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ORIGINAL RESEARCH

Integrating Foundational Sciences in a Clinical Context in the Post-clerkship Curriculum

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Abstract

Purpose This study aims to design, implement, and launch courses that integrate foundational science learning and clinical application in a post-clerkship undergraduate medical school curriculum.

Method In academic year 2015–2016 (AY15–16), as part of a comprehensive curricular revision, Vanderbilt University School of Medicine (VUSM) formally implemented "Integrated Science Courses" (ISCs) that combined rigorous training in the foundational sciences with meaningful clinical experiences. These courses integrated foundational sciences that could be leveraged in the clinical environment, utilized a variety of instructional modalities, and included quantitative and qualitative (competency-based milestones) student assessments. Each ISC underwent a rigorous quality-improvement process that required input on foundational science content, student experience, and student performance assessment.

Results Eleven ISCs were delivered to 173 students in AY15–16, with some students taking more than one ISC. Immediately after completing each course, 93% ($n = 222$) of ISC enrollees completed a course evaluation. Students (91%; $n = 201$) "agreed" or "strongly agreed" that foundational science learning informed and enriched the clinical experiences. Furthermore, 94% ($n = 209$) of students thought that the clinical experiences informed and enriched the foundational science learning. Ninety-four percent of the students anticipated using the foundational science knowledge acquired in future clinical training and practice.

Conclusion The teaching of foundational sciences in the clinical workplace in the post-clerkship medical curriculum is challenging and resource intensive, yet feasible. Additional experience with the model will inform the mix of courses as well as the breadth and depth of foundational science instruction that is necessary to foster scientifically based clinical reasoning skills in each student.

Keywords Curriculum 2.0 · Integrated science courses · Foundational science

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Introduction

Practicing physicians face a multitude of challenges in providing high-quality care in a rapidly evolving healthcare environment. Physicians must function effectively on everyday tasks, but must also be equipped to address novel clinical and operational challenges [1, 2]. In his landmark report, Flexner argued that medical students needed to understand scientific principles in order to successfully adapt to the changing landscape of medicine [3]. There is increasing evidence that a deep understanding of complex foundational science[1] plays a crucial role in effective clinical decision-making [4–8]. Studies have shown that foundational science knowledge forms a cognitive framework that anchors clinical skills and provides a model of how the human body functions from the molecular level to the behavioral and social aspects of individuals and populations [9, 10]. Furthermore, the inclusion of basic science instruction enhances the ability to learn new information, relate new learning to past information, and demonstrate flexible problem-solving abilities [11]. These abilities are key skills of adaptive expertise and are thought to represent excellence in clinical performance [11–14].

It is clear that a physician's deep understanding of foundational science is essential for successful clinical decision-making; however, the timing and placement of foundational science instruction in the undergraduate medical curriculum has been debated. The traditional Flexnerian curriculum segregated the foundational (first 2 years) and clinical (next 2 years) sciences. However, more recently, it has been recognized that foundational science education should occur across the entire medical curriculum [8, 9, 15]. Of note, a 2010 Carnegie Foundation study indicated that opportunities for knowledge training later in medical school and throughout residency would strengthen connections between formal and experiential knowledge [15].

Evidence has suggested that, to be most effective, the teaching of foundational science should be integrated with clinical applications. Specifically, the integration should be focused on promoting conceptual, cognitive connections between domains [9, 10]. Just creating proximity between foundational science and clinical concepts may not guarantee cognitive integration [10]. Rather, studies have shown that purposeful teaching of foundational science, within a clinical context, promotes retention of foundational science knowledge [16]. In one study, students in an integrated curriculum outperformed traditionally trained students during early training, and in later training (including residency), these students remained superior to the traditionally trained students when it came to accurately diagnosing clinical presentations [17]. As a result, many medical schools have sought to better integrate foundational science and clinical application throughout the medical curriculum [8, 9, 15]. However, this integration has proved to be challenging [9].

In this manuscript, we describe a Vanderbilt University School of Medicine (VUSM) strategy for achieving foundational science integration in the post-clerkship curriculum. In 2014, we created and launched 11 Integrated Science Courses (ISCs), designed specifically to deepen third- and fourth-year students' foundational science knowledge within a meaningful clinical context. Rather than simply creating proximity between basic and clinical sciences, these courses aimed to achieve cognitive conceptual links between foundational and clinical sciences by making explicit and specific connections between the two domains [9, 10].

Methods

Curricular integration of the ISCs occurred at three levels: program (curricular framework that organizes all formal learning activities at VUSM), course (individual ISCs that focus on specific topics), and session (the day-to-day course activities) [18].

