TechTrends (2019) 63:202–208
https://doi.org/10.1007/s11528-018-0352-z

ORIGINAL PAPER

Designing for Interdisciplinarity in Higher Education: Considerations for Instructional Designers

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Published online: 27 November 2018
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Abstract
Embedding interdisciplinarity into a higher educational curriculum allows students to develop competence in synthesizing and applying knowledge and skills from across multiple disciplines to address problems and find solutions that would not be possible if only a single disciplinary lens is used. This review of the literature focused on reviewing the state of interdisciplinarity, benefits and challenges of introducing interdisciplinary curriculum into a higher education environment, as well as strategies and models that could be used in designing an interdisciplinary curriculum. It provides a platform for instructional and curriculum designers for integration of interdisciplinary approaches into a curriculum design.

Keywords Cross-disciplinary · Design for interdisciplinarity · Higher education · Interdisciplinary · Multi-disciplinary · Transdisciplinary

Problems that exist in today's complex, globalized society "rarely arise within orderly disciplinary categories, and neither do their solutions" (Palmer 2001, p. vii). Yet many graduates are not ready to synthesize multiple disciplines without substantial preparation. Interdisciplinary learning environments can provide students with the necessary tools to tackle ill-structured problems. Interdisciplinary education refers to the integration of knowledge drawn from diverse disciplines to address problems that cannot be solved by a single disciplinary perspective (Bridle et al. 2013; Holley 2017; Repko 2008). Therefore, introducing interdisciplinarity into academic and professional curricula provides a framework for preparing learners to make connections between seemingly fragmented or isolated knowledge and to apply that knowledge to real-world problems (Holley 2017; Lyall and Meagher 2012; Styron 2013).

Interdisciplinarity is often viewed as a way to instill creativity, innovation, and synergy through collaboration, teamwork, application, and blurring of disciplinary boundaries (Haynes 2017). It is often seen as a desirable element of higher education (Cooper 2012), yet it is hard to implement in academic settings, since pedagogical supports are often lacking (Klein 2005). The goal of this paper is to explore the benefits of interdisciplinary education, the challenges associated with its implementation in higher education, and implications of these benefits and challenges for instructional and curriculum designers working in higher educational settings to implement interdisciplinary learning experiences.

Challenges of Disciplinarily

Discipline-based education has been at the heart of higher education for the better part of the 20th and 21st centuries, shaping boundaries for the experiences and education of students in terms of isolated subjects, concepts, models, and paradigms (Baker and Daumer 2015; Klein 2006). As Abbot (1988) noted, disciplinary scholarship focuses on building abstractions rather than solving specific problems. This approach is rooted in the need during the industrial era for specialization and diversification of labor to prepare professionals for work within specific domains. Even though disciplinary areas have evolved and produced new disciplines over time, the discipline-based structure of higher education has remained largely unchanged (Holley 2017). The discipline-

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based approach lies in a 'system of power' (Klein 2006, p. 11) that may range from the institutional structure or labor markets to the allocation of research funding, or faculty support and awards (Klein 2006; O'Meara 2005). Disciplines are also demarcated by a scientific community that builds the foundation of a discipline through peer review of research within specific domains (Aldrich 2014). Indeed, disciplines instill analytic rigor (Sandefur 2016) and serve as units of scientific knowledge (Aldrich 2014). In contrast, interdisciplinarity serves as a form of communication between disciplines (Aldrich 2014). This perception is also echoed by Holley (2017), who suggests that interdisciplinarity does not "diminish the role of the discipline in education" (p. 1) but rather recognizes the absence of boundaries in knowledge production, which allows that knowledge to extend beyond predetermined or normative silos.

Interdisciplinarity and its Typology

Interdisciplinarity is not a novel concept in education. It is closely linked with the concept of "integrative" learning, a pedagogical approach whose focus is on helping students make sense of knowledge across curricula. Integrative education has been particularly popular in undergraduate general studies, in which students take an assortment of disciplinary courses and integrate a set of subjects across several disciplines into a framework that allows them to explore more complex issues from multiple points of view (Holley 2017). However, it is also utilized in upper-level courses and professional training (e.g., Walshe et al. 2015). Yet, as Klein (2005) suggests, integrative learning is a broader concept than interdisciplinarity as it encompasses "structures, strategies, and activities that bridge numerous divides, such as high school and college, general education and the major, introductory and advanced levels, experiences inside and outside the classroom, theory and practice and disciplines and fields" (p. 8). In contrast, interdisciplinarity refers to a subset of such integrative learning where the focus is on the synthesis of disciplines. Though the term "interdisciplinary" in higher education may refer to any type of activity that traverses the boundaries of traditional disciplines, the degree of interaction among disciplines, knowledge integration, and the overarching vision or problem may vary significantly (Holley 2017; Lattuca 2001). The most common types of interdisciplinary programs may be described as cross-disciplinary, multi-disciplinary, and transdisciplinary.

