A critical review of simulation-based mastery learning with translational outcomes

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OBJECTIVES This article has two objectives. Firstly, we critically review simulation-based mastery learning (SBML) research in medical education, evaluate its implementation and immediate results, and document measured downstream translational outcomes in terms of improved patient care practices, better patient outcomes and collateral effects. Secondly, we briefly address implementation science and its importance in the dissemination of innovations in medical education and health care.

METHODS This is a qualitative synthesis of SBML with translational (T) science research reports spanning a period of 7 years (2006–2013). We use the 'critical review' approach proposed by Norman and Eva to synthesise findings from 23 medical education studies that employ the mastery learning model and measure downstream translational outcomes.

RESULTS Research in SBML in medical education has addressed a range of interpersonal and technical skills. Measured outcomes have been achieved in educational laboratories (T1), and as improved patient care practices (T2), patient outcomes (T3) and collateral effects (T4).

CONCLUSIONS Simulation-based mastery learning in medical education can produce downstream results. Such results derive from integrated education and health services research programmes that are thematic, sustained and cumulative. The new discipline of implementation science holds promise to explain why medical education innovations are adopted slowly and how to accelerate innovation dissemination.

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INTRODUCTION

This article presents a critical review of simulation-based medical education research reports that use the mastery learning model to achieve translational outcomes. The goal is to demonstrate that medical education interventions embodied in simulation-based mastery learning (SBML) can produce measureable improvements in patient care practices, patient outcomes and patient safety.

Simulation-based education

Simulation-based medical education (SBME) involves 'devices, trained persons, lifelike virtual environments, and contrived social situations that mimic problems, events, or conditions that arise in professional encounters'.[1] The use of simulation in medical education has been traced to early 18th century France[2] and to other European doctors in the 19th century.[3] Medical simulations range widely in fidelity and realism from simple task trainers to manikins, multimedia computer systems[4] and standardised patients.[5] Simulations allow medical learners to practise clinical skills under safe, controlled, forgiving conditions, undergo formative assessment, and receive focused feedback with the goals of acquiring and maintaining clinical competence. Anaesthesiologist David Gaba argues: 'Simulation is a technique – not a technology – to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner.'[6]

Medical education research spanning at least four decades demonstrates that simulation technology, used under the right conditions (e.g. curriculum integration, deliberate practice, rigorous measurement, feedback, faculty staff preparation, organisational support) can have large and sustained effects on knowledge and skill acquisition and maintenance among medical learners. These outcomes have been documented in a series of review articles that use varied approaches to research synthesis, including narrative,[4] systematic with qualitative data synthesis,[1] critical-realist[7] and systematic with quantitative data synthesis (meta-analysis)[8,9] methods. Despite their methodological differences, these reviews all conclude that SBME is highly effective, especially in comparison with no-treatment (placebo) conditions[8] and traditional clinical education.[9] This scholarship has also revealed a dose–response relationship between the intensity of SBME interventions and learning outcomes.[7]

Mastery learning

Mastery learning has its origins in educational engineering. The key question is: How shall we design an educational environment that produces maximum learning outcomes among all trainees? The answer is to create and implement a set of educational conditions, a curriculum and assessment plan that yield high achievement among all learners.

Mastery learning in medical education is a stringent form of competency-based education.[10] It originates from early research in elementary, secondary and higher education dating from the early 1960s,[11–17] and once expressed as a mathematical model.[18] As stated elsewhere,[19,20] mastery learning has at least seven complementary features: (i) baseline or diagnostic assessment; (ii) clear learning objectives, sequenced as units in increasing difficulty; (iii) engagement in powerful and sustained educational activities (e.g. deliberate skills practice, data interpretation, reading) focused on reaching the objectives[21,22]; (iv) a fixed minimum passing standard (e.g. test score, checklist percentage) for each educational unit; (v) formative assessment with specific feedback to gauge unit completion at the minimum passing standard for mastery; (vi) advancement to the next educational unit given measured achievement at or above the mastery standard (summative assessment), and (vii) continued practice or study on an educational unit until the mastery standard is reached.

