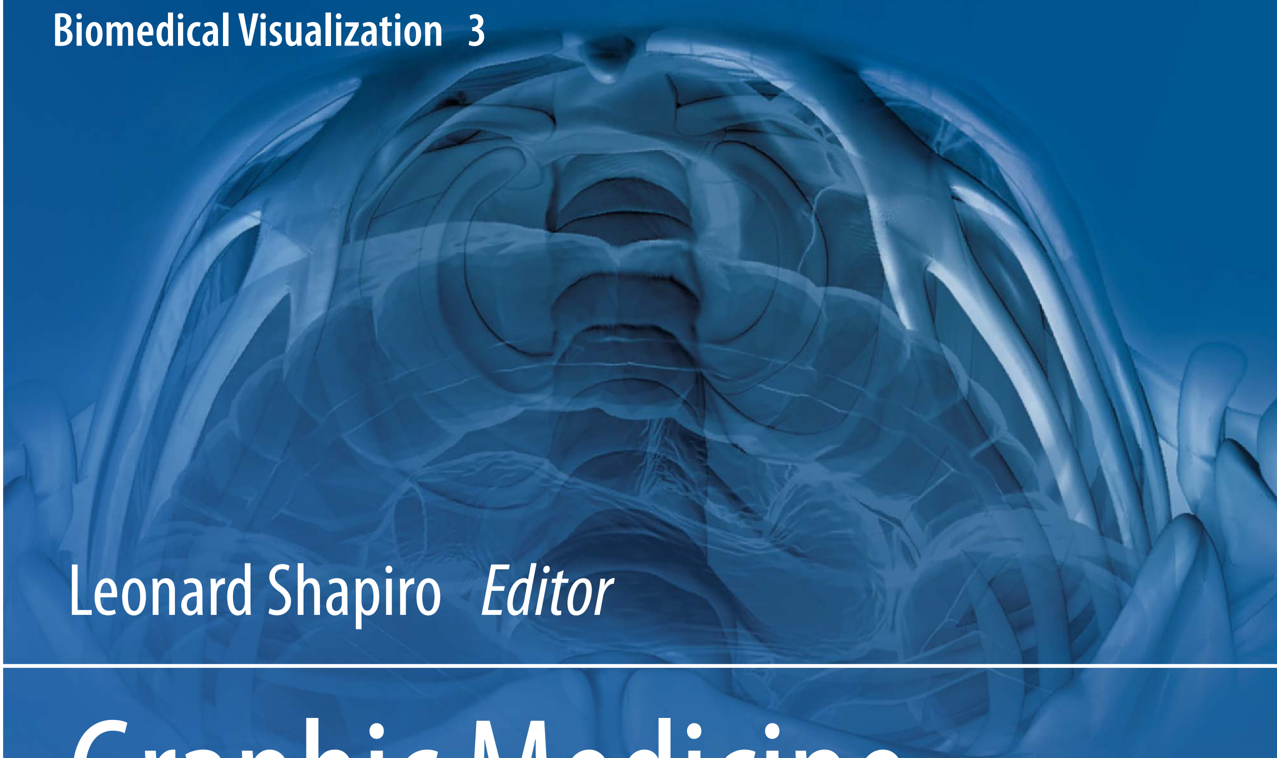
Biomedical Visualization 3



Leonard Shapiro *Editor*

Graphic Medicine, Humanizing Healthcare and Novel Approaches in Anatomical Education

Springer

Biomedical Visualization

Volume 3

Series Editor

Paul M. Rea, Anatomy Facility, School of Medicine, Dentistry and Nursing, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow, UK

The Biomedical Visualization book series invites contributions related to visualization and imaging in the biomedical sciences and related fields such as medicine, dentistry, veterinary surgery, informatics, and the allied health professions.

This can encompass work in image analysis, workflow methodologies, photogrammetry in science, animations, digital reconstructions and applications, big data and visualizations, educational methodologies, usability and evaluations, augmented and virtual reality, and 3D and 4D technologies, including 3D printing, as well as informatics, e-tutorials, MOOCs, HCI and public engagement. It can be from macroscopic to microscopic but show how we can view data and information related to the biomedical field in a much more accessible, innovative and engaging way using technology.

This series is intended for researchers, clinicians, students, and teaching staff in biomedical and medical schools who use and develop visualization and imaging techniques in medical education, patient care, and biomedical and medical research.

Leonard Shapiro
Editor

Graphic Medicine, Humanizing Healthcare and Novel Approaches in Anatomical Education

Springer

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Preface

We often gaze through a romantic lens at the lives of people like Leonardo da Vinci, Anna Morandi and Andreas Vesalius, and even though we view them as artists *and* scientists, we imagine that today the intersection and commingling of art and science is something of the very distant past. Yet, this is a misguided mindset and art and science were never and can never be divorced from one another. After all, if we pause to look we will see that the sciences, including the biomedical sciences, are overflowing with visual imagery, design, colour, aesthetics, illustrations, drawings and three-dimensional (3D) models that are critically and inextricably linked to its functioning on so many levels.

As editor for this book and as a visual artist working in the field of anatomy education, I extended an invitation to authors to consider contributing chapters that encompass the medical humanities and visual arts as they apply to the health sciences. The response is apparent in chapters by authors who explore art and humanities subjects as they relate directly to biomedical visualization. These chapters include a detailed exposé of Graphic Medicine as a vehicle for the expression of humanistic dimensions of healthcare, the fascinating history of medical illustration, comics for visual communication in medicine, the value of creativity in biomedical science education, equitable and ethical biomedical visualizations and the humanizing of healthcare. Chapters with a specific focus on anatomical education explore the creation of 3D anatomical models made of felt, visual analogies to enhance students' learning of histology, visualizing anatomy through art, archaeology and medicine, and the use of the hands for learning anatomy. These scholarly chapters sit so well together in the forum of this book, contributing to this important space within the field of biomedical visualization.

Cape Town, South Africa — Leonard Shapiro

Acknowledgement

I am greatful to each of the authors for their valuable contribution to this book, which will inform and inspire the readers.

It is a pleasure to work with Series Editor Paul Rea and Editor at Springer Nature, Ina Stoeck. Thank you for your expertise, enthusiasm and support throughout the months of work that went into preparing the contents of this book for publication. My thanks to the Springer design and production team for their attention to detail and the efficiency with which they produced this book. You all made this journey a pleasure!

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Paul M. Rea is Professor of Digital and Anatomical Education at the University of Glasgow. He is Director of Innovation, Engagement and Enterprise within the School of Medicine, Dentistry and Nursing. He is also a Senate Assessor for Student Conduct, Council Member on Senate and coordinates the day-to-day running of the Body Donor Program and is a Licensed Teacher of Anatomy, licensed by the Scottish Parliament.