The *cross-disciplinary* curriculum typically utilizes the borrowing of tools, ideas, or theories, mostly from neighboring fields, in order to explain specific phenomena (Holley 2017; Klein 2010; Lattuca et al. 2004). For example, a biology instructor may introduce chemistry concepts to explain the process of photosynthesis. A cross-disciplinary course may also be offered by two instructors from different disciplines or a single instructor who sought consultation from a professional from a different field. For example, in sharing her approaches to creating cross-disciplinary courses, Reynolds (2012) explained that she would either use input from a subject matter expert from a different discipline or would open the class to students from two different disciplines or with mixed experiences. However, the directional relationship among disciplines in these cases is often unilateral, leaving one field as a passive or even auxiliary contributor. Additionally, instructors from different disciplines maintain their own discourse and epistemology, without integrating or synthesizing the fields (Holley 2017). This model is easier to embed into a curriculum, since it does not require significant curricular planning or changes. Students are often expected to integrate such knowledge, often received in individual courses, on their own (Reynolds 2012; Tafa et al. 2011).

Multi-disciplinary teaching refers to an integration of many disciplines, although theories and approaches introduced continue to be tied to specific disciplines (Lattuca, Voight, & Fath, 2004). While students may learn many disciplinary perspectives on a given phenomenon, the perspectives are usually juxtaposed and present students with an "encyclopedic" view, without purposeful synthesis of the varying approaches (Holley 2017; Klein 2010). This model frequently has been utilized by instructors to create multi-disciplinary courses, in which students with different majors team up to learn about the other fields represented in the class and to gain experience working together on a project (e.g., Arsenault and Stevenson 2012; Zhao 2011). In this case, each instructor serves as a subject-matter expert who focuses on connecting their subject to an overarching theme (Drake 1991). However, this represents a shared, rather than collaborative, relationship (Klein 2010).

Transdisciplinarity refers to a synthesis of disciplinary areas to the extent that knowledge may no longer be attributable to a specific field; it may also include active involvement and collaboration with community and other stakeholders to co-construct knowledge (Choi and Pak 2006; Holley 2017; Lattuca et al. 2004). Unlike cross- or multi-disciplinary approaches, transdisciplinarity encourages the creation of new or shared conceptual frameworks, both in terms of methodology and theory, that transcend fields and integrate disciplinary perspectives (Klein 2010; Rosenfield 1992). In this case, an instructor serves as a guide who helps connect content to support overall goals (Drake 1991). To design such interdisciplinary experiences, Ertas (2000) suggests that a learning experience should be built around a central element that is then surrounded by competencies rooted in various disciplines. However, what such a core includes may vary from program to program.

The move towards interdisciplinarity in higher education and professional preparation has resulted in hybrid fields such as behavioral medicine, bioinformatics, nanotechnology, and human-computer interaction, among others (e.g., Stokols et al. 2008). Interdisciplinary programs rooted in the humanities are more common than those rooted in the hard sciences. The integration of interdisciplinarity into higher education varies significantly and depends on institutional or organizational structures: For example, interdisciplinary may be incorporated as part of individual courses, as specializations within a department, or as autonomous programs (Holley 2017).

Interdisciplinary Education: Benefits and Challenges

Interdisciplinary education provides students with knowledge and skills that allow them to look at the world through multiple lenses, synthesize disciplines to better understand the phenomena they explore, see the interdependencies among disciplines or individual topics, and understand larger systems in which individual disciplines exist (Cotantino et al. 2010; Cruickshank 2008; Fortuin et al. 2013; Styron 2013). Interdisciplinary learning environments help engage students in critical thinking through appraisal and synthesis of disciplinary knowledge, problem solving, and creativity and innovation, and they help students develop collaboration and communication skills (Cotantino et al. 2010; Cowden and Santiago 2016; Mobley et al. 2014; Styron 2013). More importantly, students have a chance to explore their own interests in an authentic environment and come to the realization that "knowledge in the real world is not applied in bits and pieces but in an integrated fashion" (Summers 2005, p. 627).

