sources and useful references are provided in the bibliography.

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I. INTRODUCTION

As a leader in educational technology, do find yourself overwhelmed by complexity?

New technologies attack educators with so many choices, so many consequences both foreseen and unforeseen, so much information, so quickly. Sometimes, even attending a professional conference feels like walking into Dante's version of an ice-cream shop: 34,000,000 flavors to choose from. Data-driven decision-making, online assessments for No Child Left Behind, interactive smart boards, digital portfolios, standards-based report cards, webquests, weblogs, curriculum content-management systems, video-on-demand, handheld computers and PDAs…and those are just the session topics in the **first hour** of the Ohio SchoolNet conference!

Add to that the fundamental and growing challenges of educational technology: forecasting trends, integrating into the classroom, system failures, and exhausted resources. Left with a philosophical void, educational technology leaders are forced to fight fires in reaction to one crisis after another. ***Sustainable Innovation*** enables decision-makers to understand and approach these challenges proactively. Adapted from environmental policy, the concept of sustainable development can help technology decision-makers interpret research, contextualize technology trends, design robust systems, and develop enduring policies for the future.

II. SUSTAINABLE DEVELOPMENT

Sustainable development is a concept in environmental policy that has a long history with United Nations' efforts to address environmental protection, economic development, and social equity. Briefly, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[1] In an environmental context, sustainable development is characterized by many traits including an emphasis on the welfare of the neediest, respect for diversity (both cultural and ecological), grass-roots participation, multi-lateral cooperation among stakeholders, and rigorous scientific analysis.[2]

In a broader context, however, the concept of sustainable development has been applied to a wide variety of policy fields. The concept has come to refer to any kind of practice or system that is sustainable, implying a balance between short term and long term needs and a trade-off between values of preservation and growth. Although ***sustainable innovation*** may dilute the original meaning of sustainable development, the philosophy provides a valuable perspective for educational technology leaders.

In this context, sustainable innovation refers to choices in educational technology policy and planning that moderate short term growth for the sake of long term sustainability. The foundation of this framework stands upon 4 analytical pillars: diffusion of innovations research, operations research, risk assessment and failure analysis, and public goods economics. Each field provides specific strategies for sustainable innovation in educational technology.

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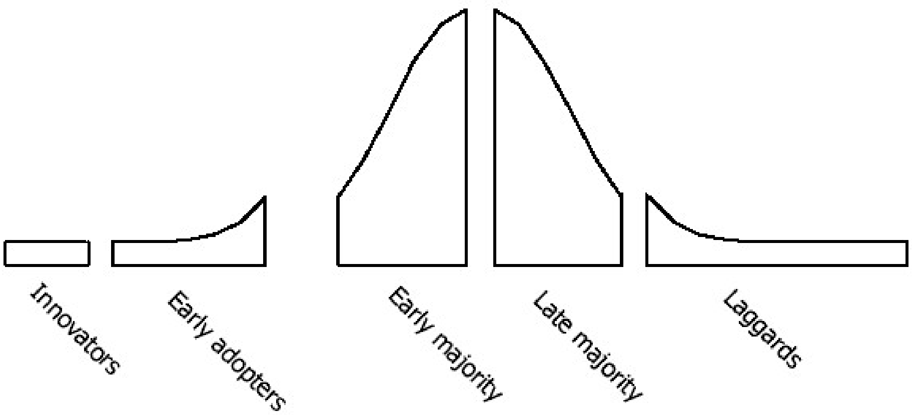
[1] Brundtland report
[2] CSD, p. 1.

III. DIFFUSION OF INNOVATIONS

One of the fundamental challenges of technology leadership in any domain, not just education, is the unpredictable pace and direction of technological change. However, extensive research in diffusion of innovations theory has developed some powerful tools for modeling of technological growth.