He is qualified with a medical degree (MBChB), an MSc (by research) in craniofacial anatomy/surgery, a PhD in neuroscience, the Diploma in Forensic Medical Science (DipFMS) and an MEd with Merit (Learning and Teaching in Higher Education). He is a Senior Fellow of the Higher Education Academy, Fellow of the Institute of Medical Illustrators (MIMI) and a registered medical illustrator with the Academy for Healthcare Science.

Paul has published widely and presented at many national and international meetings, including invited talks. He has been the lead Editor for Biomedical Visualiz(s)ation over 15 published volumes and is the founding editor for this book series. This has resulted in almost over 110,000 downloads across these volumes, with contributions from over 450 different authors, across approximately 100 institutions from 23 countries across the globe. It has over 500 citations from these volumes. He is Associate Editor for the European Journal of Anatomy and has reviewed for 25 different journals/publishers. He is the Public Engagement and Outreach lead for anatomy coordinating collaborative projects with the Glasgow Science Centre, NHS and Royal College of Physicians and Surgeons of Glasgow. Paul is also a STEM ambassador and has visited numerous schools to undertake outreach work.

His research involves a long-standing strategic partnership with the School of Simulation and Visualisation, The Glasgow School of Art. This has led to multi-million-pound investment in creating world leading 3D digital datasets to be used in undergraduate and postgraduate teaching to enhance learning and assessment. This successful collaboration resulted in the creation of the world's first taught MSc Medical Visualisation and Human Anatomy combining anatomy and digital technologies, for which Paul was the Founding Director having managed this for 12 years. The Institute of Medical

Illustrators also accredits this postgraduate degree. Paul has led college-wide, industry, multi-institutional and NHS research linked projects for students.

About the Volume Editor

Leonard Shapiro is affiliated with the Department of Human Biology, at the University of Cape Town, South Africa. He has a keen interest in Anatomy Education and has developed a number of art-based exercises to address and improve students' three-dimensional (3D) spatial awareness and observation ability. His courses and online workshops are in collaboration with lecturers who are actively engaged in improving education methodology in anatomy. These are offered to medical students in South Africa and abroad. Leonard has developed a multi-sensory observation method that crucially employs the sense of touch (haptics) coupled with the simultaneous act of drawing. It is called the Haptico-visual observation and drawing (HVOD) method. In anatomy education, the benefits of using the HVOD method include the enhanced observation of the 3D form of anatomical parts, the cognitive memorization of anatomical parts as a 3D mental picture, improved spatial orientation within the volume of anatomical parts and an ability to draw. Leonard has taught the HVOD method at the University of Cape Town (South Africa), Newcastle University (England), The University of British Columbia (Canada), Carnegie Mellon University (USA), The Gordon Museum of Pathology at King's College London (England), University College Cork (Ireland) and Weill Cornell Medical College (USA). Leonard contributes to the anatomy education discourse by presenting at anatomy conferences as well as via publications and articles. Leonard graduated in BSocSci and in BA Fine Art (Hons) from the University of Cape Town.

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Part I

History of Medical Illustration, Graphic Medicine, Humanizing Healthcare and Equitable Visualizations

1 Drawn Together: Merging the Worlds of Health and Comics Through Graphic Medicine

Oscar Li and Nathan A. Gray

Abstract

Although storytelling with sequential visual art has been a part of human narrative communication for centuries, interest in the intersection between the comic medium and health care has grown rapidly in recent years. Comics have an array of unique properties as a means for communication, and this expanding field of study, termed "graphic medicine," aims to better understand and employ these traits for diverse purposes in health care. Current applications of comics in medicine include education of clinicians and patients, processing of traumatic or transformational experiences in health, and raising public health awareness. Limitations persist surrounding acceptance of comics, educational impact measurement, and logistical barriers to producing content for health education, but the future holds significant potential for ongoing benefits to patients, clinicians, and academics. In this narrative review, we will provide an overview of the advantages of comics in communication, current applications of comics in health, and future challenges and directions for the field of graphic medicine.

Keywords

Graphic medicine · Comics · Health visualization · Medical humanities · Medical narrative · Medical education

1.1 Introduction

In the search for effective means to communicate and visualize health information, a growing number of medical practitioners, researchers, and educators are turning to the medium of comics, or "sequential art," as a format for engaging audiences. This burgeoning field exploring the interaction between comics and healthcare, termed "graphic medicine," aims to harness the unique attributes of comic storytelling in order to facilitate the transfer of valuable medical information, educate clinicians and patients, share experiences in illness, and engage audiences with topics important to public health (Green and Myers 2010).

The comic medium's approach to storytelling possesses a variety of distinct features with the potential to expand accessibility, engagement, and depth of communication surrounding complex topics related to health and medicine. An ever-expanding collection of graphic narrative work offers insight into diverse patient illness

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experiences while educators, scholars, and clinicians have begun delving deeper into uses of the comic medium as a means to improve healthcare. This narrative review aims to provide a broad overview of the attributes and advantages of graphic medicine as a means for education, to discuss current uses of comics in medical education and healthcare, and to highlight challenges and future areas for growth.

1.2 Terms and Definitions

A variety of terms have been used to describe the medium commonly referred to as "comics." These include but are not limited to "long-form cartooning," "picture novels," "sequential art," "graphic novels," or "graphic narratives." While each term may convey slightly different assumptions about appearance, length or style, the common feature is the combined use of words and images to convey a message or narrative in sequential order (McCloud 2017). Formats for comics have been transformed over the years by the advent of new technologies including the internet; however, storytelling using the medium of sequential art continues to hold a valuable place in communication and will likely remain a fixture even as new platforms arise (Petersen 2011; Sabin 2010). In this chapter, we will use "graphic medicine," "graphic narratives," and "comics" interchangeably to explore the current uses and capabilities of this unique medium.

Specifically, "graphic medicine" is a term coined by Dr. Ian Williams in 2007 to describe the intersection between comics and the world of health and medicine (Czerwiec et al. 2015). The term has been kept deliberately broad to include a variety of uses, including graphic memoirs, educational comics, academic papers, medical commentary, and other practices, both fiction and non-fiction; the movement toward the growth of comics and health includes a varied group of advocates, including clinicians, educators, scholars, professional artists, and lay public participants (Kasthuri and Peter 2021).

1.3 Unique Attributes of Comics as a Medium for Communication and Education

Sequential art has been a feature of human communication for many centuries, offering a variety of features that make it appealing as a route for delivering information (Earle 2021). In contrast to text-only resources, comics serve as a unique way of conveying information via "dual coding"—including the combined channels of both visual and textual information; comprehension and memory formation can be enhanced and enriched in this hybrid word-image format, as text aids interpretation of the images and vice versa (Aleixo and Sumner 2017). Although the majority of evidence regarding the impact of comics as a means for information delivery comes from small samples, numerous studies have suggested that presenting information in this multimodal format may result in improvements in learning and recall, and interest in the use of comics for education has been growing rapidly in recent decades (Noe and Levin 2020; Yang 2003).

