

eScholarship@UMassChan

Implementation and Preliminary Evaluation of an Entrepreneurship, Biomedical Innovation, and Design Pathway in a School of Medicine Curriculum [preprint]

Item Type	Preprint
Authors	Hafer, Nathaniel;Keenan, Christian;Deb, Anindita
Citation	Hafer N, Keenan C, Deb A. Implementation and Preliminary Evaluation of an Entrepreneurship, Biomedical Innovation, and Design Pathway in a School of Medicine Curriculum. Res Sq [Preprint]. 2024 Sep 11:rs.3.rs-4870777. doi: 10.21203/rs.3.rs-4870777/v1. PMID: 39315248; PMCID: PMC11419257.
DOI	10.21203/rs.3.rs-4870777/v1
Journal	Research square
Rights	This work is licensed under a Creative Commons Attribution 4.0 International License.
Download date	2025-01-24 05:56:16
Item License	http://creativecommons.org/licenses/by/4.0/
Link to Item	https://hdl.handle.net/20.500.14038/53899

Implementation and Preliminary Evaluation of an Entrepreneurship, Biomedical Innovation, and Design Pathway in a School of Medicine Curriculum

Nathaniel Hafer

nathaniel.hafer@umassmed.edu

University of Massachusetts Chan Medical School

Christian Keenan

University of Massachusetts Chan Medical School

Anindita Deb

University of Massachusetts Chan Medical School

Research Article

Keywords: I-Corps, Commercialization, Engineering, Entrepreneurship, Medical Education

Posted Date: September 11th, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-4870777/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background: New educational curricula are emerging to train physicians to practice healthcare in the 21st century. The University of Massachusetts Chan Medical School T.H. Chan School of Medicine (UMass Chan) implemented an MD curriculum redesign in the fall of 2022 that included seven educational pathways, including Entrepreneurship, Biomedical Innovation and Design. This pathway is modeled after the I-Corps curriculum with added material regarding engineering design. This manuscript describes this pathway curriculum and provides preliminary evaluation data and learning outcomes.

Methods: First-year (Class of 2027) and second-year (Class of 2026) pathway students were invited to participate in online surveys evaluating course material and their knowledge of course content. Course evaluations and self-assessments were performed on a 4 or 5 point Likert scale. The material assessment comprised of multiple-choice questions; some had four options while others had five. Simple means were calculated for each question of the self-assessment, and as an aggregate. A two-sample t-test was performed using those means to assess statistical significance. A distribution of correct and incorrect answers was generated between the pre and post survey results, and a chi-squared analysis was used to determine whether the two correct/incorrect distributions were significantly different.

Results: Initial results show that the program was well received, with 15/20 (75%) of first year students rating the experience as good or excellent and 8/10 (80%) of second year students rating the experience as good or excellent. Three lectures were provided during the Fall 2023 semester to 11 second-year students. Results of self-assessment of student comfort and understanding of engineering content significantly improved after delivery of these lectures. Objective student knowledge also significantly improved.

Conclusions: This new pathway curriculum at UMass Chan is designed to introduce students to the principles of innovation, entrepreneurship, and technology commercialization. An element of this pathway focused on basic engineering principles provided students with baseline understandings of biomedical design, human factors, and risk/hazard analysis. Despite small sample sizes, the results show improvements in student comfort with the material and knowledge. Novel curricula have the potential to transform medical education and prepare future physicians to practice healthcare in the 21st Century.

Background

Healthcare continues to undergo rapid change as technology and societal forces alter the way that we deliver and receive care. In response, new educational approaches have emerged to train the medical workforce. These approaches include active learning, including the use of technology for simulation, and greater emphasis on mobilizing students to learn and respond to community health needs [1]. One type of program that is becoming increasingly popular is focused on innovation and entrepreneurship. Core

curricula typically focus on a combination of scientific, business, regulatory, finance, and design topics designed to teach students how to successfully transfer knowledge into products and processes that benefit society. A growing literature describes the design, characteristics, and goals of these programs in the US, Europe, Japan, and China [2–6].