Individual Technology Selection

When an individual chooses to adopt an innovation, his/her behavior is often defined by how quickly (or slowly) s/he choose to adopt a new technology. When adopters in the market are plotted by time to adoption v. frequency of adopter type, it is commonly modeled by the familiar bell-shaped distribution:



[3]

Those on the leading edge of the technology adoption curve are in fact the small numbers of *innovators* and *early adopters* who embrace innovation quickly. At this point, production costs and prices are high, technology is not standardized, risk of market failure is high, and few people know about the technology or its benefits.

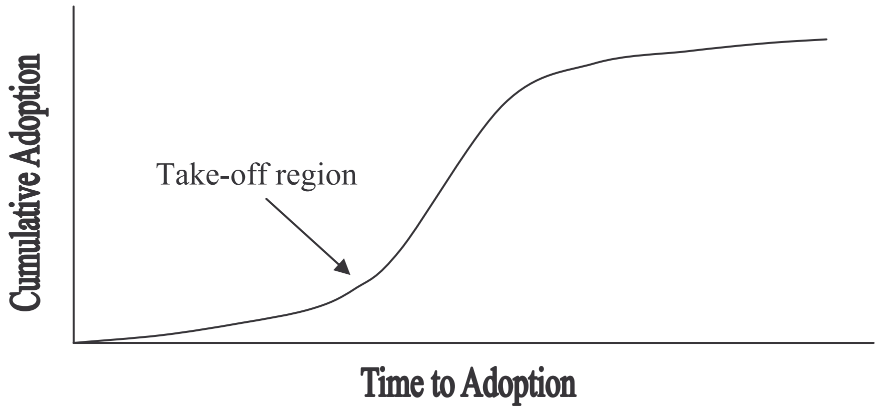
As the *early majority* joins the market, the increase in the number of adopters also increases the communication of the technology's benefits and in some cases directly increases the benefits themselves. For example, a peer-to-peer file-sharing technology like Napster or Kazaa becomes more useful as more people join the network. Those increasing benefits accelerate the adoption rate of the innovation, a phenomenon known as the *network* or *bandwagon effect*.

As the innovation spreads, industry standards develop, economies of scale lower the costs of production, and the technology even reaches the *laggards* in the market. Finally, towards the end of the life cycle of the technology, adoption rate declines towards a maintenance and replacement rate or towards zero as the technology becomes obsolete.

[3] OTA, p. 133

Aggregate Technology Adoption

Another way of understanding this same process is to plot by time to adoption v. cumulative rate of adoption, resulting in the S-shaped saturation curve:



[4]

Known as the Bass model and developed extensively by Everett Rogers, the saturation curve represents the cumulative results of a bell-shaped adoption model. Slow growth during the period of innovators and early adopters, pseudo-exponential growth as the bandwagon effect takes hold with the early and late majority, then slowing growth with the remaining laggards. As cumulative adoption levels out towards maintenance or obsolescence, the innovation is said to have *saturated the relevant market*.

Sustainable Innovation

Although successful technologies are mathematically predictable, there is a major problem in the model. The early stage of a successful technology looks exactly the same as the early stage of a failed technology: slow growth from innovators and early adopters. When deciding whether to adopt a new innovation, the growth curve is mathematically indeterminate; one cannot know for certain whether the technology will take off or whether sales will die out. Although survey research can estimate different factors in the Bass model to predict technology adoption, reliable data can be difficult to obtain.

Another problem is that a technology that does grow all the way to saturation may still only have a small *relevant market*. For example, a technology like video laserdiscs may have followed the Bass model, but only for a niche market - reaching saturation with relatively few people. Such a technology quickly becomes obsolete as a newer technology with a larger relevant market is introduced, like DVD.

Diffusion of innovations research, when applied to sustainable innovation, recommends a policy of waiting to adopt a new innovation until after it takes off in the market. Although that may be difficult to estimate, the take-off of a new technology is characterized by established industry standards, decreasing prices, multiplicity of vendors, and seemingly exponential growth in the number of users adopting the technology.

[4] UGA, Ad_SCurve.html

By contrast, if a school district positions itself on the leading edge of the technology adoption curve, it risks investment in high-cost, non-standardized systems for a niche market or, worse yet, systems that quickly become obsolete by the introduction of a competitive technology.