While technology has recently made digital media such as video or audio highly accessible, comics still maintain distinct strengths compared to more passive routes for receiving information. Comics require the reader to participate in an active role in comprehension by connecting separate scenes and deducing missing parts of the narrative between image panels. This cognitive activity is given the name "closure," and it requires the reader to fill in the missing story from the limited information provided (McCloud 2017). Closure can be utilized between panels to indicate a change in time or location, compelling the audience to actively imagine these changes to continue along the story. Closure can also be prompted within an individual panel by deliberately leaving ambiguity for the reader to imagine. For example, intentionally leaving certain parts of a panel blurred or with text that is illegible enables readers to interpret what is happening in their own ways.

Even disparate images delivered in sequence can be pieced together based on one's personal experiences to create a story. For example (Fig. 1.1), three illustrated frames with images viewed in isolation (a suitcase, a plane in the air, and a man in a row of seats dreaming of the beach) that could appear unrelated are seamlessly connected by the reader, even without text, to create a narrative of preparation, travel, and destination. Because personal experience affects this process of interpretation, closure allows for different readers to have different understandings of the story despite reading the same comic. A reader from an era without air travel might struggle to make sense of the connections between the frames while most modern audiences would connect the panels with minimal effort.

The added cognitive work required to read and understand comics invites readers to play a more active role in processing and interpreting the content. For example, an observational study using an educational comic about electronic health record self-advocacy behaviors found that readers were more engaged with their healthcare and more willing to advocate for themselves when exposed to the comic (Alkureishi et al. 2021). This high level of engagement was similarly found in another study in New Zealand, where a comic "Caretoon" approach, using user-guided generation of personalized comics for an online public health survey, outperformed the equivalent text-only approach in terms of reach and diversity of audience (Kearns et al. 2021b).

In addition to increased reader engagement, the dual-coding feature of comics may also help overcome barriers of language or literacy. Even when challenges arise with text comprehension, readers can derive the arc of the story or meaning through the image-based narrative track. A growing body of research has examined the use of comics as a beneficial tool for language teaching and acquisition (Wijaya et al. 2021). In particular, studies have highlighted the advantages in vocabulary development, comprehension, and engagement for English Foreign Language (EFL) readers (Cimermanová 2015; Merc 2013). In healthcare settings, where information must be conveyed in a way that accommodates a variety of language and literacy levels, comics offer a promising avenue for delivering vital health communication between clinicians and patients.

In addition to their strengths in reader engagement, comics offer a broad and flexible palette of tools *inside* each panel, including line weight and style, text appearance, color and shading, as well as variables *outside* the panels, including page layout, sequence and panel sizes that can aid in conveying meaning, or making messages memorable (Eisner et al. 2008). In addition, the simplicity or abstraction of imagery in some comics may allow a broader population of readers to place themselves into the narrative, with deliberately reductionist characters that are not constrained to an obvious age, ethnicity, gender, or body type (McCloud 2017). Exchanging photo-realistic representations for more fluid or exaggerated figures expands the range of mood and expression.

All of these strengths stemming from the structure of the medium, as well as the cognitive participation required from participants, combine to form a route for communication that is highly adaptable for a wide variety of audiences. Finally, for readers such as patients or health care students who may be inundated with text materials in coursework or educational handouts in clinical settings, comics provide a stimulating and engaging alternative for information consumption. A common finding in many studies of comics for medical education is the enthusiasm of readers for this alternative form of content delivery (Adamidis et al. 2022; Joshi et al. 2019; Park et al. 2011).

1.4 "Graphic Pathographies" as a Means for Communicating Patient Experiences

In recent decades, the practice of narrative medicine has been established as a central component of the medical humanities and describes the application of a story to medical education and practice (Charon 2001). Exposure to narrative literature has been proposed as a means of facilitating more compassionate care and interdisciplinary

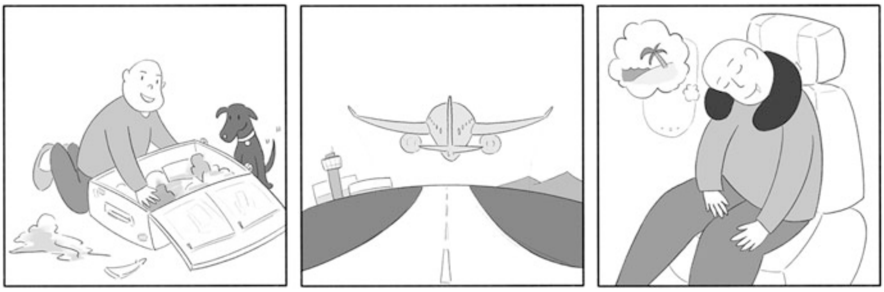

Fig. 1.1 Illustration of the concept of "closure" in which narrative is constructed from sequential images (illustration by Oscar Li). Author image

collaboration (Liao and Wang 2020). Stories can provide a broader perspective on life experiences and enhance a person's ability to empathize with others despite different lived experiences and personal beliefs (Kidd and Castano 2013).

Within this growing focus on narrative medicine, graphic medicine offers a particularly compelling format for presentation of illness narratives. "Graphic pathography" is a term coined by Green and Meyers to refer to a specific subgenre in graphic medicine that presents the patient's experience of illness in the graphic narrative form (Green and Myers 2010). Presenting illness using the medium of comics offers potential benefits both for creators and readers, as those with an illness and those adjacent exchange intimate and personal perspectives on topics as diverse as suffering, disability, and mortality. As comics are not necessarily bound by the traditional expectations and rules of prose, creating graphic pathography may allow a person to document lived experiences with health when words alone prove insufficient or too restrictive (Joshi et al. 2019). Because patient experiences are by their very nature highly individualized, every graphic pathography is also unique and deeply personal, with an idiosyncratic perspective on what medicine might otherwise reduce to a standardized list of signs or symptoms.

The individuality of style and expression can be easily seen in evaluating various graphic pathography memoirs. For example, two comic creators both chose to recount their experience receiving a diagnosis of breast cancer through comics. In "Cancer Made Me a Shallower Person" by Miriam Engelberg, the author uses simple lines in black and white, loose text, and a relaxed drawing style that may feel to some readers like peering into a diary entry (Engelberg 2006). In contrast, Marisa Acocella Marchetto also describes her breast cancer experience in her book "Cancer Vixen," but she employs bold colors, frenetic linework, and a more structured text style (Marchetto 2006). Despite describing the same diagnosis, both authors use their distinct approach to draw readers into their own varied experience of the illness.

The flexibility and freedom provided by blending words with the immediacy of artwork offers a spectrum of expression and intimacy that can be hard to achieve in other media, and use of graphic medicine in this way can intersect with some aims of art therapy, allowing for the exploration of distressing symptoms and processing illness (Czerwiec et al. 2015; Regev and Cohen-Yatziv 2018). Self-expression through creative art therapy has been suggested as a means for enhancing coping in psychiatric and psychological conditions, to improve quality of life (Chiang et al. 2019), and comic integration as a form of art therapy may be one suitable vehicle for such an intervention (Shwed 2016). While potential use of graphic medicine as a form of therapy should be guided by a trained art therapist, creating graphic pathographies still offers promising benefits for creators seeking an outlet for documenting their experiences.