The goal in mastery learning is to ensure that all learners accomplish all educational objectives with little or no variation in outcome. The amount of time needed to reach mastery standards for a unit's educational objectives varies among learners.[19,20]

Most research to study the outcomes of the mastery learning model has been conducted in the settings of elementary and secondary education.[23,24] Results from rigorous research involving schoolchildren consistently show 'extremely positive student learning outcomes'.[23] Such work has been extended into higher education studies in which a moderate effect size has been achieved for mastery learning knowledge interventions compared with traditional classroom instruction.[25] Cook and colleagues recently published a systematic review and meta-analysis of mastery learning for health professionals using technology-enhanced simulation compared with any intervention or no intervention.[26] Results from this review show that 'mastery SBME was associated with large effects on skills (41 studies; effect size [ES] 1.29 [95% confidence interval, 1.08–1.50]) and

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moderate effects on patient outcomes (11 studies; ES 0.73 [95% CI, 0.36–1.10]).'[26]

Translational outcomes

Translational outcomes are educational effects measured at increasingly distal levels beginning in a classroom or medical simulation laboratory (T1) and moving downstream to improved and safer patient care practices (T2), better patient outcomes (T3)[27–30] and collateral educational effects (T4) such as cost savings, skill retention, and systemic educational and patient care improvements.[31,32] Similar ideas about translational outcomes have been expressed by Kalet *et al.*,[33] who describe educationally sensitive patient outcomes, such as patient activation and clinical microsystem activation, as key goals of medical education.

This article has two objectives. Firstly, it aims to critically review SBML research in medical education, evaluate its implementation and immediate results, and document measured downstream translational outcomes. Secondly, it aims to address implementation science, scholarship that aims to break down barriers to efficient and effective medical education and the provision of health care. The theme throughout the article is that continued reliance on historical methods of clinical medical education should be reduced and augmented by rigorous, evidence-based, mastery learning practices.[34] We conclude with a coda that addresses recent Accreditation Council for Graduate Medical Education (ACGME) policy statements about competency-based education, professional education milestones, and outcome assessment.

METHODS

This is a qualitative synthesis of mastery learning translational science (TS) research. The study addresses a focused question: What is the evidence that SBML outcomes achieved in the educational laboratory (T1) transfer to downstream patient care (T2), patient improvement (T3) and collateral (T4) outcomes? We critically review selected research reports that employ the mastery learning model in medical education and measure immediate and downstream translational outcomes. The review is deliberately selective and critical, rather than exhaustive. It relies on Norman and Eva's 'critical review' approach to literature synthesis[35,36] combined with the 'realist review' approach advanced by Pawson and colleagues.[37] Eva argues: 'A good educational research literature review… is one that presents a critical synthesis of a variety of literatures, identifies knowledge that is well established, highlights gaps in understanding, and provides some guidance regarding what remains to be understood. The result should give a new perspective of an old problem… The author… should feel bound by a moral code to try to represent the literature (and the various perspectives therein) fairly, but need not adopt a guise of absolute systematicity.'[36] Pawson *et al.*[37] agree by stating: '…the review question must be carefully articulated so as to prioritise which aspects of which interventions will be examined.'

The critical-realist approach to integrative scholarship[38] begins by defining the scope of the review, identifies a focused question and sets a clear purpose. Search terms are defined and a sampling strategy is formulated using a theory-based framework. However, unlike a systematic review (with or without meta-analysis), the intent of a critical-realist review is to collect, integrate and interpret results from the most compelling studies that satisfy the search terms and strategy. The search and written presentation need not be exhaustive. A critical-realist review judges the relevance and rigor of available research studies in terms of the theoretical framework. The goal is to summarise findings from different studies qualitatively, and to seek confirmatory and contradictory findings. A critical-realist review also attends to the contexts in which research studies reside in order to elucidate and explain what makes educational interventions work in a way that numbers alone cannot capture.[35–37]