Program Level

VUSM Curriculum 2.0 [19] was designed to prepare students to successfully practice in the dynamic health-care systems of this century. We took a "spiral approach" with longitudinal integration of foundational science learning [20]. Curriculum 2.0 is divided into three phases: Foundations of Medical Knowledge (year 1), Foundations of Clinical Care, which includes the core clinical clerkships (year 2), and the Immersion Phase (years 3 and 4) (Fig. 1). The 2-year, post-clerkship Immersion Phase is intended to provide a rigorous and highly individualized learning experience by allowing students to select from a menu of courses based on individual preferences, career goals, and competency achievement. Immersion Phase courses include: ISCs, Advanced Clinical Experiences, Acting Internships, a Research Immersion, and Advanced Electives (Figs. 1 and 2). Whereas Advanced Elective are more "classroom" based and Advanced Clinical Experiences and Acting Internships are more "workplace" based," the ISCs are designed to combine both "classroom" and "workplace" learning (Fig. 2). Furthermore, Advanced Clinical Experiences and Acting Internships reflect rigorous learning of primarily a single discipline, whereas the ISCs and Advanced Electives have the flexibility to align with one or multiple disciplines (Fig. 2). This course menu is designed to ensure that all students, independent of their specific course selections, meet the goals of the Immersion Phase and fulfill

[1] At VUSM, foundational sciences are broadly defined to encompass the knowledge and skills that form the foundation of clinical practice; it focuses on the "why" of patient care rather than the "what" or "how" (i.e., clinical decision making). Foundational science includes basic science, population and system science, sociological and psychological science, and where appropriate, humanities (e.g., medical ethics). The emphasis is on origins, composition, purpose, mechanisms, interactions, and consequences.

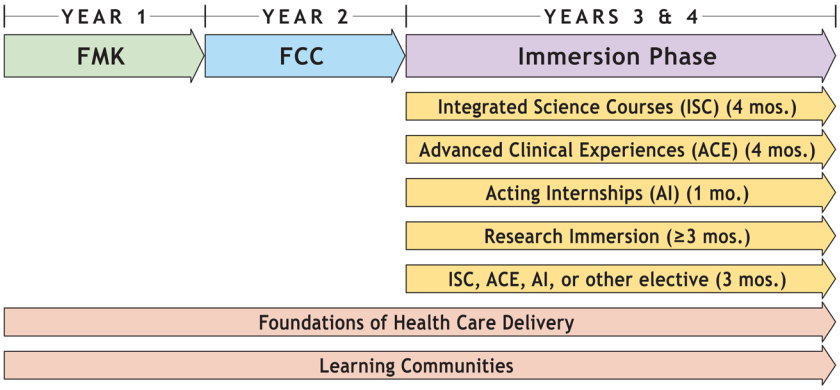

Fig. 1 The Immersion Phase is a highly individualized medical student experience. Curriculum 2.0 is composed of three phases: Foundations of Medical Knowledge (FMK, year 1), Foundations of Clinical Care (FCC, year 2), and the Immersion Phase (IP, years 3 and 4). There are four main types of courses in the Immersion Phase: Advanced Electives (AEs), Advanced Clinical Experiences (ACEs), Acting Internships (AIs), Integrated Science Courses (ISCs), and a Research Immersion (RI). Students in the Immersion Phase select from a menu of courses but are required to take at least four ISCs, four ACEs, one AI, 3 months of RI, and three additional formal courses that may include these or other course types (such as a research experience), over the course of the Immersion Phase. The total months required is shown in parentheses. Foundations of Health Care Delivery and Learning Communities are two longitudinal courses that span the entire curriculum

Curriculum 2.0 graduation requirements. The goals of the Immersion Phase are to deepen foundational science knowledge during meaningful clinical engagement, solidify clinical skills, enhance practice-based learning skills, ensure readiness for the intern role and residency, expand knowledge and skills regarding scholarship, enhance leadership skills, and encourage professional development (https://medschool.vanderbilt.edu/ume/IP).

Course Level

The 11 ISCs are interdisciplinary courses designed to enhance foundational science knowledge in the context of meaningful clinical activities (Table 1; Online resource 1). Students in the Immersion Phase are required to take four of these 4-week modular ISCs before graduation. The focus is on learning relevant conceptual models and theoretical foundations that are translatable to different specialties and to new situations, diseases, or treatments. Foundational science learning is anchored in and reinforced by patient care experiences. The courses contextualize foundational science within disease processes to optimize the transfer of information [21]. The ISCs foster the use of prior knowledge to master and create new knowledge and skills, leveraging both horizontal and vertical integration of foundational sciences.