Like graphic pathography creators, readers, too, may benefit from exploring graphic narratives surrounding illness and medical treatments. Despite the individual nature of the illness experience, graphic pathographies can facilitate community-building and education through connecting individuals who share similar lived experiences (Green and Myers 2010; McNicol 2017). Readers from both medical and non-medical backgrounds could potentially benefit from exploring these windows into the lives of those living with illness, finding a path for more compassionate communication and understanding (Yu 2018). Patients who read graphic pathographies can learn about their illnesses, possibly understand their prognoses with more clarity, and maybe even mentally prepare for their next steps (Czerwiec et al. 2015).

The lens of the comic provides particularly sharp focus for daily life with physical pain or limitations. In his graphic novel, *My Degeneration*, cartoonist Peter Dunlap-Shohl tells the story of his diagnosis and coping with Parkinson's disease, sharing how neurologic symptoms' impacted not only his life, future, and function, but also his identity and work as an artist (Dunlap-Shohl 2015). In Fig. 1.2, Dunlap-Shohl describes his struggle to cope with pain and adaptation in his work as a comic artist; the frantic, quivering lines and pitchfork driven into his shoulders connect us to his experience of Parkinsonian tremors and postural pain, providing a memorable representation of his daily lived experience.

Graphic pathographies have been used to explore health experiences as varied as diabetes, Alzheimer's disease, bipolar disorder, and gender transition. In "Super Late Bloomer: My Early Days in Transition" by Julia Kaye (2018), the author uses a collection of comics surrounding her early months of gender transition as a creative way to document her experiences, thoughts, and feelings through the process. Comics have proven to be a particularly valued space for highlighting narratives of vulnerable or marginalized populations, such as the LGBTQ+ community, those living with disability, and patients suffering from chronic illness or pain (Councilor 2021; Squier and Krüger-Fürhoff 2020; Venkatesan et al. 2022; Wegner 2020). In a medical culture where the perspective of clinicians often dominates narratives surrounding health, graphic pathographies are a potent forum for recentering the story around the patient's perspective.

Although medicine is often reduced to the narrow sphere of the patient–doctor relationship, a whole team of supporters and caregivers are also affected by the illness experience. A growing subset of graphic pathographies have been created by close contacts such as family members or medical care team members to reflect on illnesses from their point of view (Sethurathinam 2018). Utilizing comics in this way allows for a more vivid representation of certain illnesses and the impact they have, not only on a patient but also the community around them.

For example, in her memoir "Aliceheimer's: Alzheimer's Through the Looking Glass," creator Dana Walrath uses illustrated vignettes to give readers a glimpse into her time caring for her mother who moved in with her after her mother's diagnosis of Alzheimer's dementia; Walrath shared that creating the book allowed her to process her grief as well as to capture and record moments from their time together (Walrath and Walrath 2016). Her work features raw sketches, handwritten text, and representations of her own mother, robed in pages cut from the book "Alice in Wonderland." In Fig. 1.3, from her graphic memoir, Walrath represents the gradual decline of her mother, explaining that she "isn't losing tangible parts, but she is disappearing," through a series of papercut figures with omitted features. Mood, movement, and mourning are conveyed in the art style and grayscale color scheme.

The engaging and intensely personal nature of first-person illness narratives through comics makes them a promising route for providing health professionals with a richer look into the lives patients lead outside the confines of the clinical space. Medical trainees who read these comics can learn more about patient experiences from their perspectives and potentially form better connections with future patients (Anderson et al. 2016; Williams 2012). As a subgenre of graphic medicine, graphic pathographies serve as powerful medical narratives capable of intimate storytelling with diverse potential applications for trainees in healthcare.

Fig. 1.2 Example image from the "graphic pathography" *My Degeneration* in which author Peter Dunlap-Shohl shares his experience with Parkinson's disease (Dunlap-Shohl 2015). Reproduced with permission

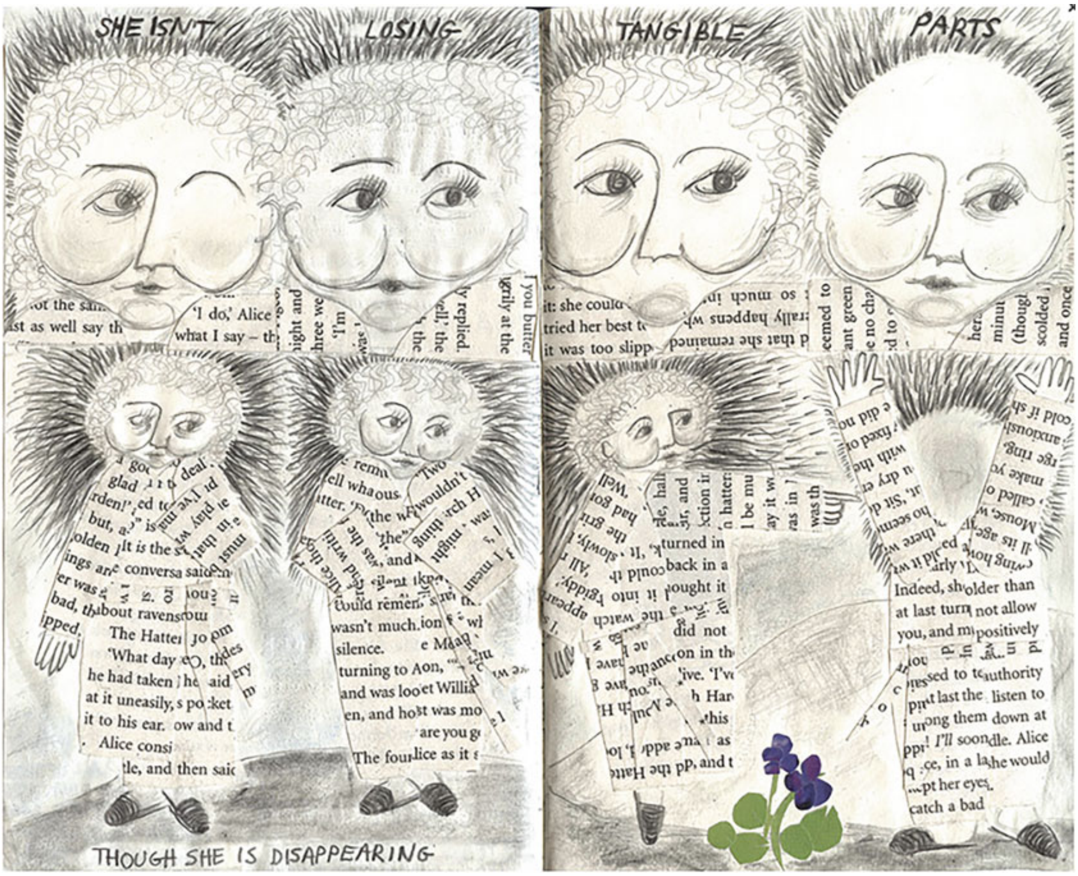

Fig. 1.3 Example image from the caregiver graphic memoir *Aliceheimer's: Alzheimer's Through the Looking Glass* by author Dana Walrath (Walrath and Walrath 2016). Reproduced with permission