However, if a school district never pilots innovative technologies, or if all school districts wait to adopt a new technology, then the innovation process will inevitably fail. Therefore, just as districts should wait for proven and mature technologies to adopt for large-scale implementation, it is critical to leave room for innovation by facilitating pilot projects for new technologies. Similarly, district-level innovation requires government policy to invest in this form of educational innovation basic research: grants that reduce the risk of adopting unproven technologies and encourage innovation, NOT massive implementation programs that focus on saturation of an unproven technology.

Thus, diffusion of innovations research suggests specific strategies for sustainable innovation in educational technology:

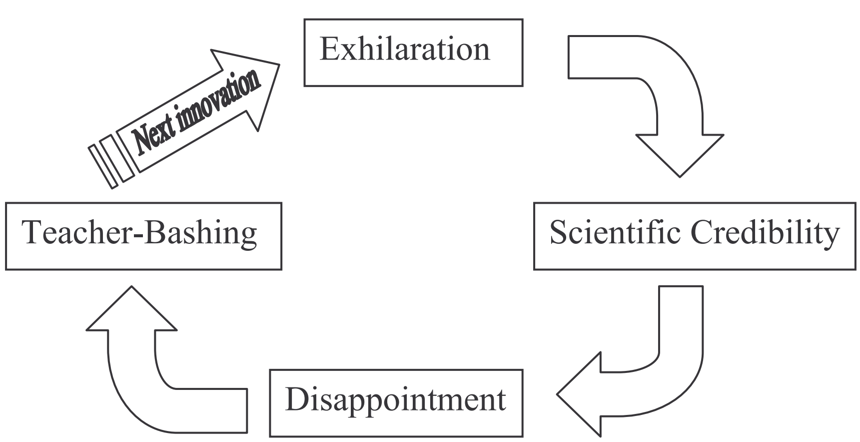
- Delay adoption of new technologies until after the take-off period in the market
- Adopt technologies with a large relevant market (not just a niche educational market)
- Adopt technologies with established industry standards
- Adopt technologies where multiple vendors compete on price
- Adopt technologies that manifest exponential growth in the number of users
- Leave room for innovation with small pilot projects
- Government policy that facilitates educational innovation as basic research

IV. OPERATIONS RESEARCH

Knowing whether and when to adopt a new technology is only the first step. Educational technology leaders next face the challenge of integrating that new technology throughout their organization. Operations research / management science has developed useful analytical tools for the implementation of innovations.

Implementation Process

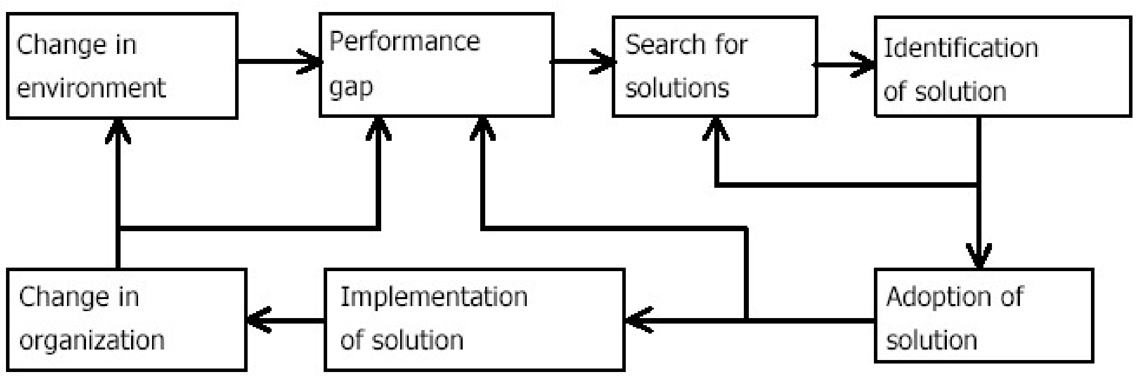
The traditional, simplistic understanding of innovations in education can be modeled as:



[5]

A new innovation generates excitement within the educational community and the public, preliminary research studies suggest genuine effectiveness, real-world application in schools and classrooms fail to meet expectations, leading to finger-pointing and blame (usually of teachers). The cycle then repeats itself with the next innovation.