In August of 2022, the University of Massachusetts Chan Medical School T.H. Chan School of Medicine (UMass Chan) implemented a major curriculum change entitled the ‘Vista Curriculum.’ The goal was to develop a contemporary and innovative curriculum that promotes curiosity and inquiry, empowers learners and enables future physician leaders to equitably and expertly care for diverse patient populations. All students in this new MD curriculum participate in a ‘pathway’ that provides foundational training in team-based project work and critical thinking combined with pathway-specific knowledge. This pathway-specific training serves as the foundation of a faculty-mentored longitudinal project that spans medical school [7]. Through interactive class sessions and outside research, students complete a group Pathways Longitudinal Project (PLP) throughout their four years of medical school. The PLP is a longitudinal team-driven project with required participation by all students in Vista pathways. These projects may be new initiatives or may build upon existing initiatives that have demonstrated value to UMass Chan. Through the PLP, students strive to make a longitudinal and sustainable impact on patients, the health system, community, or global population. The seven pathways include 1) Structural Inequity, Advocacy and Justice; 2) Entrepreneurship, Biomedical Innovation and Design; 3) Clinical Care; 4) Clinical, Community and Translational Research; 5) Education; 6) Population, Community and Global Health; and 7) Health Systems Science.

Prior to 2022, the UMass Chan curriculum lacked any formalized curriculum surrounding design thinking, product commercialization, entrepreneurship, or engineering analysis. Many peer institutions have developed design thinking and innovation curricula similar to the UMass Chan pathways model. These peer institutions have various differences, but all include a focus on innovation and new product design. Other topics that are included in many of the peer institution’s options, but are not common to all of them, include: leadership, entrepreneurship, health systems science, and medical technology engineering. [8–18] Given that UMass Chan has its own unique resources, curricular needs, and required competencies for its students, creation of a unique pathway was necessary to properly meet all the needs of this institution.

The process for creating this Entrepreneurship, Biomedical Design, and Innovation pathway included adapting material from the National Science Foundation’s Innovation Corps (I-Corps) program as well as additional lectures about biomedical design, human factors design, and hazard analysis, which were identified as important concepts that are not part of the I-Corps curriculum. [19–22] While the I-Corps material covered entrepreneurship and business development aspects thoroughly, there was still a gap in content related to engineering analysis aspects.

Engineering analysis utilizes multiple sequential steps in the design and prototyping of a solution to any problem and is commonly taught in engineering school curricula and some business school curricula.

The focus of this project was to augment the I-Corps curriculum with facets of engineering analysis, by way of three additional lectures to the pathways students. The objectives related to engineering analysis included: 1) hazard analysis; 2) engineering design with focus on design inputs, design constraints, and systems-level design; 3) human factors design and how it is used in all steps of designing a solution; 4) assessment of students' understanding of the content.

This manuscript describes the Entrepreneurship, Biomedical Innovation and Design pathway curriculum and provides preliminary evaluation data and learning outcomes. The lessons learned from these data are informing further adjustments to the content and learning objectives of this pathway.

Methods

Participants described in this manuscript are members of the UMass Chan School of Medicine Class of 2026 (11 students) and 2027 (21 students) in the Entrepreneurship, Biomedical Design, and Innovation pathway. The UMass Chan Institutional Review Board (IRB) determined that the survey questionnaires used in this manuscript are not human subjects research, therefore a Clinical Trial Number is not applicable.

Course Evaluation

Students were sent a link inviting them to complete an electronic survey at the end of the fall and spring semesters hosted on the Online Access to Student Information and Scheduling (OASIS) platform. Students responded to questions on a 4-part Likert scale where 1 = poor, 2 = fair, 3 = good, 4 = excellent. Survey responses were anonymous. The UMass Chan Institutional Research, Evaluation, and Assessment group in the Office of Educational Affairs compiled and analyzed data, then provided reports to instructors.

Engineering Content Evaluation

Prior to the engineering course section, all second-year students in the pathway received a pre-assessment survey that included questions about their knowledge of course material. These questions established the students' baseline knowledge before the lectures were given. The survey was developed, approved by the pathway director (NH), and delivered prior to the first session.

All students received the same three lectures. One focused on hazard analysis, one focused on engineering design, and one focused on human factors analysis and design. Each lecture included a portion of the allotted time to using the skills just presented and apply them to each students' longitudinal project that is part of the pathway program.

After the third lecture concluded, the students received a post-assessment survey, comprised of the same questions as the pre-assessment. The post-assessment survey also included questions to assess

the students' perceptions on how the material was presented, how much material was presented, and any opportunities for improvement in the delivery of the curriculum.