The selection of course topics was aided by literature reviews, faculty and student interviews, and reviews of first- and second-year curricula, with a focus on high impact disease processes. The foundational sciences covered include those reported by the 2010 International Association of Medical Science Educators (IAMSE) Flexner Revisited Study Group

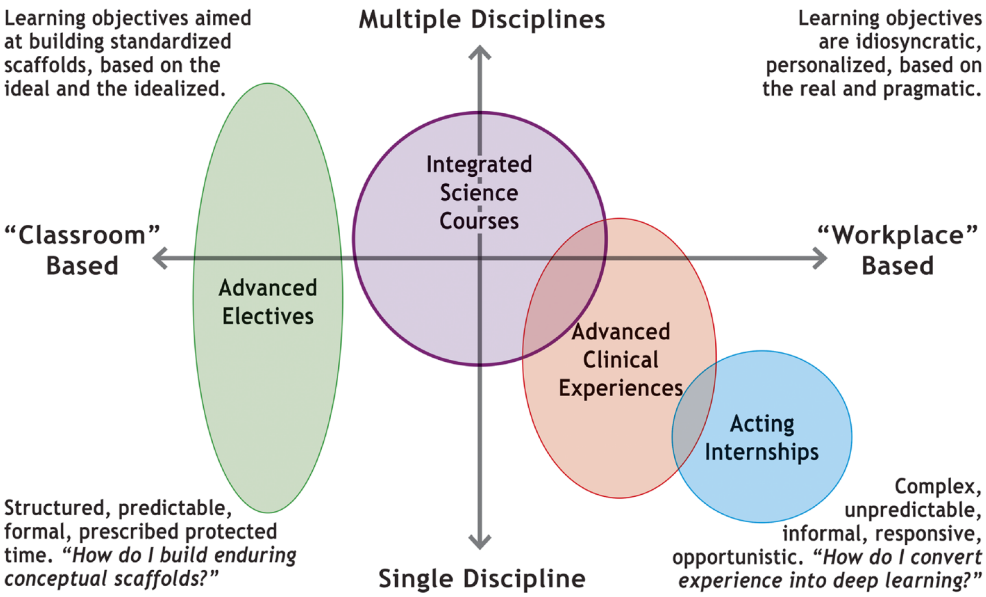

Fig. 2 Integrated Science Courses are at the Core of the Immersion Phase. ISCs can teach across multiple clinical disciplines or focus on a single one. Each ISC utilizes a variety of didactic and active learning formats, mixing classroom teaching with workplace (i.e., clinical) learning, to convey foundational science concepts that are translatable across different specialties and are applicable to new situations, diseases, or treatments. Assessment is rigorous, weighted toward the understanding of foundational sciences that underlie clinical care, and based on competency milestones

Table 1 ISCs offered in academic year 2015–2016

Course name	Capacity[a]	Enrollment[b]	Number of offerings[c]
Cardiovascular Diseases	16	16	2
Community Healthcare	24	21	3
Critical Illness	96	86	4
Diabetes	32	16	2
Getting Hooked: Addiction	32	12	4
Global Health	60	18	4
Immunity and Infections in the Immune-compromised Host	32	16	4
Injury, Repair, and Rehabilitation	32	13	4
Medical Imaging and Anatomy	32	27	4
Precision Cancer Medicine	24	14	2
The Skinny on Obesity	40	28	5

[a] Total student capacity in academic year 2015–2016

[b] Total number of students enrolled in the course in academic year 2015–2016

[c] Number of 4-week offerings of the course in academic year 2015–2016

as being critical to the foundation of medical practice [8]. As recommended by this Study Group, it was important for the foundational science topics selected, and decisions about the breadth and depth taught, be influenced by the biomedical research community, with guidance from the clinical practice fields [8]. Thus, most of the courses were co-directed by a scientist and a practicing clinician. During course conceptualization, ISC directors met with the Immersion Phase leadership and with seven Master Science Teachers (MSTs). The MSTs are PhD or MD/PhD faculty with diverse expertise across the basic sciences and extensive pre-clerkship educational experience. The MSTs assessed the basic science content of the ISCs and recommended basic science content that could be included in each course. Studies have shown that purposeful repetition within a clinical application context promotes retention of basic science knowledge [16]. Thus, in addition to introducing new core foundational science content, the courses also included foundational science previously learned during the first 2 years of the curriculum.