That simplistic and admittedly negative model of educational innovation is actually a reflection of a complex innovation process:



[6]

The *adoption*, *implementation*, and *change in organization* stages of the innovation process can be grouped together as the organizational (as opposed to market) diffusion process – how an innovation spreads through an organization. Most theories focus on one factor – the network or *bandwagon effect* – as the most important factor. As more people adopt an innovation, they "infect" others throughout the organization with their knowledge, skills, and attitudes. Indeed, classical diffusion models are as applicable to infectious disease epidemiology as they are to diffusion of innovations, and *train-the-trainer* and *change agent* educational technology models are based on the this theory.

Implementation Factors

A more sophisticated set of factors has been developed from analyzing the historical cycle of educational technology, historical approaches to education reform, diffusion of innovations theory, cost modeling, and education policy research. Assigned to the various stages of the diffusion process, and identified as having a positive, negative, or indeterminate influence on the process.

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[5] Cuban, pp. 5-6
[6] Zaltman et. al., p. 5

Those implementation factors include:

	Diffusion Stages		
Factors	Adoption	Implementation	Organizational change
Educational Tech			
Incentives		+	
Staff development			+
Impact on teaching			+ / -
Education Reform			
Unique to education	+		
Non-economic	+		
Multiple uses			+
Scope of support	+	+	
	Diffusion Stages		
Factors (continued)	Adoption	Implementation	Organizational change
Diffusion Theory			
Efficiency	+		
Communicability	+	+	
Compatibility	+	+	+
Relative advantage	+		
Reversibility	+		
Divisibility	+		
Complexity	-	-	
Commitment	-		
Gatekeepers	-	-	
Point of origin	+ / -		
Terminality		+ / -	
Cost Modeling			
Ongoing costs			+ / -
Deploy computers		+	
Staged implement.		+	
Policy Research			
Leadership	+		

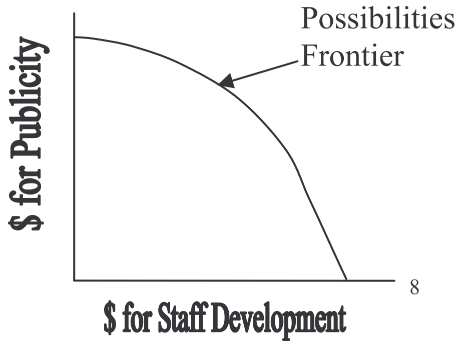
[7]

Brief definitions of these factors can be found in the Appendix. The key issue is that a one- or few-dimensional strategy to technology implementation provides an unreliable foundation for planning. For example, relying on a *train-the-trainer* system for developing teachers' technology skills presumes the successful adoption and implementation of an innovation, and fails to address other factors influencing organizational change, including *impact on teaching*, *compatibility* with organizational culture, and *ongoing costs*.

[7] Liu, p. 51 (ref. various sources)

Sustainable Innovation

In economic theory, a *possibilities frontier* describes a set of optimal solutions, consisting of several optimal combinations of factors rather than the maximization of a single factor. For example, rather than maximizing the amount of food produced, or maximizing the amount of clothing produced, there exists a possibilities frontier that defines the set of all optimal combinations of food and clothing in a given economy:



[8]

This concept of a possibilities frontier also applies to technology planning. Rather than allocating resources to maximize a single strategy, robust technology planning should spread resources across multiple strategies that address multiple factors for success.

For example, an *incentive* program alone (e.g. a laptop program that requires teachers to take technology training workshops) is a high stakes gamble on a single factor. A better strategy would also include teachers in the laptop selection process (expanding the *scope of support*), initially focus on the use of email (enhancing *communicability*), limit the tasks initially required to be performed with the laptop (reducing *complexity*), establish a deadline for teachers to join the program (leveraging *terminality*), and implement the program by building or grade level (*staging implementation*).