Higher education institutions strongly support interdisciplinary collaboration (Friedow et al. 2012). Students enrolled in interdisciplinary programs benefit from seeing their instructors model interdisciplinary approaches and behaviors, including lifelong learning and exploration (Styron 2013). Instructors also benefit, as an interdisciplinary perspective allows them to share teaching practices and to explore their own disciplines from new angles (Cruickshank 2008). Yet, oftentimes, it is individual motivation that makes them cross boundaries and explore the richness other disciplines may add to the topics that interest them (Kandiko 2012). However, instructors, instructional designers, and curriculum designers often are not well prepared to design interdisciplinary learning experiences, due to differences in discourses and epistemologies across disciplines (Baker and Daumer 2015; Reynolds 2012). For this reason, designers and instructors alike need a comprehensive understanding of interdisciplinarity and how it can be embedded into a higher education curriculum (Stefani 2009).

Pedagogical Considerations

Teaching through an interdisciplinary lens requires pedagogical support (Augsburg et al. 2013). Yet there is no single pedagogy that facilitates interdisciplinary teaching and learning (Klein 2005). Synthesis and meaning making are at the heart of interdisciplinary learning. Interdisciplinarity is constructivist in nature, focusing on application of knowledge and development of higher order critical thinking and reflexivity skills; in this paradigm, learners must pose meaningful questions about a complex problem, sift through and synthesize multiple sources of information and perspectives, see how they intersect, and develop a holistic framework to answer those questions (Klein 1990, 2005). However, there are challenges with each of these steps. For example, problem definition is often framed as a disciplinary process, which can later translate into challenges with identifying relevant bodies of knowledge external to the discipline being taught. Students' preparedness and prior educational and professional experiences impact and shape their interdisciplinary learning. As a result, students may experience the same kinds of challenges their instructors face in devising teaching methods and approaching epistemological divides (Bradbeer 1999).

To enable learners to engage in such a critical review of disciplines, an interdisciplinary teaching approach requires "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman 1987, p. 8). However, as Richards (1996) suggested, "team-taught courses often fail to achieve their objectives precisely because the individual members of the instructional team never really begin to understand their common concerns in a fashion that may be properly called interdisciplinary" (p. 16). Designing an interdisciplinary learning experience requires close collaboration, team planning, and co-teaching of subjects by faculty from different disciplines. It also provides opportunities to blend teaching techniques (Lefeber et al. 2013).

Another set of problems with designing an interdisciplinary curriculum stems from what Jacobs (1989) called potpourri and polarity problems. The *Potpourri Problem* refers to a quick sampling of multiple disciplines without addressing meaning making in depth. This can happen at a course level or program level, for example when a department adds courses to a degree program for breadth without fully accounting for the challenges associated with implementing and/or delivering interdisciplinary coursework (DeSanto 1978). The *Polarity Problem* identifies the inherent conflict between interdisciplinary and disciplinary approaches, where those who teach individual disciplines may feel insecure and marginalized.

As an example, Gillis et al. (2017) reviewed 26 Canadian universities that together enroll just over 71% of all Canadian undergraduate and graduate students. Each of these universities offer interdisciplinary programs. However, many of interdisciplinary undergraduate programs focus on a single broad domain or a combination of up to three domains. In these cases, students learn about each domain separately through siloed courses or longer two-semester courses that cover objectives from two disciplinary courses. Most graduate programs reviewed allow students to choose their own learning path, taking courses from different disciplines without additional scaffolding for synthesizing what they have learned. Such synthesis may occur while students work on their own research projects, but instructional support related to this synthesis typically is not included in graduate curricula.

Measuring Interdisciplinary Competence

Interdisciplinary thinking is a complex cognitive skill with a range of subskills (Van Van Merrienboer 1997). Boix Mansilla (2010) outlined four cognitive processes that, when activated, may contribute to improved outcomes around interdisciplinary integration: 1) establishing purpose; 2) weighing disciplinary insights; 3) building leveraging integrations; and 4) maintaining a critical stance. In order to elicit these processes, students' work should engage both disciplinary and interdisciplinary insights. Some artifacts may be more representative of interdisciplinary cognitive processes than others, and it may take a significant amount of time for students to develop an adequate level of complexity in this process. It is also difficult to move from mere use of one discipline in support of another, characteristic of cross- or multi-disciplinary approaches, towards the synthesis of disciplines constitutive of transdisciplinarity (Spelt et al. 2009). Therefore, it is important to ensure that the assessment of interdisciplinary competence accounts for the complexity of the cognitive and metacognitive work comprising a truly transdisciplinary course or program.