We searched multiple databases (MEDLINE, EMBASE, PsycINFO, Web of Science) and also examined reference lists of widely cited papers and review articles from December 2012 to January 2013. Search terms included 'simulation-based education', 'simulation training in health care', 'mastery learning' and 'simulation-based mastery learning'. This approach yielded 3514 articles published between 1968 and 2013. Two reviewers independently reviewed the titles and abstracts of all retrieved articles. Articles were excluded if they were not written in English, did not involve education in the health professions, or did not use a form of simulation (including standardised patients, task trainers and full-body human patient simulators). Mastery learning was defined as an educational programme featuring all of the seven steps listed above. Interventions that did not include a step (e.g. absence of baseline testing, deliberate practice or formal summative assessment) were excluded for

failing to meet the definition of mastery learning. The full texts of articles that were not excluded based on abstracts (n = 66) were read by two reviewers. All disagreements were resolved by consensus. We identified 23 articles on SBML published from 2006 to 2013 that measured outcomes at least on the T1 level.

Several studies that did not explicitly state the term 'mastery learning' in the title or text were included. In these cases, descriptions of the type, intensity and quality of the educational intervention (e.g. 'demonstrating all critical steps flawlessly') as part of a comprehensive educational intervention were synonymous with the mastery learning model.

RESULTS

The mastery model has been used in medical education skill acquisition studies for a variety of clinical skills. Table S1 (online) summarises a selective review of research studies that employ the mastery learning model and also measure downstream TS outcomes.

The clinical skills addressed in these mastery learning studies range from interpersonal to technical and procedural skills, which account for a majority of the learning outcomes. The skills include management of intensive care unit (ICU) patients on ventilators,[39] and a variety of invasive and non-invasive medical procedures including thoracentesis,[40] lumbar puncture,[41,42] communicating with a chronically ill patient about goals of care (code status discussion),[39] cardiac auscultation,[43] advanced cardiac life support,[44–46] temporary haemodialysis catheter insertion,[47,48] paracentesis,[49,50] laparoscopic surgery[51–54] and central venous catheter insertion.[31,32,55–59] Table S1 also shows that mastery learning medical education outcomes have been measured at all four TS levels. Specific examples include improved procedural and communication skills measured in a simulated setting (T1),[39–41,44,47,49,51,52,55] and at the bedside (T2).[39,42,43,45,46,53,55,56] Several studies report the impact of SBML on patient outcomes that relate to a reduction in complications, and refer to a reduced hospital length of stay, fewer blood transfusions and fewer ICU admissions,[50] improved quality of surgical care,[54] and reduced catheter-associated bloodstream infections (T3).[57] Collateral effects (T4) are demonstrated by reduced health care costs[31] and impact on other trainees in the learning environment.[32] Finally, several studies show that SBML outcomes are largely robust to decay but may require booster training at set time intervals.[46,48,58,59]

An illustrative example of SBML in medical education is seen in a recent study by Barsuk *et al.*[41] that compared the acquisition of lumbar puncture (LP) skills in postgraduate year (PGY) 1 internal medicine (IM) residents' in a mastery learning curriculum with that of PGY-2, -3 and -4 neurology residents using traditional clinical education. Figure 1 shows that IM residents expressed wide variation in LP skills at baseline pre-testing using an LP simulator. However, after a minimum 3-hour education session featuring deliberate practice[21] and feedback, all IM residents met or surpassed a mastery standard for LP skills at post-test. By contrast, only two of the 36 (6%) traditionally trained PGY-2, -3 and -4 neurology residents from multiple training programmes met the passing standard using the LP simulator, although they had much more clinical experience in LP. The investigators also report that 42% of the traditionally trained neurology residents did not even specify routine laboratory tests for cerebrospinal fluid after the specimen was obtained. The research report concludes: 'Few [traditionally trained] neurology residents were competent to perform a simulated LP despite clinical experience with the procedure.'[41] An editorial that accompanied the publication of the LP research comments: 'The Barsuk *et al.* study is clearly a wake-up call for all of us who were trained in the era of "see one, do one, teach one" – the so-called "apprenticeship" model of clinical training. The old training methods are no longer enough to ensure the best education, and thus the best care for patients.'[60]

DISCUSSION

This critical review shows that SBML is a powerful educational model that improves clinical skills and has important downstream effects on health and society. This review also illustrates an important point about the documenting of TS outcomes from health professions education research. Translational science education outcomes cannot be achieved from single, isolated studies. Instead, TS results in medical education derive from integrated education and health services research programmes that are thematic, sustained and cumulative, as in the series of studies on central venous catheter insertion that produced results from T1 to T4 levels.[31,32,55–59] Such translational education research programmes must be carefully designed and executed to capture and reliably measure downstream results.[28,29] Use of