Thus, operations research in technology implementation suggests specific strategies for sustainable innovation:

- Plan for a cyclical implementation process, including all phases of innovation
- Spread resources across multiple implementation strategies
- Accept trade-offs among different strategies to optimize towards a possibilities frontier
- Pursue innovations that expand the entire possibilities frontier, not just a single factor

V. RISK ASSESSMENT / FAILURE ANALYSIS

Technology research and development relies on the fields of risk assessment and failure analysis, and educational technology leaders can benefit from both perspectives. Risk assessment is an analytical tool that defines the probability of possible outcomes to determine acceptable risks.[9] Failure analysis is a reverse engineering methodology that identifies the root cause of a systems

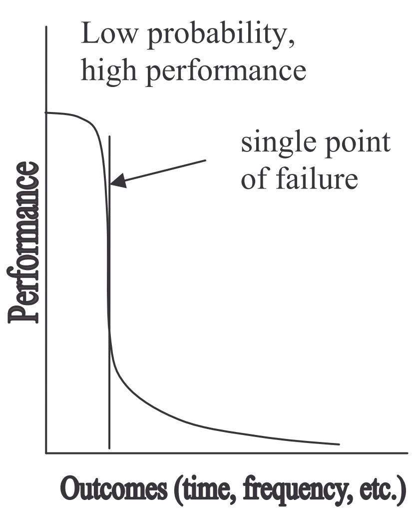
[8] Pindyck and Rubinfeld, p. 577.
[9] OEM DOE report

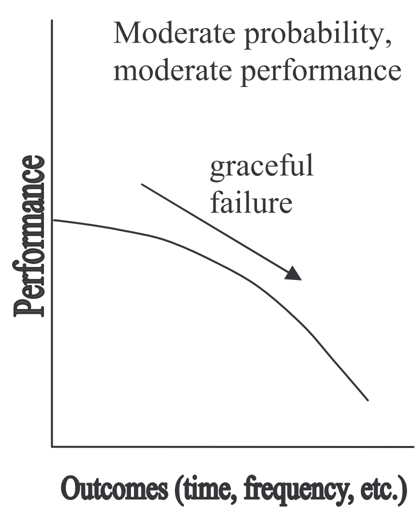
failure.[10] When applied to computers and networks, failure analysis is often defined in terms of fault tolerance, which seeks to eliminate *single points of failure*.[11] When combined, risk assessment and failure analysis contribute to the design of robust systems where one or a few problems do not result in a systems-wide failure. A system with such robust behavior is said to exhibit *graceful failure*.

When the concept of risk assessment is applied to educational technology, one defines performance not in terms of ideal conditions, but in terms of probabilities of different scenarios. For example, rather than defining server performance by processor speed and storage capacity, define performance by probabilities of downtime, access delays, lost data, etc. Risk assessment applies to individual components and to whole systems, so that risk can be reduced by more reliable components (server upgrades) and / or more robust systems (server redundancy).

When failure analysis is applied to educational technology, one examines system failures not just to restore service, but also to determine root causes. Failure analysis can help shift technology practices away from repetitively fixing a recurring problem (even in an automated way) towards preventing the problem from occurring. For example, rather than running an overnight script to re-standardize computer systems to a default image, failure analysis can help prevent virus penetration, incompatible software installations, and other incidents that require such repetitive re-imaging. Failure analysis applies to technical systems as well as human processes, so that failure can be prevented by improved technical design (better security) and / or improved personnel skills (user education).

All of these concepts, when applied to educational technology, emphasize a preference for moderate probability of acceptable performance over low probability of high performance. A low probability, high performance system may have a single point of failure and exhibits a steep risk profile. A moderate probability, moderate performance system has no single point of failure and has a shallow risk profile, exhibiting graceful failure.