The self-assessment questions asked students to rate their level of comfort and their perception of their understanding of the material on a 5-point Likert scale, where 1 was the lowest level of confidence/competence, and 5 was the highest. The material assessment comprised of multiple-choice questions; some had four options while others had five. Simple means were calculated for each question of the self-assessment, and as an aggregate. A two-sample t-test was performed using those means to assess statistical significance. For the material-based multiple-choice questions, the answers were labeled as either completely correct or incorrect. A distribution of correct and incorrect answers was generated between the pre and post survey results, and a chi-squared analysis was used to determine whether the two correct/incorrect distributions were significantly different.

Results

Entrepreneurship, Biomedical Design, and Innovation Pathway Description

This pathway gives students a hands-on customer discovery learning experience that teaches students how to successfully transfer knowledge into products and processes that benefit society. The commercialization and innovation content is adapted from the National Science Foundation's I-Corps program, the premiere federally-funded innovation and commercialization training in the U.S. Students learn the Business Model Canvas, with a focus on Customer Segments and Value Proposition. Additional content focuses on the patient's journey through the healthcare system, the U.S. healthcare ecosystem, and insurance, reimbursement, and payment models. Students also learn the customer discovery (interview) process to get the perspective of possible customers, partners, and competitors. This guides students in how to deal with the chaos and uncertainty of commercializing innovations and creating ventures. Interviews lead to real-world insights, assessing key components of the business model, and often lead to pivots or refinements. The course goals are to: 1) provide aspiring physician-entrepreneurs an experiential learning opportunity to help determine the commercial readiness of a technology; 2) connect students to the tools and resources needed to successfully commercialize technology; and 3) develop an understanding of the commercialization process, increasing the ability to lead and play an active role in advancing a technology. The curriculum for the first and second years of this pathway is found in Table 1.

Table 1
Curriculum for Entrepreneurship, Biomedical Design, and Innovation Pathway

Year 1	
Week	Content
1	I-Corps approach and Business Model Canvas (BMC) overview Identifying customer segments and value propositions
2	Customer Discovery
3	Customer Discovery simulation: interviewing patients and providers
4	Workflows and ecosystems in healthcare
5	Critical actions for life science companies
6	Regulatory vs economic adoption
7	Minimal viable product and intro to US healthcare reimbursement
Year 2	
1	Distribution channels
2	Customer relationships
3	Intro to Biomedical Design
4	Intro to hazard analysis
5	Intro to human factors analysis
6	Technology transfer and intellectual property
Summary of content presented over the first two years of the Entrepreneurship, Biomedical Design, and Innovation pathway. Each class is 2–3 hours and consists of student presentations about what they’ve learned from customer discovery and instructor presentations about the Business Model Canvas and product development.	

The course is designed to promote active learning. Each class includes an assignment to watch videos outside of class time that introduce elements of the Business Model Canvas and Customer Discovery. In-class time is dedicated to student presentations focused on lessons learned from customer interviews and didactic presentations that emphasize key parts of the class content. One session in the first year includes simulated customer interviews in the UMass Chan Simulation Center, where students practice their interview skills with standardized professionals playing the role of a clinician or patient.

Curriculum Evaluation

At the end of each semester students were invited to complete a pathway evaluation survey. Initial results show that the program was well received. 15/20 (75%) first year students in the Fall 2023 and 13/21 (62%) in the Spring 2024 rated the experience as good or excellent. 8/10 (80%) second year

students rated the experience as good or excellent in both Spring 2023 and Fall 2023. Students were also asked if the curriculum met their expectations. 16/20 (80%) first year students in the Fall 2023 and 13/21 (62%) in the Spring 2024 rated the experience as good or excellent. 8/10 (80%) second year students rated the experience as good or excellent in both Spring 2023 and Fall 2023. Full results are presented in Table 2.