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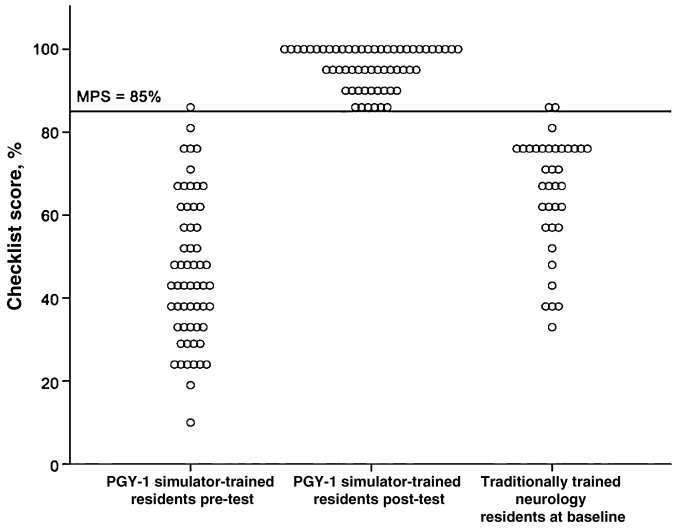

Figure 1 Clinical skills examination (checklist) pre- and final post-test performance of 58 simulator-trained first-year internal medicine residents and baseline performance of 36 traditionally trained neurology residents. Three internal medicine residents failed to meet the minimum passing score (MPS) at initial post-testing. PGY = postgraduate year. (From Barsuk *et al.*[41] Reprinted with permission of Wolters Kluwer Health)

the mastery model is one way for medical educators to contribute to today's rapidly changing health care environment. The studies reviewed here clearly show that SBML education research can improve health for individuals and populations. Ensuring a well-trained and competent workforce is likely to have additional far-ranging benefits, including better patient care practices and improved patient outcomes, that require further study.[29]

The findings of this selective, critical review of SBML present more details about the designs, measures, outcomes and translational qualities of its constituent studies than earlier systematic reviews of patient outcomes in SBME.[26,61] These two approaches to integrative scholarship are complementary but not identical. Variation in the definitions of search terms and the inclusion and exclusion criteria used to identify eligible studies is responsible for differences in the number and interpretation of research reports included in these reviews. Greater uniformity is likely to be achieved as terminology becomes standardised.

Mastery learning programmes in medical education do not occur in a vacuum. They operate successfully in a professional context that has personnel, material and institutional resources that advance the mastery learning agenda. An effective programme in one setting may not transfer to another organisation. Dissemination of innovations like SBML in health care is very difficult and is shaped by 'perceptions of the innovation, characteristics of the individuals who may adopt the change, and contextual and managerial factors within the organisation'.[62]

Implementation science addresses the mechanisms of education and health care delivery.[63,64] The aim of implementation science is to '[study] and seek to overcome health-care organisational silos and barriers, pockets of cultural inertia, professional hierarchies, and financial disincentives that reduce health-care efficiency and effectiveness'.[29] The slow adoption of mastery learning in medical education is a case study of implementation science. The intellectual foundation of mastery learning was established in 1963,[11] 5 decades ago, and subsequent incarnations within and outside medical education have occurred up to the present.[10,12–17] The educational and health care advantages of mastery learning are unequivocal.[19,20,28,29] However, educational inertia grounded in Osler's *natural method of teaching*, now known as the 'apprenticeship model' of clinical education, is a key reason why mastery learning is not yet prominent in medical education.[34] We encourage widespread adoption of the mastery learning model in medical education emphasising 'excellence for all' as habitual methods of clinical education are augmented by evidence-based competency approaches.