However, as Boix Mansilla and Duraisingh (2007) observed in the evaluation of student work, instructors and evaluators often resort to considerations about the level or intensity of interdisciplinarity inclusion rather than focusing on the quality of work and effectiveness of integration of disciplines. To overcome this challenge, they devised an evaluation framework aimed at creating a culture of interdisciplinary evaluation. This framework includes three criteria important to measuring interdisciplinarity:

1) *Strong foundation or grounding in a discipline* to ensure the foundational insights and limitations of the discipline before attempting to integrate diverse disciplines.
2) *Advancement through integrating multiple disciplinary lenses*, where students can evoke epistemic frames of synthesized knowledge across disciplines and articulate their understanding.
3) *Critical awareness as to how to synthesize disciplinary knowledge*. At this point, students develop a metadisciplinary understanding of their own work and are aligned with clear goals and interdisciplinary framing of the issue at hand. This requires significant involvement in their work and judgment about why specific considerations were made.

Lattuca et al. (2013) developed a set of criteria to measure interdisciplinary competency in engineering students. It outlines eight major considerations that are aligned in part with the recommendations by Boix Mansilla and Duraisingh (2007):

1) *Awareness of disciplinarity.* A certain level of disciplinary knowledge is a cognitive apparatus that supports understanding of other disciplines. Additionally, understanding the social constructedness of disciplines may motivate learners to explore other disciplines.
2) *Appreciation of disciplinary perspective.* This refers to a process of moving from general understanding to more specific knowledge. Such appreciation requires seeing both the advantages of and challenges or gaps in individual disciplines.
3) *Appreciation of non-disciplinary perspectives.* Here, learners can demonstrate appreciating knowledge beyond their immediate discipline in order to address complex problems. Lattuca et al. (2013) also highlight the importance of working with stakeholders to understand a problem or issue from their point of view in order to embrace a non-disciplinary perspective.
4) *Recognition of disciplinary limitations*. Here, the focus is on a critical attitude towards and awareness of the limitations of individual disciplines and overcoming partiality to a specific field or discipline.
5) *Interdisciplinary evaluation*. Students should critically evaluate advantages and gaps or limitations of each discipline as part of interdisciplinary body of knowledge.
6) *Finding common ground*. Learners need to dynamically modify and adapt their perspectives in view of the information they collect from multiple disciplines and the viewpoints of others.
7) *Reflexivity.* Understanding the relationship between disciplines is a key part of their integration and synthesis, understanding one's own biases, and coming to a more complex or complete view of problems.
8) *Integrative skills*. This refers to the actual ability to integrate and synthesize disciplines by drawing insights from the relevant areas to devise a possible solution. Such solutions would be less complete if viewed through a single disciplinary lens (Newell 2001).

This range of components comprising interdisciplinary competence requires diverse assessment activities that reflect higher level cognitive processes, including critical thinking, problem solving, and integration of disciplines. Strategies include assessment of artifacts from collaborative project/problem-based learning in an interdisciplinary environment, as this allows students to showcase their competence of higher-order skills (e.g., Biasutti and EL-Deghaidy 2015); experiential or service learning opportunities that would allow students bring together knowledge across different fields (e.g., Rooks and Winkler 2012); reflections and portfolios that encourage students to synthesize their knowledge across multiple subjects (e.g., Wang 2009); and self and peer assessment (e.g., Hersam et al. 2004) to name a few.

Design Process Models and Considerations

Ensuring students' adoption of an interdisciplinary lens requires well-designed learning experiences that promote effective and efficient integration of disciplines and help students build their own holistic framework to explain a phenomenon. In designing an interdisciplinary experience, Yang (2009) suggests starting with two basic questions: *Why would we need to focus on interdisciplinary experiences in this particular course or program?* and *What outcomes can students achieve by taking such interdisciplinary courses?* Approaching a course through an outcome-based lens allows instructors and instructional designers to focus on what students can gain from it, why it might be important to them, and student output, thus ensuring their motivation and engagement.