[10] Pizzo, FailureAnaly.htm
[11] Kalinsky, OEG20020729S0030

Sustainable Innovation

Besides avoiding single points of failure (improved fault tolerance), graceful failure actually contains a more sophisticated underlying principle. Specifically, designing for graceful failure implies sacrificing performance for the sake of redundancy. For example, an organization that relies upon a single, highly-skilled individual to perform key technical tasks may enjoy high performance in that technical area until that single individual is no longer available. Similarly, concentrating data on a single, high-performance server may seem optimal under ideal conditions (peak performance). However, a more robust approach would be to train multiple staff and purchase multiple servers to provide redundancy (distributed systems), even if those staff are less-skilled and those servers are lower-performance.

In this way, the loss of a single technical expert does not result in a catastrophic organizational crisis; nor does the loss of a single server result in catastrophic loss of data. It is true that peak performance may be diminished because redundant communication among multiple units – whether staff members or servers – degrades efficiency. However, the risk profile is shallower and the system is more robust.

Finally, successfully designing for graceful failure will require systematic analysis not just of system failures, but of individual faults. For example, it is easier to identify server problems when all data resides on a single server. When that server fails, the need to address the problem is both urgent and obvious. However, for a redundant server system that fails gracefully, problems tend to be hidden. A single server may begin to develop performance issues (faults), but no one may notice those issues until the problems grow and spread sufficiently to bring down the entire system (failure). Thus, in designing for graceful failure, technology leaders must also systematically analyze non-catastrophic problems with individual components (fault analysis).

Thus, risk assessment and failure analysis suggest specific strategies for sustainable innovation:

- Redefine performance in terms of probabilities of performance levels
- Analyze system failures to identify root causes, not just to restore services
- Prevent problems through both technical design and human process improvements
- Accept trade-offs between performance and redundancy
- Eliminate single points of failure
- Define failure analysis to include non-catastrophic fault analysis

VI. ECONOMICS OF PUBLIC GOODS

In economic theory, a public good is essentially something that would not be provided by a free market, because a public good is nonrival and nonexclusive.[12] For example, clean air is a classic public good. For a given amount of clean air, there is no additional cost for one more person to breathe it (nonrival), nor can someone be prohibited from breathing it (nonexclusive).

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[12] Pindyck and Rubinfeld, p. 648.

Public goods suffer from several characteristics of market failure:

1. *Free-riders*: Because public goods are nonexclusive, people can enjoy the benefits without contributing to the cost of providing them.
2. *Market externality*: Because there is no direct relationship between supply and demand, price cannot be determined by market equilibrium and is often skewed.
3. *Tragedy of the commons*: Because there is no increase in price for increasing consumption, public goods become depleted. There is no incentive for consumers to reduce their consumption.

Public education fits the category of a public good. Generally, for a given number of classrooms and school buildings, there is very little additional cost for one more student (nonrival). Neither can one exclude a resident of a school district from enjoying the benefits of a public education, except in rare circumstances (nonexclusive). Unfortunately, this means that public education is subject to the same *free-rider*, *market externality*, and *tragedy of the commons* problems as other public goods.
Furthermore, technology in schools is itself a public good. Internet bandwidth, for example, is shared by all users and there is virtually no additional cost for adding one more user (nonrival). Nor is a new student generally denied access to the Internet (nonexclusive). Therefore, educational technologies like school Internet bandwidth tends to suffer from the same market failures as other public goods. Internet bandwidth used for educational purposes is also consumed for entertainment purposes (free-riders). Those who use a disproportionate share of Internet bandwidth do not generally face an increasing price as they consume more resources (market externality). Finally, available bandwidth tends to be depleted, as individuals continue to increase their usage until performance degrades for everyone (tragedy of the commons).

Finally, school technology planning often falls into the *tragedy of the commons* because technology is typically viewed as a one-time, up-front capital investment rather than an ongoing, operating cost. A common scenario in a school district might be:

1. Passage of a bond issue to fund technology
2. Political and fiscal incentives to deploy high performance systems
3. Expiration of support agreements, failure and obsolescence of equipment
4. Depletion of technical, financial, and human resources as ongoing costs grow

Sustainable Innovation

There are some common approaches to dealing with public goods such as clean air or education. Most commonly, a governing body uses *regulation* to manage public goods. It might consist of a policy (technical or human) that restricts video and audio streaming over the school's Internet connection. Far from being a reactionary restriction on freedom of information, regulation of this type of public good is often a necessary responsibility of educational leadership.