What will it take for health science education programmes to implement the mastery learning model to achieve TS goals? Table 1 identifies components of an SBME translational research programme that

incorporates mastery learning derived from an earlier report.[29] The components include: (i) health professions learners; (ii) educational resources; (iii) human resources, and (iv) institutional support. Table 1 identifies evidence in support of mastery learning programmes that is well established and points out gaps in understanding that warrant research attention. These gaps refer to the utility of SBML for acquiring team-based competencies, the attributes of skilful SBML instructors, the leadership needed to support SBML programmes, and many other issues. Medical educators who intend to adopt the mastery learning model in a local context should attend to these and other variables – institutional culture, history, inertia – as the programme is introduced.

This review is subject to several limitations that derive from the lack of reliable research data and that warrant attention as the field of SBML advances in medical education and becomes more refined.

The current review shows that SBML holds promise for fulfilling the goal of achieving TS outcomes, but does not yet provide definitive, airtight answers. Few medical mastery learning studies have achieved downstream results at the T2 (better patient care practices) and T3 (better patient outcomes) levels. Table S1 reveals that several research groups have reported T2 and T3 results for paediatric LP,[42] cardiac auscultation,[43] advanced cardiovascular life support,[45,46] temporary haemodialysis catheter insertion,[48] paracentesis,[50] laparoscopic surgery[53,54] and central venous catheter cannulation,[55–57] but much more research is needed. Translational T2 and T3 results are more likely to be achieved through educational and health services research programmes that are thematic, sustained and cumulative rather than in single, one-shot studies. Translational T4 outcomes (e.g. cost-effectiveness, collateral results) can be achieved when researchers design studies and measure outcomes that transcend educational and clinical variables and are alert to unintended research outcomes.

Translational educational outcomes have also been achieved by a medical education research programme that approximates SBML but does not report all mastery features explicitly (e.g. baseline assessment, minimum passing standard). An obstetric education research group in the UK has reported statistically and clinically significant reductions in infant birth complications (i.e. brachial palsy injury) caused by shoulder dystocia and neonatal brain injury from lack of oxygen during birth as a consequence of simulation-based training of individuals and teams.[65–67] These are all T3 outcomes. Research to identify the features of this educational intervention that produce good clinical outcomes among patients and to establish whether the features conform with the SBML model is required.

Education and health services research programmes that employ SBML and technology-enhanced simulation,[8,26] and that aim to achieve clinical outcomes in the health of individual patients or the wider public[26,33,61] must be crafted carefully, be rigorous and attend to such details as the unit of analysis (i.e. the learner or patient) issue in original health care research.[61] Quantitative and qualitative research programmes are needed not only to demonstrate that innovations like SBML produce intended results, but also to show how and why the results are achieved in different settings.[68]

The selection or creation of measures that yield reliable data that permit valid decisions to be made about the effects of educational interventions represents a persistent issue in medical education research. Most of the studies covered in this review used observational checklists as principal outcome measures and produced data with acceptable reliabilities. Although many of the checklists have a procedural focus, they also include items that involve communication skills (e.g. obtaining patient consent, verifying orders with health care team members), team leadership, ordering and interpreting laboratory tests, calculating and adjusting ventilator settings, attending to patient and family emotions, and many other cognitive, social and affective variables. On the horizon, haptic measures hold promise to provide reliable data that can be used to reach valid decisions about key health care variables.[69] The delivery of quality health care is very complex on technical, affective, social and professional grounds. The development of educational programmes and outcome measures that capture this richness is a constant challenge in medical education research.

Simulation-based mastery learning is beginning to produce strong and lasting educational effects when it is implemented, managed and evaluated with thought and rigor. We believe the mastery model, with or without simulation technology, holds great promise to help medical learners to acquire and maintain a broad array of technical, professional and interpersonal skills and competencies. Continued research is needed to endorse or refute this assertion.