A framework for ISC student assessment that included both quantitative and qualitative components was developed by the Immersion Phase team to comply with the institutional assessment program and was implemented across all ISCs (Table 2). The assessment framework was aligned with each course's learning objectives and incorporated 11 of the VUSM milestones that were mapped to the six competency domains of the Accreditation Council for Graduate Medical Education (ACGME) [22–25]. For the ISCs, the Medical Knowledge domain was the primary assessment focus; however, student assessment in Patient Care, Interpersonal Communication, Practice-Based Learning and Improvement, Systems-Based Practice, and Professionalism was also emphasized. Grades in ISCs were Honors, High Pass, Pass, or Fail. The levels of "threshold," "target," and "reach," for each competency domain, were designated by the VUSM Standing Assessment Committee. Threshold is defined as the minimal performance that learners should achieve at the current training level. Target is defined as the expected average behavior of learners

Table 2 ISC student assessment framework

Final grade	Quantitative score	Summative competency ratings (qualitative score)*
Risk of failure (course director discretion)	< 70%	Any sub-threshold or > 2 thresholds
Pass	At least 70%	No more than 2 thresholds
		All others at target or above
High pass	At least 80%	At least 3 reaches
		All others at target
Honors	At least 90%	Nothing below target
		5 reaches

*The levels of "threshold," "target," and "reach" for each competency was designated by the Standing Assessment Committee at VUSM

at this point in their medical education. Reach is defined as student performance that exceeds behaviors expected of learners at the current stage of training.

All ISCs underwent a quality improvement review to identify strengths and weaknesses and to develop improvement plans. The review included input in three major domains: (1) foundational science learning and integration, (2) medical student satisfaction, and (3) student assessment (Fig. 3).

Foundational Science Learning and Integration

Foundational science content, delivery, assessment, and integration were evaluated by two groups of accomplished faculty with expertise in either the basic or population health sciences, respectively—the MSTs and Population Health Science Reviewers (HSRs). These experts comprehensively reviewed all course materials (including PowerPoint slides, reading materials, quizzes and exams, and assessment rubrics) and generated reports based on their impressions.

Medical Student Satisfaction

Student focus groups were held after the first offering of each ISC to garner feedback regarding the course topic, organization, and assessment. Using rapid cycle improvement, members of the student curriculum committee and VUSM education leaders held bimonthly sessions to discuss course strengths and concerns, which were then communicated to the Immersion Phase Leadership Team and the appropriate ISC directors.

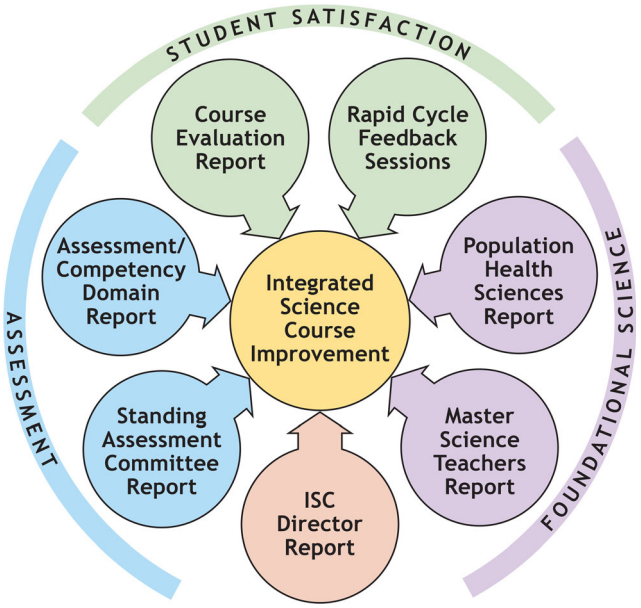

Fig. 3 ISC quality improvement process. Each ISC is subject to a quality improvement process that includes input from three major domains: (1) foundational science learning and integration, (2) medical student satisfaction, and (3) student assessment. Feedback was garnered from multiple sources as indicated. The data were discussed at an annual course consultation meeting, which was used to prioritize areas for course improvement during the next academic year

In addition to rapid cycle feedback sessions, we collated the results of secure, anonymous, and standardized 26-question post-course surveys completed by all students who took an ISC over the course of the year (Online resource 2). Electronic surveys were sent to students immediately after the completion of each ISC, with a request to complete the survey within a 2-week period. The data from the course surveys were compiled into a Course Evaluation Report.

Student Assessment

A rigorous evaluation of each ISC's approach to student assessment was conducted by two members of the VUSM Standing Assessment Committee (SAC), utilizing a checklist of best practices for assessment that included requirements set by the Liaison Committee on Medical Education (LCME). Furthermore, an aggregate report was generated that specified the final grade and competency domain assessment distributions across the learners in each course. These data were used to analyze the number of milestone assessments captured for each course, the milestone assessment standings, and the final grade trends.