Table 2

Student evaluation of the Entrepreneurship, Biomedical Design, and Innovation pathway curriculum

Question	1 = poor n (%)	2 = fair n (%)	3 = good n (%)	4 = excellent n (%)
Class of 2027 students, Fall 2023 (n = 20)				
Overall, how would you rate this pathways experience?	2 (10)	3 (15)	10 (50)	5 (25)
The pathways curriculum met my expectations	2 (10)	2 (10)	13 (65)	3 (15)
Class of 2027 students, Spring 2024 (n = 21)				
Overall, how would you rate this pathways experience?	2 (10)	6 (29)	6 (29)	7 (33)
The pathways curriculum met my expectations	2 (10)	6 (29)	7 (33)	6 (29)
Class of 2026 students, Fall 2022 (n = 42)				
Overall, how would you rate the quality of this pathways educator's curriculum delivery?	1 (2)	7 (17)	24 (57)	10 (24)
Instructor was effective in guiding my interests towards specific pathways content areas	1 (2)	6 (14)	28 (67)	7 (17)
Class of 2026 students, Spring 2023 (n = 11)				
Overall, how would you rate this pathways experience?	1 (9)	2 (18)	4 (36)	4 (36)
The pathways curriculum met my expectations	0 (0)	3 (27)	4 (36)	4 (36)
Class of 2026 students, Fall 2023 (n = 10)				
Overall, how would you rate this pathways experience?	0 (0)	2 (20)	2 (20)	6 (60)
The pathways curriculum met my expectations	0 (0)	2 (20)	3 (30)	5 (50)
At the end of the year students were invited to participate in a course survey where they were asked to rate questions according to a 4-point Likert scale where 1 = poor and 4 = excellent. Number of student responses = n, % of overall total in parentheses.				

Delivery and Preliminary Evaluation of Engineering Course Content

Three lectures were provided during the Fall 2023 semester to 11 second-year medical students in the Entrepreneurship, Biomedical Innovation, and Design pathway. Prior to the start of the lecture series, the pre-survey was distributed to all students in this cohort, of which nine filled out the survey. The three unique lectures were delivered weeks apart from one another, where two were delivered over Zoom and one was delivered in-person. The first lecture was entitled “Introduction to Biomedical Design” and was delivered over Zoom, the second lecture was entitled, “Hazard Analysis and Risk Management” and was delivered in-person, and the third lecture was entitled, “Human Factors Design” and was delivered over Zoom. After the three lectures were delivered, the post-survey was provided to the same 11-student cohort, of which nine students filled it out. A blank copy of the pre-survey is in Appendix 1 and a blank copy of the post-survey is in Appendix 2. The survey responses of the pre-survey are in Appendix 3 and the survey responses of the post-survey are in Appendix 4. The results of the questions where students reflected on their own sense of comfort and understanding are summarized in Table 3. The aggregate average of the students’ responses to each question was compiled along with a standard deviation. A two-sample t-test was performed to evaluate whether the differences between the pre-survey results and post-survey results for each question were statistically significant.

Table 3
Results of Self-Assessment of Comfort and Understanding of Engineering Curriculum.

#	Question	Pre-Test Average \pm SD (n = 9)	Post-Test Average \pm SD (n = 9)	t-test p-value
1	How well do you believe you understand engineering design principles?	2.22 \pm 1.39	4.00 \pm 0.50	0.001199*
2	How comfortable are you with engineering hazard analysis and associated risk management?	1.33 \pm 0.71	4.00 \pm 0.50	< 0.0001*
3	How comfortable are you with the engineering design process and generating inputs and outputs?	1.67 \pm 1.00	3.89 \pm 0.60	0.000016*
4	How comfortable are you with creating and using a decision-making matrix to help weigh options in a quantified manner?	1.67 \pm 1.12	3.89 \pm 0.60	0.000039*
5	How comfortable are you with utilizing human factors analysis in designing new technology?	1.56 \pm 0.73	4.22 \pm 0.67	< 0.00001*
<p>This table presents the average rating that students evaluated themselves before and after the lecture series. Students were presented the same prompts both times and were able to rate their understanding/comfort on a scale from 1 to 5, where 1 was little to no comfort or understanding of the material and 5 was very comfortable or high understanding of the material. Each question was evaluated for statistical differences using a two-sample t-test, with the associated p-values in the last column. The * is indicative of statistical significance as the p-value is less than $\alpha = 0.05$.</p>				

In the pre-survey and post-survey, the students were also asked questions about the content of the lectures, which were presented as multiple-choice questions. This was to assess their baseline knowledge and any changes that occurred after the lectures. The performance of the students on each question are presented in Table 4. The results were then analyzed by a Chi-Squared test to see if there was a statistically significant difference in the distribution of correct and incorrect answers before and after the lecture series was delivered. The associated p-value of < 0.0001 is less than the $\alpha = 0.05$, indicating a statistically significant difference in score distributions.