1.5 Graphic Medicine in Undergraduate Medical Education

Medical schools throughout the world have integrated the humanities into their undergraduate medical curriculum through studies of medical ethics, literature, and the arts. A study in 2017 found that 70.8% of medical schools offered required humanities courses with each student completing 43.9 h on average (Klugman 2018). While the evidence base for many of these initiatives driving humanities is still in early development, graphic medicine offers a vibrant avenue for delivering such content and a ripe field for study of its impact. It has been suggested that studying the medical humanities may allow medical students to build upon multiple skills including better communication, cultural flexibility, professionalism, and self-reflection, although additional study is needed to prove its effect (Ousager and Johannessen 2010). Shapiro and colleagues describe the potential for medical humanities in enhancing students' "observational and pattern recognition skills" (Shapiro et al. 2006). To medical students, the study of medical humanities is also generally perceived as valuable, with younger students highlighting the need to keep an open-minded perspective of medicine during the pre-clinical years and older students stating the desire for a break from intense clinical education (Petrou et al. 2021).

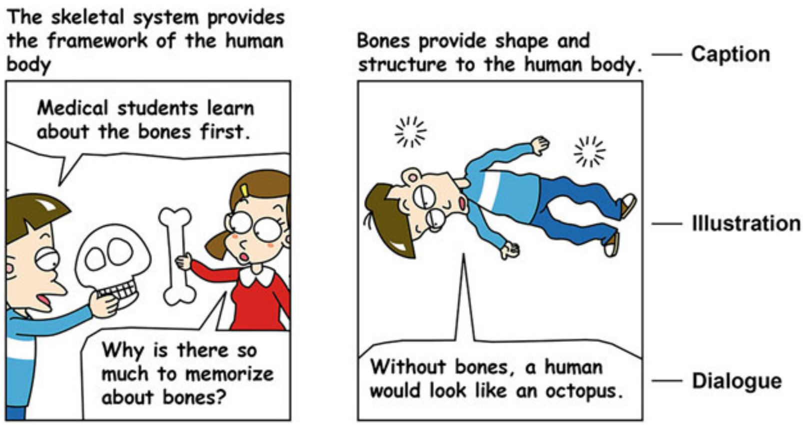

Fig. 1.4 Panels from anatomy education comic demonstrating combined use of dialogue, text, and illustration (Kim et al. 2017). Reproduced with permission

As one form of medical humanities, graphic medicine integrates both narrative medicine and visual arts and has been increasingly examined as a tool for advancing undergraduate medical education. Educators seeking new formats to reach students have turned to comics as a creative and engaging way to present both the humanities and scientific information. Despite the fact that many students have not been exposed to medical comics, one study found that after a brief introduction to graphic medicine, the majority of over 600 surveyed students perceived medical comics as "useful" or "very useful" (Adamidis et al. 2022). This enthusiasm for the format may possibly lead to better information retention and acceptance from learners. For example, 84% of medical students at Penn State College of Medicine who reviewed educational comics prior to completing their psychiatry clerkships reported high satisfaction in terms of information presentation and convenience (Joshi et al. 2019).

Integration of comics into medical education is not confined to the field of humanities, however. Efforts have been undertaken in various contexts to use comics as an aid for education regarding topics as diverse as statistical concepts and microbiology (da Silva and Vieira 2022; Tigges et al. 2021). There is also a growing interest in using comic formats as a way to humanize numerical data visualization, with applications of such "data comics" found both as standalone instruments and as explanatory insertions among graphic pathographies (Engebretsen and Kennedy 2020). As part of one such application of graphic medicine to scientific undergraduate medical education, anatomy professors at two medical schools in Korea have created and used more than 700 comics to engage students in course material and convey important points in a field that some students might otherwise believe "seems boring" (Park et al. 2011). Intervention using educational comics on basic human anatomy found medical students who were presented with graphic medicine material had improved course grades (Kim et al. 2017). In this series of comics titled "*Anna & Tommy*," students are provided content through a mix of infographic or diagram-based materials combined with segments of dialogue and interaction between characters, as demonstrated in Fig. 1.4.

In addition to helping medical students master scientific information, comics can also be used to help learners develop professional skills, understand different points of view, and enhance clinical reasoning. Thacker et al. used a transdisciplinary graphic medicine teaching session as a case study in helping undergraduate medical students explore the difficult topics of clinical complexity and uncertainty (Thacker et al. 2022). In a similar effort conducted by Vaccarella, students were introduced to core elements of the comic medium and guided through analysis of graphic pathographies, with the author suggesting that students "improved their understanding of narrative temporality by examining the sequential component of graphic storytelling, and incorporated this new awareness into their diagnostic reasoning skills" (Vaccarella 2013). Qualitative analysis of survey and interview responses from third and fourth year medical students who viewed two comics about diabetes self-management found graphic stories to be a useful tool in simulating reflective practice and promoting empathy maintenance during training (Wang et al. 2018).

Examination of these illness narratives offers insights into the potential benefits for students. In his book *Diabetes: Year One*, author Tony Pickering uses a series of graphic poems to share his experiences of adjusting to a diagnosis of type 1 diabetes (Pickering 2017). Learning about diabetes self-management from a textbook provides useful technical information, but seeing the patient's experience of daily life, including the interruptions posed by medications, testing, and fluctuations in blood sugar helps contextualize illness as one part of a patient's broader story (Pickering 2019).

While teaching graphic medicine to medical students might seem difficult given the inherently subjective and individualized aspects of reading comics, several different strategies have been proposed to help facilitate students' exploration of artwork in humanities education. One such strategy is the "Visual Thinking Strategy" (VTS), which involves the following three questions: *(1) What's going on in this piece? (2) What do you see that makes you say that? (3) What more can we find?* (Myers and Goldenberg 2018; Yenawine 2013). These questions can be sequentially utilized and discussed with medical students to dig deeper into each graphic medicine piece they encounter.