At the end of the academic year, course directors were asked to complete a report that outlined their impressions regarding course strengths and weaknesses, rapid cycle changes made, planned improvements for the next academic year, and any requests to the Immersion Phase leadership team and VUSM for assistance in making the quality improvements. Data from these three evaluative activities were synthesized and then shared and discussed with the course directors at a comprehensive course consultation meeting. A summary of the results and consultative discussion were written and reported to the course directors and Undergraduate Medical Education Committee (UMEC), which is responsible for the quality of the curriculum and compliance with LCME requirements.

Session Level

The ISCs were designed to provide an exceptional learning experience. They used a variety of curricular strategies and clinical settings and addressed a wide spectrum of foundational sciences (Online resource 1). Students spent about 50 h/week in ISC-related activities, including face-to-face classroom learning, clinical experiences, reading, online modules, completion of assignments, and self-directed learning. The courses employed multiple modes of instruction, with an emphasis on experiential and active learning. Students were challenged to leverage previously learned or novel basic science concepts to solve clinical problems. To promote curriculum innovation, we intentionally allowed each ISC to develop "organically" under the leadership of content experts, guided by general ISC expectations and after formal training in

curriculum design and content delivery. As a result, individual ISCs developed innovative instructional methodologies, approaches to integrate foundational science learning with clinical experiences, and strategies to assess foundational science knowledge acquisition.

An example of one of these ISCs is the "Precision Cancer Medicine" course, which was initially offered in September and February of academic year 2015–2016 (AY15–16). The three course co-directors were a basic scientist with expertise in cancer biology, a medical oncologist, and a surgical oncologist. Course activities included seminars, online modules, case-based learning, team-based learning, self-directed learning, clinical experiences, and weekly tumor board meetings. A typical weekly schedule is provided in Table 3. To help align clinical experiences with student interests, students selected from a variety of clinical specialties for a total of 16 one-half days over the 4 weeks. Each student had to choose one longitudinal primary clinic (medical, pediatric, radiation, or surgical oncology) and one secondary clinic (hereditary cancer, pathology, interventional radiology, interventional pulmonology, or cardio-oncology). For the longitudinal clinics, students were matched with one preceptor for the duration of the 4 weeks. In the course, students were challenged to integrate foundational science within their unique clinical experiences. Integration was facilitated by answering weekly essay questions that required students to describe how the application of novel or previously learned foundational science principles drives clinical decision-making in the context of their oncology clinical experiences. Answers were shared and discussed with the class to promote cross-disciplinary learning and peer teaching. Furthermore, case- and team-based learning activities included reading of the primary literature and application of newly acquired foundational science knowledge to clinical scenarios.

Results

Eleven ISCs were launched in the first full implementation of the Immersion Phase in AY15–16. A list of the courses, course capacity, enrollment, and number of offerings is provided in Table 1. Most courses ($n = 7$) had two course directors with a range of one to three directors. ISCs are described more fully in Online resource 1, which delineates the foundational sciences, clinical settings, and sample curricular elements for each course. In the initial full rollout during AY15–16, 80 (78% of the class) third-year and 93 (89% of the class) fourth-year medical students enrolled in at least one of the eleven ISCs offered, with a range of one to four ISCs taken per student and nearly half ($n = 81$) completing more than one ISC. The courses with the largest total enrollment were Critical Illness ($n = 86$), the Skinny on Obesity ($n = 28$), and Medical Imaging and Anatomy ($n = 27$).

Table 3 Example schedule of the "precision cancer medicine" ISC from week 1

	Monday	Tuesday	Wednesday	Thursday	Friday
7:30 AM–12 PM	Course introduction "Meet the expert" seminar: cancer epidemiology Self-directed learning	Hematology/oncology clinic[b]	Melanoma tumor board[b] Case-based learning activity 1 Online module 1–3 review	Hematology/oncology clinic[b]	Self-directed learning
1 PM–5 PM	No mandatory ISC activities[a]	No mandatory ISC activities[a]	Interventional oncology clinic[b]	Hematology/oncology clinic[b]	TBL1: oncogene addiction "Meet the expert" seminar: inherited cancer susceptibility

[a] Longitudinal curricular elements preclude mandatory ISC activities on Monday and Tuesday afternoons

[b] Patient-centered clinical experiences (shaded) are embedded in the course

Of the 239 course evaluation surveys (Online resource 2) sent to enrolled students between July 2015 and April 2016, 93% (n = 222) were completed (complete rating data are provided in Online resource 3). Students were required to complete the survey no later than 2 weeks after the end of each course. Students rated the courses highly for the overall learning experiences (mean of 4.59 ± 0.08 on 1–5 scale, with 5 being the best), clinical relevance (4.66 ± 0.07), and mix of learning activities to support objectives (4.63 ± 0.08). Students felt that courses motivated them to continue learning about the course topic (4.63 ± 0.08) and contributed to their professional development (4.69 ± 0.08). They also felt strongly that participation in the ISCs helped them to learn relevant foundational sciences (4.51 ± 0.08) and anticipated using this knowledge in their future training and practice (4.56 ± 0.09).