Bigg's Model of Constructive Alignment (2003) is an outcome-based model and has been promoted as an effective framework for developing interdisciplinary learning experiences (Stefani 2009; Yang 2009). Bigg's model originated from a portfolio assessment of student work that reflected their thinking, integration of knowledge and experience, and self-representation as professionals. It is based on two main design principles: a) outcome-based and b) constructively aligned, and it consists of three main parts (Biggs and Tang 2011):

a) *Intended learning outcomes (*ILOs) are central to the teaching and learning ecosystem and are to be designed first. ILOs can be designed at three levels, e.g., institutional (what graduates in general should be able to do); program (what graduates from specific majors should be able to do); and course (what course completers should be able to do). Each ILO is designed to go beyond a topic and should include an activity. Such ILOs should reflect the interdisciplinarity of the program and its place within an institution.
b) *Teaching and learning activities* (TLA) embed active and collaborative learning and are aligned with ILOs; an instructor serves as a guide and facilitator of such learning.
c) *Assessment tasks* (AT) are assessable activities aligned with the ILOs (i.e., constructive alignment design principle). The focus of learning and assessment is on the quality or mastery of learning as outlined in outcomes and not on the accumulation of points. As such, learners are tasked with identifying their work that best reflects the ILOs and providing reflective statements that show how their artifacts meet ILOs. The latter serves as yet another point of connection and synthesis of disciplines.

Overall, the model offers a consistent approach to designing learning experiences that are rooted in interdisciplinarity and focused on students to ensure their learning. While originating as a framework for professional development, Biggs and Tang (2011) suggest that it could be applied to any college course. Additional research on using the theory in interdisciplinary teaching and learning is still needed (Gharaibeh et al., 2013).

The *Interdisciplinary Concept Model* (Jacobs and Borland 1986) offers a framework for course development with interdisciplinarity at its core, where instructors and designers can brainstorm and evaluate topics and disciplines that might be included in an interdisciplinary course or program. The model includes several steps to help develop an interdisciplinary curriculum that allows students to remain aware of individual disciplines while making a deliberate effort to explore other disciplines:

1. *Select an organizing/core theme* that serves as a foundation for the interdisciplinary experience. An organizing theme should have a reasonable scope to ensure that students are able to explore and master topics.
2. *Brainstorm associations* with disciplines that treat the selected topic or theme, as well as subtopics within each discipline. Such associations should include a wide range of ideas, which later may be scoped down.
3. *Identify guiding questions to define the scope and outline topic sequence.* This step supports a balancing of discipline representation and ensures the class can deliver the proposed diversity of topics and discussions that might ensue from them.
4. *Identify and outline activities* to allow for an in-depth exploration of the topic/theme.

Ullrich et al. (2014) discussion of the Interdisciplinary Program in Neuroscience (IPN) at Georgetown University is an example of this model. This program strives to train well-rounded neuroscientists and focuses on the development of professional identity. The core of the program embraces seven professional skill domains necessary for working in an interdisciplinary field such as neuroscience. These domains include leadership, oral and written communication, teaching, public outreach, ethics, collaboration, and mentorship. Learners are actively involved not only in theoretical discussions and synthesis of disciplines, but also in the practical application of co-constructed knowledge, including taking on leadership roles and writing grant proposals. Additionally, students are heavily engaged in the co-design of the program. While working on the program design, the faculty discovered that they did not always share assumptions about the perceptions and meanings of definitions for such professional skills.

Conclusions and Considerations

Engaging students in interdisciplinary experiences helps them develop higher-order metacognitive skills, such as critical thinking and the ability to view problems through diverse disciplinary lenses; it also guides students to synthesize disciplinary knowledge to devise innovative solutions (Cowden and Santiago 2016; Holley 2017). Yet the design and implementation of an interdisciplinary curriculum can be a challenge for instructors, instructional/curriculum designers, and students alike. These challenges may be due to differences in epistemological views, the existing constraints of the traditional higher education system, or a lack of pedagogical frameworks that support the introduction of interdisciplinary approaches (Baker and Daumer 2015; Klein 2005, 2006). The strategies and models discussed in the current paper may provide some insight into the ways that collaboration among co-instructors, potentially with the help of instructional designers, can support the creation of learning experiences that overcome the challenges of disciplinary language and epistemologies.

Compliance with Ethical Standards

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

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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