Another example of potentially useful discussion prompts comes from a case study that explored a co-learning experience between the physician and patient (Anderson et al. 2016). The following discussion questions from Anderson and colleagues are intended for the physician and patient to answer, but they can also serve as prompts that may help students navigate reflection upon reading a graphic medicine piece:

1. *Whom did you identify with and why? Whom did you not identify with and why not?*
2. *What did each need to know about the other?*
3. *As the patient, what would you want the doctor to have done differently? As the doctor, what would you want the patient to have done differently?*
4. *How might this story change your next doctor–patient encounter?*

In addition to medical education interventions which involve reading and interpreting graphic medicine, some institutions have provided opportunities for medical students to create their own original comics as a form of self-reflection on a variety of themes, including their formation as clinicians, abuses in training, the role of medicine, patient connections, and handling emotional experiences. At Penn State College of Medicine, Dr. Michael Green, MD, MS has been teaching an elective course on graphic medicine to fourth year medical students since 2009 where, in the context of a broader introduction to graphic medicine, medical students produce their own comics (Green 2013). Upon assessing comics produced by medical students who took the course over the span of 6 years, Green found recurring themes including *"(1) how I found my niche, (2) the medical student as patient, (3) reflections on a transformative experience, (4) connecting with a patient, and (5) the triumphs and challenges of becoming a doctor"* (Green 2015).

The themes explored in these comics produced by medical students are important for self-reflection as medical school is a transformative experience involving both personal and professional growth as well as significant stress and anxiety. In one analysis of themes in comics produced by medical students, the most commonly coded theme was "overwhelmed," with other common content descriptors including "inadequate," "frustrated," and "helpless" (Maatman et al. 2020). Graphic medicine creates a safe and relaxed space for medical students to explore these experiences, thoughts, feelings, and reflections (Whiting 2020). The perceived informality and safety of comics is a strong stimulus toward open disclosure and externalizing distress;

in one analysis of 240 students invited to share a stressful experience in comic format, approximately 19% reported sharing a stressful experience via comic that they had never shared with anyone else before (Maatman et al. 2022b).

1.6 Graphic Medicine in Graduate Medical Education

While the potential for graphic medicine's use in graduate medical education has received less attention than that of undergraduate medical training, there is growing interest in using graphic medicine in this context, and several recent projects have attempted to incorporate comics into training after medical school. Like medical school, residency and fellowship training are periods of transformative professional and personal growth; however, time and energy are two resources that many residents find lacking due to the intensity of training. In the setting of these limitations, graphic medicine may offer advantages as an efficient and engaging medium for learning. Graphic medicine at this level of medical training is generally divided into two types of activities: (1) **receiving:** reading and discussing medically relevant comics, and (2) **delivering:** drawing comics to share experiences and self-reflect (Maatman et al. 2022a).

Including graphic medicine in graduate medical education can serve to teach residents skills and highlight important aspects of patient care and empathy, in similar ways to the previously described applications of comics in undergraduate medical education. Internal medicine residents from the Medical College of Wisconsin found that using a comic book to learn about patient safety was both acceptable as an educational exercise and increased their confidence in their ability to identify patient safety issues (Maatman et al. 2019). In a study conducted among neurology residents who participated in a 4-week graphic medicine seminar (which involved reading and discussing graphic memoirs featuring neurologic disease), residents cited better appreciation for symptoms as well as increased empathy, with 97% reporting that the course was a "good use of their time" (Ronan and Czerwiec 2020). Similarly, endocrinology residents at the University of Toronto who completed a 12-month curriculum reading and discussing four graphic novels noted that the curriculum helped them with sharing difficult experiences and building empathy (Sutherland et al. 2021). In one effort directed toward patients cared for by resident physicians in an outpatient clinic, comics from a patient-centered transition packet helped patients identify their new doctor and improved follow-up rates (Pincavage et al. 2015).

While few efforts have yet been undertaken to incorporate graphic medicine into surgical postgraduate training, the intersection of visual art and surgical science offers valuable opportunities for honing skills in diagnosis, observation, and communication (Cohen et al. 2022). Visualization and a strong knowledge of anatomy are especially important components for a successful surgeon, and surgical education has long relied on accurate medical illustrations in teaching anatomy and procedural techniques (Netter 1957). With a strong foundation for graphic learning already established as part of surgical textbooks and presentations, graphic medicine might seem to be a natural fit for conveying information in the field. In one exploratory attempt to present preparatory surgical information in comic form, residents and nurses were presented with a graphic narrative titled "The Thyroidectomy Story" as a supplement to previously delivered lecture and text materials surrounding thyroidectomy with the goal of introducing "technique, narrative, and medical illustration skills (interpersonal communication skills)" (Babaian and Chalian 2014).

1.7 Graphic Medicine Creation as a Platform for Processing Experiences in Health Care

Outside of the context of structured medical education, many students, trainees, and practicing clinicians have turned to creating graphic medicine both privately and publicly as a forum for reflection, communication, and community-building (Kasthuri and Peter 2021). Sharing work publicly through online social media platforms such as Twitter and Instagram offers rapid feedback, responsive discussion, and expressions of support or empathy from colleagues or patients alike. In online graphic medicine posts, trainees and practicing professionals from across disciplines have shared comics reflecting on their experiences both in the clinical setting and in their lives outside of practice. While these efforts rarely appear to be created in the context of a structured therapeutic relationship, some creators appear to benefit from the catharsis and processing. Graphic medicine has potential as a powerful mechanism for self-reflection, including processing of negative or traumatic experiences that occur in the practice of medicine (Czerwiec et al. 2015).

Comics can also be utilized to record transformative or connective experiences with specific patients. Dr. Mike Natter, who is now a practicing endocrinologist, created monthly "Progress Notes"; graphic medicine pieces for Annals of Internal Medicine to document his experiences of the medical training process. In one such piece, titled "Tethered," Natter relays his experience as a resident of caring for a patient "trapped" in the hospital on an infusion, with limited options for discharge due to her uninsured status (Natter 2019). In a few simple panels, he intimately conveys their shared feelings of helplessness as doctor and patient.

Another highly active creator in the online graphic medicine space has been author and physician Dr. Shirlene Obuobi, who goes by "ShirlyWhirlMD" online. She has used her comics for years over the course of medical school, residency, and fellowship to explore a variety of topics including the traumas of training, attempts to maintain work–life balance, gender inequities, and systemic racial injustice in medicine. By using comics, she is able to address difficult and complex topics in a more accessible and less "hostile" format (Obuobi et al. 2021).

1.8 Comics and Sequential Art in Public Health Education

As the success of any public health education initiative relies on its ability to effectively engage and inform a broad audience, there has long been interest in using comics for this purpose. In light of the many unique properties of comics discussed above, graphic medicine has tremendous potential for engaging wide and diverse populations surrounding topics in science and medicine that otherwise might seem inaccessible (Farinella 2018). Public health initiatives have been using various forms of sequential art for decades to educate about topics as diverse as skin cancer, HIV/AIDS, and the dangers of smoking (King 2017). As early as 1950, the New York State Department of Mental Hygiene published its "Chic Young's Blondie in: Scapegoat, Love Conquers All, Let's Face It, On Your Own" to promote mental health services (New York State Department of Mental Hygiene 1950).