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Table 1 Components of a simulation-based mastery learning translational education and research programme that incorporates mastery learning

Component	Evidence that is well established (examples)	Gaps in understanding What remains to be understood
Learners		
Health professionals in training: individuals and teams	The mastery model works with individual performance for individual tasks[40] and individual performance within teams[44]	Does the mastery learning model work for team-based competencies and can these have translational outcomes? Derive team-based metrics and mastery standards that are translatable to the clinical environment
Highly motivated	Learners who volunteer and consent for a study can significantly improve their skills and mastery outcomes[41]	What motivates learners: extrinsic versus intrinsic variables? Does participation in a study select high achievers? Do the role(s) of the study investigators or faculty staff affect motivation? Does evaluation apprehension impact performance? What is the motivation for faculty staff to educate learners to a mastery level?
Educational resources		
Training materials appropriate to learning objectives	There is a clear description of learning resources used in the study, such as rigorous measures that yield reliable data[55]	Are the outcomes dependent upon specific institutionally developed resources? Are these resources available with reasonable options for other institutions?
Trained faculty staff	The report states that faculty staff are trained and experienced in teaching with simulation[49]	What are the explicit experiences and skill set that make simulation instructors, not just those participating in a study who have additional motivation to succeed, effective? What are criteria that can generalise to other institutions?
Space	Education and evaluation are carried out in a protected location: skills centre or in situ[43]	What is the minimum and maximum space required? Does the learning environment need to be separate from the clinical environment? Separation is often facilitated during effectiveness studies, but is this true in general?
Training time	What is the average training time required for a skill set? What is the range across skill sets? How was the training time scheduled?[41]	How is training time negotiated? Is there explicit involvement with training programme leadership?
Educational funding to support the issues above	Funding support protects time for faculty, space and resources[45,46]	What are the ongoing costs of building and sustaining a mastery training programme? Beyond the one-time start-up capital costs, what is the cost of training learners to a mastery level? What is the evidence that mastery learning studies with funding are better rated?
Institutional senior leadership support	External leadership support for the programme increases the likelihood of success[57]	What is the minimum leadership support that is needed: curricular institutionalisation, funding support, faculty recognition and reward? Are there extrinsic drivers for the institution (e.g. accreditation, patient safety)?

Table 1 (Continued)

Component	Evidence that is well established (examples)	Gaps in understanding What remains to be understood
Human resources		
Scientist-leaders and staff	Functionally diverse research teams are more effective than homogeneous teams[75–77]	Is there an optimal formula for research team composition?
Institutional support		
Value and reinforce T1 SBME outcomes in situ	Institutional leadership supports and advances the goal of translational outcomes[56,57]	What are the critical components for an institution to adopt a translational outcomes training programme?
Advance science of health care delivery and patient safety	Institutional leadership sets an agenda for the advancement or improvement of health care quality outcomes and improved patient safety[56,57]	Can translational outcomes be achieved without full institutional support and culture change? What is the minimum level of change required to reach a 'tipping point'?
Patient records that contain reliable data	There is an explicit description of the electronic health care record (or paper) and how it was accessed to retrieve reliable data to evaluate translational outcomes[49]	What are the resources required (patient records) and what expertise is required to access them and to mine reliable and meaningful patient outcomes that are relevant to the training programme?

Coda

The ACGME[70] and medical education scholars[71] have called for new approaches to clinical education and an assessment-based focus on professional competencies, educational milestones and high achievement standards. This means that undergraduate clerkship directors, postgraduate residency and fellowship programme directors, and directors of continuing medical education programmes must rethink and reorganise educational offerings to remove passive clinical experiences and install rigorous educational practices. Simulation-based mastery learning coupled with rigorous formative and summative educational evaluation is an implicit feature of these arguments.[72] Medical educators across the continuum, from the directors of undergraduate basic science courses and clinical clerkships, to the directors of postgraduate residency programmes, medical school curriculum committees and academic deans, should endorse SBML as a new paradigm.

The fulfilment of this new clinical education paradigm will not be easy. Educational inertia, conventional thinking, financial disincentives and bondage to time-based educational schedules are barriers that must be breached before SBML can be adopted in medical education.[29] These barriers can be overcome. The scientific and translational outcome paradigm shift that SBML promises for medical education – time variation, uniform outcomes – is a revolutionary idea, a disruptive innovation, the time of which has come.[73] Simulation-based mastery learning coupled with technology-enabled assessment[74] will reduce our reliance on the apprenticeship model of clinical medical education. We cannot continue to educate 21st century doctors using 19th century technologies. Medical educators should endorse, implement and evaluate mastery learning programmes across the undergraduate, graduate and continuing medical education continuum.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Summary of a selective review of research studies that employ the mastery learning model and measure downstream translational science outcomes.

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