Importantly, students rated the relationship between foundational science and clinical experiences highly (Table 4). The majority of students "agreed" or "strongly agreed" that foundational science learning was embedded in the clinical experiences (93%; 4.44 ± 0.18), foundational science learning informed and enriched the clinical experiences (91%; 4.43 ± 0.2), clinical relevance was provided during non-clinical foundational science learning activities (93%; 4.51 ± 0.16), and the clinical experiences informed and enriched the foundational science learning (94%; 4.51 ± 0.16) (Table 4). Representative student comments included, "This was hands down the best class I've taken in my life," "Fantastic integration of basic science with clinical medicine," "Emphasis was appropriately placed on foundational concepts initially and then extended to clinical applications," and "Dr. X did a phenomenal job balancing our clinical duties with the science portion of the ISC."

Student ISC evaluations also elucidated opportunities for course improvements, the majority of which focused on assessment, an issue that is curriculum wide. Lower scores were received for clarity of performance expectations with regard to the grading process (4.19 ± 0.11) and provision of feedback (4.19 ± 0.10) (Online resource 3). Narrative comments reflected lower student satisfaction with the assessment processes. Representative comments are as follows, "I feel immersion courses may be graded very differently from each other" and "Lack of clarity in grading procedures…unsure of the value of peer feedback on performance, as some peers may be more or less harsh than others." These assessment issues relate to the overall assessment system and are not specific to the ISC format. VUSM continues to refine this innovative competency-based approach. As much as possible, issues specific to individual courses were addressed at the ISC course consultation meeting in AY15–16 and improved in subsequent course iterations in AY16–17.

Discussion

In AY15–16, VUSM launched a menu of challenging, modular courses that successfully integrated foundational science during meaningful clinical engagements for third- and fourth-year medical students (Table 1; Online resource 1). Results and feedback from the comprehensive course review process, student course evaluations, and course registration led us to critically evaluate our processes and to implement changes.

Evaluation Process

The evaluation process for AY15–16, described above, identified opportunities for further improvement. Although the multidisciplinary comprehensive course reviews were labor intensive, they provided valuable feedback and guidance for future course iterations. In response, ISC directors have continued to refine their courses' foundational science content

Table 4 ISC evaluation outcomes—foundational science learning

When considering this course's clinical experiences and your learning of the relevant foundational sciences, how would you characterize the relationship:	No. of student responses					Mean (95% CI)*
	Strongly disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly agree (5)	
Foundational science learning was embedded in the clinical experiences	0	3	11	92	115	4.44 (4.35–4.53)
The foundational science learning informed and enriched the clinical experiences	0	6	14	79	122	4.43 (4.33–4.53)
Clinical relevance was provided during non-clinical foundational science learning activities	0	1	13	79	128	4.51 (4.43–4.59)
The clinical experiences informed and enriched the foundational science learning	0	2	10	83	126	4.51 (4.43–4.59)

*The mean score from all 11 courses are presented for each evaluation question with 95% confidence interval (CI) shown in parentheses. Results are based on 222 medical student responses and a 5-point Likert scale, with 5 being the best

and delivery, make the clinical experiences more relevant, and make student assessment more rigorous and transparent. We expect to refine our ongoing curricular quality improvement process and extend it to other Immersion Phase courses to assure that we continue to meet the needs of medical school graduates in the rapidly evolving landscape of healthcare in the twenty-first century.

Experience Standardization

Results from students' course evaluations guided the Immersion Phase team to focus on standardizing assessment strategies across the ISCs (Online resource 3). Although we developed an assessment framework to be used by all ISCs, students perceived that assessment was variable between courses and sometimes within a single course. During the clinical experiences, students received milestone assessments from faculty and residents across the Medical Center as well as at community and international sites. We currently are investigating the variability of faculty responses to these milestone assessments. In addition, we are considering ways to standardize commonly used assessment rubrics across all ISCs. To enhance the overall quality of assessment, the Immersion Phase leadership is providing level-setting faculty development, and faculty are being instructed to supply multiple assessment points across each course. Students have been provided with a mobile-enabled application that allows solicitation of assessment directly after a clinical encounter from the clinical faculty or staff who is most able to assess their individual performance.