Other health entities utilize comics to promote awareness, prevention, and detection practices for certain medical conditions. For example, a 16-page comic book on skin cancer was distributed to 8000 households to educate the recipients about early signs of skin cancer (Putnam and Yanagisako 1982). The study coordinators found that readers described the comic as accessible and that the comic promoted change in increasing the use of sunscreen, protective clothing, and skin self-examinations (Putnam and Yanagisako 1982). In another study, adolescents who read an AIDS education comic scored higher on levels of knowledge regarding HIV transmission and prevention compared to the control group (Gillies et al. 1990).

A more recent application of graphic medicine for public health education is a comic created in Seattle to help the public understand necessary steps to take during a large-scale emergency that requires medical countermeasures (Li-Vollmer 2018). The creators believed that using a comic, with better integration of narrative, dialogue, and emotion, would allow them to more effectively educate the public about what to do in times of emergencies that require a medical intervention such as mass testing or medication administration, such as a pandemic. The study materials used illustrations paired with clear instructions to inform people about what to expect and encourage them to have an action plan in place ahead of crisis; while impact was not measured, the study authors reported strong engagement with the content online as well as broad reach through social media (Li-Vollmer 2018).

Another recent example of graphic medicine's application to public health is the use of comics to educate the public about nonalcoholic fatty liver disease (NAFLD) (Alemany-Pagès et al. 2022a). Researchers in Portugal created the comic book, "A Healthy Liver Will Always Deliver," using graphic narrative and accurate biomedical illustrations to convey information about NAFLD prevention, regression, and health outcomes (Alemany-Pagès et al. 2020, 2022b). In one panel of the comic, Alemany-Pagès and colleagues used illustration and text to demonstrate the progression of a healthy, red liver to a cirrhotic, black and bumpy liver; they also gave each hepatocyte a memorable cartoon face and showed the progression of emotions from happy to surprise to uneasy and ultimately to the death of each cell interspersed with fibrotic tissue. Such blends of creativity and data have the potential to engage audiences who might otherwise ignore a text-only educational tool.

When paired with a strong base of culturally aware practices (such as audience involvement to inform accurate dialogue and illustrations), comics can also be a rich platform for telling stories in public health that incorporate perspectives not typically included in Western narratives. "Lissa: a story about medical promise, friendship, and revolution" is a long-form graphic medicine piece set during the Egyptian revolution that explores a broad variety of topics, including social determinants of health for the development of kidney and liver disease, genetic risks for breast and ovarian cancer, healthcare accessibility, and the interplay between public health and political revolution (Hamdy et al. 2017; Hamdy and Nye 2019). Using a combination of research and numerous interviews with affected populations, the team used comics as the medium for disseminating the story to "show" rather than "tell" the ways that political dynamics influence individual health within a broader global framework (Hamdy and Nye 2019). The team's well-informed attention to appearance, dress, and scenery in the narrative draws readers into another perspective in a way that text-only materials might not capture.

Numerous additional applications of comics as the medium for public health outreach help re-center the focus of medicine on patients' experiences and allow readers to glimpse into the inner monologues of those directly affected. When created with culturally appropriate and sensitive graphics, comics can be a valuable tool for helping the public gain a better understanding of the information being presented and how it applies to their own lives.

1.9 Graphic Medicine During the Era of COVID-19

The COVID-19 pandemic provides an excellent case study in highlighting the diverse applications of comics in health for creators, clinicians, health authorities, and the public. In early 2020, when much of the world shut down to contain the spread of the novel coronavirus, a variety of daily activities including work and communication had to rapidly shift to online virtual means. This mandatory isolation presented challenges for disseminating accurate science communication and public health updates as new research on curbing the pandemic evolved. Comics served as a natural way to fill those needs by presenting scientific information in the form of engaging narratives that were easy to create and share despite widespread social distancing (Kearns and Kearns 2020). The *invisible* nature of coronavirus as a viral pathogen made science visualization especially important for education of a public that maintained a broad spectrum of receptiveness to information and a broad range of health literacy levels. With much of the world already transitioning work and communication to online spaces at the height of the pandemic, comics offered a natural vehicle for communicating through the internet. From a broad view, the COVID-19 pandemic offers a dramatic practical representation of nearly all the applications of graphic medicine described in prior portions of this chapter.

One of the most common applications of comics during the early stage of the pandemic was patients using graphic pathography to tell their stories of illness, caregiving, and loss with COVID-19. Several people who contracted COVID-19 created comics that illustrated their thoughts as they managed symptoms with the infection progression. Jason Chatfield, a New Yorker cartoonist, documented his experience with COVID-19 as a public warning in his graphic medicine piece “Covid-19 Diary” (Canva 2020). In this comic, Chatfield provides caricatures of his physical symptoms including fevers, aches, chills, and anosmia to tell his personal story. Other individuals created comics to cope with social isolation and find humor amid frustration or loneliness. For example, professional cartoonist and author Roz Chast created and posted comic panels through social media, highlighting hyperbolic extremes of pandemic behavior, such as panic buying Fig Newton boxes or placing the family dog into a hazardous materials suit. Such creation and sharing were not confined to professional artists, as members of the lay public also used artwork to share stories of frustration, humor, suffering, and illness, or to exhort others toward safety measures to slow viral spread. Regardless of skill level, patients of all ages and backgrounds used comics as a means of documenting their lived experiences during the pandemic, both positive and negative.

In addition to individual pathographies, comics were also utilized by institutions and larger medical entities as public health initiatives to educate the public about measures to slow viral spread. Comics provided a more approachable communication medium to motivate the general public, including children, toward responsible behavior during the global pandemic (Ghia et al. 2020). The National University of Singapore Yong Loo Lin School of Medicine published “The COVID-19 Chronicles,” a series of 100 educational comics that explored the pandemic and educated readers in a humorous yet effective way (Kearns et al. 2021a; Tan and Yong Loo Lin School of Medicine 2022). Alongside comics that aimed to address responsible behavior in public settings, comics about the vaccine and its benefits were created to aid in the COVID-19 vaccination campaign. “Having a Vaccine for Coronavirus” by Sheila Hollins and illustrated by Lucy Bergonzi is a short graphic medicine piece that utilized basic health icons instead of words in its panels to recount the vaccination experience, answer questions, and ease fears about pursuing a vaccine (Hollins 2021).

In addition to broader institutional efforts, individuals who wanted to share additional accurate information about curbing the virus also took advantage of the spread of comics via social media to educate others. For example, Dr. Ciléin Kearns, a medical illustrator and doctor who uses the moniker “Artibiotics” online, created several infographics that describe best practices including social isolation, proper hygiene, and information about the spread of COVID-19. Using bold colors, Kearns employed a combination of graphs and text to show how transmission occurred between the affected and unaffected, with red clouds representing transmission of viral particles through short-range aerosol particles (Kearns and Kearns 2020). Other practitioners used their knowledge and background in medicine to design comics to combat misinformation about COVID-19. Dr. Tommy Brown, a doctor in the United Kingdom created comics to debunk several COVID-19 conspiracy theories including the myth that face masks causing carbon dioxide poisoning, concerns that the vaccine might change the recipient’s DNA, and the misconceptions that the vaccine had been rushed through the approval process or was only for the elderly or at-risk populations (Brown 2021).