Table 4
Changes in student knowledge before and after delivery of the engineering course content.

#	Question	Correct Answer	Correct or Incorrect?	Pre-Test Count	Post-Test Count
1	The process of determining if design outputs reach the design input goals is called:	Verification	Correct	5	9
			Incorrect	4	0
2	The process of testing whether a device meets a users' needs and wants, even if it reaches all of the design input goals, is called:	Validation	Correct	6	7
			Incorrect	3	2
3	What are the three components to a problem statement	The problem, the affected population, and the harm	Correct	2	7
			Incorrect	7	2
4	Besides the hazard and harm, what is the third component for initial hazard analysis	The situation of use	Correct	2	8
			Incorrect	7	1
5	When assessing the impact of a hazard, what are the two most important factors for consideration?	Severity of damage and likelihood of damage	Correct	4	7
			Incorrect	5	2
			df	9	χ^2
					p-value
					< 0.0001
The table summarizes the number of correct and incorrect answers for each of the five knowledge assessment questions, before and after the lecture series occurred. The results were evaluated for a statistically significant difference using a Chi-Squared analysis, where the pre-test results were treated as the expected baseline. The associated p-value of < 0.0001 is less than the $\alpha = 0.05$, indicating a statistically significant difference in score distributions.					

The post-survey also included questions regarding the delivery and content of the lecture series. Students were asked to rate how much they agreed with various prompts and provide a rating of whether the amount of material delivered in each lecture was too much, too little, or just right. The results of these multiple-choice feedback questions are provided in Table 5. All respondents either agreed/strongly agreed with the statements, 'the lectures provided were clear and easy to follow', 'the lectures provided were helpful and can be applied to my project', and 'the lectures provided were helpful and can be applied to my career as a physician'. All 9 respondents felt that the lectures presented provided students with the right depth of understanding of the material.

Table 5
Post-Survey Feedback on Engineering Lecture Series.

#	Prompt	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	The lectures provided were clear and easy to follow	0	0	0	2	7
2	The lectures provided were helpful and can be applied to my project	0	0	0	4	5
3	The lectures provided were helpful and can be applied to my career as a physician	0	0	0	4	5
		Definitely not enough depth of material	Slightly not enough depth of material	Just Right	Slightly too much depth of material	Definitely too much depth of material
4	The lectures presented provided me with the right depth of understanding of the material	0	0	9	0	0
The table shows the results of the four multiple choice feedback questions that were answered as part of the post-survey.						

Lastly, the post-survey also provided optional free-text opportunities for students to provide their narrative feedback on aspects that they enjoyed, and aspects for improvement that they would like to see. Of the nine responses, three provided responses to these optional questions. While a few of the comments provided praise of the lectures and the corresponding lecturer, there were a few notable quotes. One student remarked, "These were incredibly helpful lectures for our projects especially for students, like myself, with no engineering experience." Another remarked, "I loved the stories you added in to make it funny and engaging. I wish there were more diagrams."

Discussion

Medical education is evolving in response to rapid changes in the healthcare system. This manuscript describes a new pathway curriculum designed to introduce students to the principles of innovation, entrepreneurship, and technology commercialization. While it is still too early to measure long term outcomes of student learning and career choices, initial feedback and evaluations suggest that student learning and acceptance of the program is high.

The engineering lecture series had the goal of increasing engineering analysis education in the medical school curriculum and delivering the content in a way that was engaging and led to educational benefits. Evaluation and student comments to date indicate that students enjoy the curriculum and appreciated its delivery. The results in Table 3 show that there was a noticeable increase in the students' levels of comfort and self-assessed understandings of the material, whereas the results in Table 4 and the associated chi-squared analysis show that students' knowledge of the material significantly improved after the three lectures. One limitation of these data are the small sample sizes, which are discussed in greater detail below. Student feedback from the lecture series suggests that the content was engaging applicable applicable to their projects and careers.