Each ISC utilized unique settings and constraints to integrate and assess foundational science learning within available clinical experiences (Online resource 1). In the spring of 2016, a daylong retreat was hosted for all ISC Directors to share their innovations and discuss common challenges. As a result, best practices were shared and courses began to migrate, where appropriate, toward a more standardized "product" without stifling innovation or uniqueness. We also have monthly ISC director meetings at which best practices are shared and refined. The goal of improved ISC quality and effectiveness continue to be fostered through monthly Course Director meetings and subsequent annual course consultations.

Demand and Enrollment

The menu of ISCs, and their content, will continue to be refined on the basis of ongoing evaluation of the core foundational sciences required of graduating medical students. Furthermore, the timing and frequency of ISC offerings will be modified to meet student demand and enrollment. Across the 11 ISCs launched in AY15–16, there were 392 available slots for third- and fourth-year student enrollment, and 70% (n = 274) of the slots were filled. Many of the courses had waitlists while others did not fill in some months they were offered. The months of highest ISC demand were September, October, February, and March. No courses were offered in the months of July and December as students were known to have conflicts. To broaden the scope of offerings and meet enrollment demands, we launched four new ISCs: "Infectious Diseases" and "Sexual Medicine" in AY16–17 and "Emergency Care: Cell to System Science" and "Healthy Aging and Quality Dying" in AY17–18. The addition of these four courses resulted in an ISC capacity increase to 486 in AY17–18. Currently, the majority of courses are offered in the highest demand months mentioned above.

Additional experience with the Immersion Phase model is needed to determine the appropriate mix of courses required of each student. The breadth and depth of foundational sciences may change as we consider what graduating medical students will need to know and be expected to do as they embark on careers across the full range of medical specialties. We are currently creating in-depth curriculum and concept maps to address any gaps in the Immersion Phase. Furthermore, because students are selecting these courses from a menu, we are interested in understanding their motivation to enroll in certain ISCs over others. We aspire to evaluate the impact of this educational innovation on our graduates' ability to integrate evolving scientific knowledge into practice throughout their careers.

Resources

The ISCs are resource intensive. In addition to appreciable faculty contact time to teach the foundational sciences, we are constrained in our offerings by sufficient access of the ISC students to meaningful clinical experiences. Some early course offerings received lower evaluation scores for their clinical component because the students felt they were shadowing rather than participating in patient care. Teaching foundational science in the clinical environment is challenging, requiring supervising clinicians to have the time and the knowledge to teach during patient care. This has proved more challenging for some courses and domains than others. As such, we encourage our course directors to bring the "clinic to the classroom" to ensure that foundational science is integrated in the clinical scenarios. Furthermore, there are opportunities for us to provide physician faculty development to help them teach foundational science at the depth that is expected. These activities can then be evaluated by our quality improvement team to ensure high-level integration.

In summary, the development of Integrated Science Courses at VUSM demonstrate how teams of foundational science and clinical domain experts can successfully collaborate to design and execute modular courses that integrate foundational science knowledge with clinically meaningful engagements during the post-clerkship phase of an undergraduate medical curriculum.

Although designing and offering these courses was a daunting task, highly innovative courses emerged. ISCs covered a breadth of foundational science and clinical experiences that students found engaging. More importantly, students felt that they learned foundational science that would be used throughout their future medical training and practice. Future studies should investigate the impact of this type of curricular innovation on learning outcomes.