Another common approach is *marketization*, which attempts to restructure the environment so that market forces can work on behalf of the public interest.[13] No Child Left Behind is an

[13] Andrisani & Hakim.

example of marketization, where students are given the right to transfer out of a "failing school." Such competition for pupils is intended to pressure schools to improve. In educational technology, marketization might be a system that grants teachers a certain quota of computer lab time, which they could trade with one another for other educational benefits (access to smart board / projector systems or media center space or other resources). Such a market would allocate computer lab time to those teachers that value it the most, while other teachers would increase their access to resources they value more.

Thus, the public goods economics suggests several strategies for sustainable innovation in educational technology:

- Intentionally limit consumption of technology resources
- Plan for depletion of resources – it will never be "more than enough"
- Determine initial investments based on support for ongoing costs
- Accept regulation as a necessary responsibility
- Use marketization to help achieve efficient public good resource allocation

VII. CONCLUSION

Diffusion of innovations theory defines strategies for what technologies to adopt, and when to adopt them. Operations research defines strategies for how to integrate those technologies throughout the educational organization. Risk assessment and failure analysis define strategies for designing robust technology systems and allocating technology resources. Public goods economics defines strategies for regulating and marketizing such technology resources.

These abridged concepts bring powerful perspectives to the field of educational technology. Understanding the *relevant market* for an innovation and waiting for it to *take off*, allocating resources in terms of a *possibilities frontier*, designing for *graceful failure* and avoiding *single points of failure*, and managing technology resources as a public good with *regulation* or *marketization* are specific strategies that are grounded in research and applicable for educational technology leaders at all levels.

These perspectives combine together in a philosophy of ***sustainable innovation*** for educational technology that moderates short term growth for the sake of long term sustainability. This philosophy can guide educational technology leaders in implementing a policy-driven decision-making process that foresees and forestalls crises, plans for long-term growth, and forms organizational structures that are both flexible and standardized.

We can no longer afford to create technology departments, spend technology budgets, and implement technology systems based on instinct, vendor recommendations, and the latest 'innovative approach' flavor of the month. As educational technology leaders, we need a comprehensive framework for sophisticated policy analysis to guide our decision-making. *Sustainable innovation*, informed by diffusion of innovations theory, operations research, risk assessment, failure analysis, and economics, can guide decision-making in all aspects of technology policy and planning.

APPENDIX

Organizational diffusion of innovations: factor analysis definitions

Factors	Definitions
Educational Tech	
Incentives	Inducements or rewards for individuals to adopt innovation
Staff development	Education / training for individuals in use of innovation
Impact on teaching	How the innovation changes the teacher's role in the classroom
Education Reform	
Unique to education	Extent to which innovation was developed specifically for education
Non-economic	Benefits unaccounted for by economic cost / benefit analysis
Multiple uses	How innovation provides benefits in more than one domain
Scope of support	Breadth of constituency supporting the adoption of innovation
Diffusion Theory	
Efficiency	Innovation's impact on increasing production, decreasing costs
Communicability	Bandwagon effect: Ease of communication of info about innovation
Compatibility	Extent to which innovation is consistent with organization's values
Relative advantage	Superiority of innovation to other options
Reversibility	Ease of undoing adoption and implementation process
Divisibility	Ease of adopting / implementing innovation in modules
Complexity	Measure of adopter's difficulty in understanding innovation
Commitment	Resources organization must expend to adopt innovation
Gatekeepers	Number of organizational levels with access controlled by individuals
Point of origin	Political value attributed to source of innovation
Terminality	Deadlines, real or artificial, that force adoption decision
Cost Modeling	
Ongoing costs	Maintenance, replacement, staffing, etc. – operating costs
Deploy computers	Diffusion of computers throughout organization
Staged implement.	Ease of adopting / implementing innovation in stages
Policy Research	
Leadership	Political value attributed to source of adoption decision

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