As mentioned above, the small sample size of 9 students completing the engineering content is a limitation. As additional student classes complete the program we will accumulate data related to learning metrics. The growth of the program from 11 students in the Class of 2026 to 21 students in the Class of 2027 is a positive trend. Regarding the results of Table 3 and the associated t-tests, the results were all statistically significant, however the sample size of 9 suggests that a normal distribution was not achieved. This small sample size does considerably decrease the power of the results and increases the chances for type II errors. However, type II errors occur when the results falsely fail to reject the null hypothesis, which in this case assumes that the lecture series does not change the students' self-reflected understandings and comfort with the curriculum. Given that the small sample size increases the chance of falsely failing to reject, and the results of the t-tests rejected the null hypothesis, it seems as though an educational significant outcome occurred. Regarding the chi-squared analysis (Table 4), this was used because the students' answers to the knowledge-based questions were labeled in a binary of correct or incorrect. With that in mind, the null hypothesis would be that the distribution of correct and incorrect answers would not be significantly different despite the lecture series. However, the small sample size does again impact the power of those results, so the results may not be as generalizable if they were applied to a larger audience. However, regardless of the sample size and statistical test, the trend is that more students answered correctly on the post-survey than the pre-survey, which is reassuring.

Conclusions

This new pathway curriculum at UMass Chan is designed to introduce students to the principles of innovation, entrepreneurship, and technology commercialization. An element of this pathway focused on basic engineering principles provided students with baseline understandings of biomedical design, human factors, and risk/hazard analysis. Despite small sample sizes impacting the power and generalizability of the results, the results show improvements in student comfort with the material, students' knowledge of the material, and their enjoyment and applicability of the curriculum. As additional cohorts move through the curriculum, our evaluation will continue to measure student satisfaction and learning outcomes. Another consideration for future study is the student population. This manuscript is solely focused on the students in the Entrepreneurship, Biomedical Design, and Innovation pathway. Additional work is planned to evaluation student perceptions and learning related to

the other six pathways offered by UMass Chan. A final consideration is to expand the engineering content. Seeing as engineering analysis is quite vast, three lectures certainly does not cover all the applicable content that students may need. Material that could be introduced includes prototyping, experimental design to test the prototype quality, and the FDA regulation of medical devices.

Abbreviations

UMass Chan, University of Massachusetts Chan Medical School T.H. Chan School of Medicine

PLP, Pathways Longitudinal Project

I-Corps, Innovation Corps

IRB, Institutional Review Board

OASIS, Online Access to Student Information and Scheduling

Declarations

Ethics approval and consent to participate – This work was determined to be not human subjects research by the UMass Chan IRB.

Consent for publication – Not applicable

Availability of data and materials - All data generated and analyzed during this study are included in this published article and its appendix information files.

Competing interests - The authors declare that they have no competing interests.

Funding – NH reports funding support from the National Institutes of Health grants UL1TR001453 and U54HL143541, and the National Science Foundation grant 2048498. The funding agencies had no role in the conceptualization, design, data collection, analysis, decision to publish, or preparation of the manuscript.

Authors' contributions - NH conception of the work, analysis of data; writing and editing the work; CK conception of the work, collection and analysis of data; writing and editing the work; AD analysis of data; writing and editing the work.

Acknowledgements – The authors would like to thank Adam Marowski and Pawel Chojnowski for their excellent work as Educational Program Specialists. The authors would also like to acknowledge the work of Susan Barrett and colleagues in the Institutional Research, Evaluation, & Assessment group in the Office of Educational Affairs, UMass Chan Medical School.