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Compliance with Ethical Standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Mylopoulos M, Regehr G. How student models of expertise and innovation impact the development of adaptive expertise in medicine. Med Educ. 2009;43(2):127–32. https://doi.org/10.1111/j.1365-2923.2008.03254.x.
2. Cutrer WB, Miller B, Pusic MV, Mejicano G, Mangrulkar RS, Gruppen LD, Hawkins RE, Skochelak SE, Moore DE, Jr. (2017) Fostering the development of master adaptive learners: a conceptual model to guide skill acquisition in medical education. Acad Med 92 (1):70–75. doi:https://doi.org/10.1097/ACM.0000000000001323.
3. Flexner A (1910) Medical education in the United States and Canada. A Report to the Carnegie Foundation for the Advancement of Teaching. Boston, MA.
4. Woods NN, Brooks LR, Norman GR. The value of basic science in clinical diagnosis: creating coherence among signs and symptoms. Med Educ. 2005;39(1):107–12. https://doi.org/10.1111/j.1365-2929.2004.02036.x.
5. Woods NN, Neville AJ, Levinson AJ, Howey EH, Oczkowski WJ, Norman GR. The value of basic science in clinical diagnosis. Acad Med. 2006;81(10 Suppl):S124–7. https://doi.org/10.1097/00001888-200610001-00031.
6. Woods NN. Science is fundamental: the role of biomedical knowledge in clinical reasoning. Med Educ. 2007;41(12):1173–7. https://doi.org/10.1111/j.1365-2923.2007.02911.x.
7. deBruin ABH, Schmidt HK, Rikers RM. The role of basic science knowledge and clinical knowledge in diagnostic reasoning: a structured equation modeling approach. Acad Med. 2005;80(8):765–73. https://doi.org/10.1097/00001888-200508000-00014.
8. Finnerty EP, Chauvin S, Bonaminio G, Andrews M, Carroll RG, Pangaro LN. Flexner revisited: the role and value of the basic sciences in medical education. Acad Med. 2010;85(2):349–55. https://doi.org/10.1097/ACM.0b013e3181c88b09.
9. Kulasegaram KM, Martimianakis MA, Mylopoulos M, Whitehead CR, Woods NN. Cognition before curriculum: rethinking the integration of basic science and clinical learning. Acad Med. 2013;88(10):1578–85. https://doi.org/10.1097/ACM.0b013e3182a45def.
10. Kulasegaram K, Manzone JC, Ku C, Skye A, Wadey V, Woods NN. Cause and effect: testing a mechanism and method for the cognitive integration of basic science. Acad Med. 2015;90(11 Suppl):S63–9. https://doi.org/10.1097/ACM.0000000000000896.
11. Mylopoulos M, Woods N. Preparing medical students for future learning using basic science instruction. Med Educ. 2014;48(7):667–73. https://doi.org/10.1111/medu.12426.
12. Bransford JD, Schwartz DL. Rethinking transfer: a simple proposal with multiple implications. Rev Res Educ. 1999;24:61–100.
13. Mylopoulos M, Lohfeld L, Norman GR, Dhaliwal G, Eva KW. Renowned physicians' perceptions of expert diagnostic practice. Acad Med. 2012;87(10):1413–7. https://doi.org/10.1097/ACM.0b013e31826735fc.
14. Mylopoulos M, Regehr G. Cognitive metaphors of expertise and knowledge: prospects and limitations for medical education. Med Educ. 2007;41(12):1159–65. https://doi.org/10.1111/j.1365-2923.2007.02912.x.
15. Cooke MI, Irby DM, O'Brien BC, Shulman LS. Educating physicians: a call for reform of medical school and residency: Jossey-Bass; 2010.
16. Ling Y, Swanson DB, Holtzman K, Bucak SD. Retention of basic science information by senior medical students. Acad Med. 2008;83(10 Suppl):S82–5. https://doi.org/10.1097/ACM.0b013e318183e2fc.
17. Schmidt HG, Machiels-Bongaerts M, Hermans H, ten Cate TJ, Venekamp R, Boshuizen HP. The development of diagnostic competence: comparison of a problem-based, an integrated, and a conventional medical curriculum. Acad Med. 1996;71(6):658–64. https://doi.org/10.1097/00001888-199606000-00021.
18. Goldman E, Schroth WS. Perspective: deconstructing integration: a framework for the rational application of integration as a guiding curricular strategy. Acad Med. 2012;87(6):729–34. https://doi.org/10.1097/ACM.0b013e318253cad4.
19. Vanderbilt University School of Medicine (2017) https://medschool.vanderbilt.edu/ume/curriculum-20.
20. Harden RM. What is a spiral curriculum? Med Teach. 1999;21(2):141–3. https://doi.org/10.1080/01421599979752.
21. Norman G. Teaching basic science to optimize transfer. Medical Teacher. 2009;31(9):807–11. https://doi.org/10.1080/01421590903049814.
22. Swing SR, Clyman SG, Holmboe ES, Williams RG. Advancing resident assessment in graduate medical education. J Grad Med Educ. 2009;1(2):278–86. https://doi.org/10.4300/JGME-D-09-00010.1.
23. Nasca TJ, Philibert I, Brigham T, Flynn TC. The next GME accreditation system—rationale and benefits. N Engl J Med. 2012;366(11):1051–6. https://doi.org/10.1056/NEJMsr1200117.

24. Pettepher CC, Lomis KD, Osheroff N. From theory to practice: utilizing competency-based milestones to assess professional growth and development in the foundational science blocks of a pre-clerkship medical school curriculum. Medical Sci Educ. 2016;26(3):491–7. https://doi.org/10.1007/s40670-016-0262-7.

25. Lomis KD, Russell RG, Davidson MA, Fleming AE, Pettepher CC, Cutrer WB, et al. Competency milestones for medical students: design, implementation, and analysis at one medical school. Med Teach. 2017;39(5):494–504. https://doi.org/10.1080/0142159X.2017.1299924.