References

1. Han, ER., Yeo, S., Kim, MJ. et al. Medical education trends for future physicians in the era of advanced technology and artificial intelligence: an integrative review. *BMC Med Educ* 19, 460 (2019). <https://doi.org/10.1186/s12909-019-1891-5>
2. Niccum BA, Sarker A, Wolf SJ, Trowbridge MJ. Innovation and entrepreneurship programs in US medical education: a landscape review and thematic analysis. *Med Educ Online*. 2017;22(1):1360722. doi: 10.1080/10872981.2017.1360722. PMID: 28789602; PMCID: PMC5653943.
3. Arias J, Scott KW, Zaldivar JR, Trumbull DA, Sharma B, Allen K, Gravenstein N. Innovation-Oriented Medical School Curricula: Review of the Literature. *Cureus*. 2021 Oct 5;13(10):e18498. doi: 10.7759/cureus.18498. PMID: 34754659; PMCID: PMC8567699.
4. You, X., Wu, W. Assessing the impact of Medical Education's Innovation & Entrepreneurship Program in China. *BMC Med Educ* 24, 519 (2024). <https://doi.org/10.1186/s12909-024-05467-2>
5. Brady C, Zarb M. Non-traditional skills in undergraduate medical education - the development of a teaching programme. *Scott Med J*. 2018 Aug;63(3):80-81. doi: 10.1177/0036933018776837. Epub 2018 May 27. PMID: 29806541.
6. Nakao K, Umezu M, Iwasaki K. Biodesign program introduction in Japan: promotion of entrepreneurship and viewpoints of education on medical technology innovation. *J Artif Organs*. 2022 Dec;25(4):350-359. doi: 10.1007/s10047-022-01317-4. Epub 2022 Mar 3. PMID: 35239081; PMCID: PMC9643197.
7. UMass Chan Medical School Pathways Program, <https://www.umassmed.edu/oume/curriculum/Vista-Curriculum/parallel-curricular-programs/Worcester-track/> . Accessed July 12, 2024.
8. Distinction Tracks. College of Medicine – Tucson. <https://medicine.arizona.edu/education/md-program/distinction-tracks> . Accessed July 19, 2024.
9. MD programs: School of Medicine: School of Medicine: Case Western Reserve University. <https://case.edu/medicine/md/academics/pathways-programs> . Accessed July 19, 2024.
10. Paths of Excellence: Healthcare Innovation, University of Michigan Medical School. <https://medschool.umich.edu/programs-admissions/md-program/md-curriculum/impact-curriculum/paths-excellence/paths-excellence-healthcare-innovation> . Accessed July 19, 2024.
11. Jefferson Medical School. Scholarly inquiry tracks. <https://www.jefferson.edu/academics/colleges-schools-institutes/skmc/undergraduate-medical-education/curriculum/Scholarly-Inquiry/Scholarly-Inquiry-Tracks.html>. Accessed July 19, 2024.
12. University of Pennsylvania Medical School. MD program Areas of Concentration. <https://www.med.upenn.edu/student/areas-of-concentration.html> . Accessed July 19, 2024.
13. Innovation Medicine Program (IMED). Chicago Medicine. <https://chicago.medicine.uic.edu/education/md-curriculum/campus-specific-programs/innovation-medicine-imed/> . Accessed November 25, 2021.

14. Rutgers Health Robert Wood Johnson Medical School. Distinction Programs. https://rwjms.rutgers.edu/education/medical_education/distinction-programs/distinction-in-medical-innovation-and-entrepreneurship. Accessed November 25, 2021.
15. Stanford Medicine Scholarly Concentrations. <https://med.stanford.edu/md/student-research/scholarly-concentrations.html> . Accessed July 19, 2024.
16. Clinical practice innovation and entrepreneurship. George Washington School of Medicine and Health Sciences. <https://smhs.gwu.edu/oso/track-program/clinical-practice-innovation-and-entrepreneurship/lecture-series> . Accessed July 19, 2024.
17. Scholarly concentrations program. Medical Education Brown University. <https://education.med.brown.edu/scholarly-concentrations>. Accessed November 25, 2021.
18. Grailer JG 3rd, Alhallak K, Antes AL, Kinch MS, Woods L, Toker E, Garbutt JM. A Novel Innovation and Entrepreneurship (I&E) Training Program for Biomedical Research Trainees. *Acad Med*. 2022 Sep 1;97(9):1335-1340. doi: 10.1097/ACM.0000000000004716. Epub 2022 May 3. PMID: 35507454.
19. Blank S. We Have A Moral Obligation June 21, 2017. Available from: <https://steveblank.com/2017/06/21/a-moral-obligation/>, accessed February 5, 2023.
20. Osterwalder A, Pigneur Y. *Business Model Generation*. Hoboken, NJ: John Wiley & Sons; 2010.
21. National Science Foundation. I-Corps™ Curriculum and Resources 2017. Available from: <https://beta.nsf.gov/funding/initiatives/i-corps/webinars-resources>, accessed February 5, 2023.
22. Nearing K, Rainwater J, Neves S, Bhatti P, Conway B, Hafer N, Harter K, Kenyon N, McManus MM, McNeal DM, Morrato EH, Rajguru SM, Wasko M. I-Corps@NCATS trains clinical and translational science teams to accelerate translation of research innovations into practice. *J Clin Transl Sci*. 2020 Dec 7;5(1):e66. doi: 10.1017/cts.2020.561. PMID: 33948285; PMCID: PMC8057475.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Appendix.docx](#)