At the height of the pandemic, practitioners were often left to wrestle in isolation with both the physical and emotional toil of widespread death, suffering, and uncertainty. They were cut off from a public that at times had little understanding of what was happening within healthcare settings. Many clinicians turned to comics to share their experiences, process their traumas, and educate the public about what they were seeing in clinics, nursing homes, emergency departments, and the hospital wards. These comics created by practitioners offered the public a window into spaces that were often left unseen by non-clinicians during the strict isolation precautions instituted at the outset of the pandemic (Callender et al. 2020).

In one example, an intensive care unit nurse Agnes Boisvert from St. Luke's hospital in Boise, Idaho and illustrator Isabel Seliger collaborated to produce a comic for National Public Radio (U.S.) entitled, "How One COVID-19 Nurse Navigates Anti-Mask Sentiment," to share Boisvert's personal experiences grappling difficult emotions including anxiety, hope, disappointment, and frustration during the pandemic (Kellman et al. 2021). Boisvert describes her challenges in facing the anti-mask sentiment in her community while trying to educate them about all the loss and death she witnesses in the hospital (Kellman et al. 2021).

1.10 Challenges and Future Directions

Despite the promise and potential of creating and disseminating graphic medicine to improve healthcare, significant challenges and opportunities remain. Comics have long wrestled for recognition and legitimacy against stereotypes of the medium as "low-brow," juvenile, or primarily recreational rather than educational. This ambivalence or bias against comics may be particularly pronounced in some arenas of academic medical education, where even the terminology of "comics" may be avoided in favor of terms that appear to lend greater cultural authority, such as "graphic novel" or "graphic essay" (Humphrey 2014). While interest in comics is growing among medical schools, clinicians, and even scholarly scientific journals, longstanding misunderstanding of the medium may still create barriers to use. Some individual readers who do not consider themselves comic consumers may also be resistant to the idea of accepting comics for educational or coping purposes due to preconceived ideas about the medium.

While the accessibility and openness of comics as a medium for anyone invites many creators into the process, the highly subjective nature of graphic medicine also provides room for unforeseen misinterpretation and possible challenges in making comparisons among different pieces of work. Experiences of illness are also by their nature individualized and not always generalizable to the general public. Dramatic imagery could promote connection among patients sharing an illness or could provoke anxieties or anticipatory distress in patients delving deeply into the experiences of someone whose illness has progressed beyond their own; thus far, there is little research into the effects of reading graphic pathography among patients affected with the illness represented.

Graphic medicine's use of caricature, hyperbole, abstraction, metaphor, and an author's visual recall to convey emotional or traumatic experiences may also leave the field subject to criticisms that readers are being offered a view of illness and healthcare that is more "fiction" or embellishment rather than "fact." However, Pedri argues that this unique space of graphic memoir, not wholly constrained to either fact or fiction, may be part of its power—abolishing the boundary between the two and allowing the creator to better represent and acknowledge their inherently subjective experience of events (Stein and Thon 2013).

In addition to theoretical constraints mentioned above, there are practical barriers to the implementation of comics in education. Making high-quality educational comics is an extremely labor-intensive process that involves careful planning, scriptwriting, drawing, and sometimes coloring. Adapting materials to language and developmental level also requires deliberate attention to the nature of both text and illustration. For example, if a comic is intended for children or pediatric patients, using vocabulary appropriate to developmental level and less detailed imagery may help readers better understand the story. However, these challenges are not insurmountable. Medikidz is a global initiative that has successfully created a broad library of comic materials directed at illness and healthcare education for children and youth, using the combined expertise of comic creators and physicians (Thakkar 2011). Their model has been extremely successful, distributing millions of copies of books explaining topics as diverse as cancer, clinical trials, and head lice.

In addition to the practical challenges of creating comics, measuring graphic medicine's effects and impact can also be difficult. Most studies only look at short-term effects of graphic medicine exposure or have used primarily qualitative data to demonstrate potential uses (Gillies et al. 1990; Kim et al. 2017). Future studies need to also examine the long-term effects of graphic medicine on learning and memory retention, employing controls or comparators, and ideally using larger samples with randomization. Another difficulty is heterogeneity of intervention, which is inherent to graphic medicine studies. Comics can take an infinite number of styles, forms, and quality, making it difficult to generalize positive findings regarding the successful application of one comic to similar applications of different comics, even for the same general purpose. While studies of text versus comics have been undertaken, future study should also compare comic formats of education delivery to other modern media methods including video and interactive digital tools. Such data would bolster the case for comics and help overcome bias against the comic medium as a serious form of information delivery.

Finally, as the role of graphic medicine in healthcare and education grows, it is important to ensure that comics are inclusive and broadly applicable. Creating comics that connect with their intended audience through sensitive and appropriate character representation is critical, but requires deliberate effort (Hague and Ayaka 2018). Having visually relatable characters can help readers better place themselves into the narrative, but the nuances of accurate use of language, dress, and culture can be difficult to capture without preparation. Ill-informed or inaccurate attempts to connect with the idiosyncrasies of culture could actually alienate rather than engage an audience. "Lissa: a story about medical promise, friendship, and revolution," mentioned previously, provides an example of how intensive contextual effort can help a production team develop a culturally appropriate reflection of characters in a long-form comic book; the production team for this graphic narrative relied on hundreds of interviews and ethnographic research in Egypt and the USA in the process of producing their comic (Hamdy et al. 2017).

A promising response to the challenge of developing culturally sensitive and accurate graphic medicine materials is the involvement of potential intended audience members in conceptualization, creation, and editing of materials. When comic materials are created with the aid of the intended target audience, the individuals' expertise in their lived experience can be merged with the technical expertise of comic creators and public health educators. In one such effort, McNicol and Leamy describe a case example of collaboration between people living with dementia and the study team, working together to create comics about dementia (McNicol and Leamy 2020).

In another example of such co-creation, public health researchers "crowdsourced" educational models for HIV pre-exposure prophylaxis (PrEP) in China through an open call for content material and also invited participants from the community to be part of the judging process (Sha et al. 2022). Comic formats were one form of materials submitted and were chosen as part of the final selected content for integration into the intervention, which will be rolled out among the study participants with follow-up over 12 months to assess effectiveness in promoting PrEP adherence following initiation. Future graphic medicine work like this, involving partnership with the community during both conceptualization and creation, has the potential to better ensure that materials are relevant and useful to their target audience.

1.11 Conclusions

The expanding forum of graphic medicine offers a wealth of opportunities for communication, connection, and coping in science and medicine. The scope and acceptance of graphic medicine continue to grow rapidly, mandating ongoing development in comics literacy and scholarship to guide the development of the field. While the scope of this review is by no means comprehensive, we have attempted to provide a broad overview of advantages of the comic medium as a vehicle for delivering content in a way that humanizes health information through art and narrative. In addition, we have highlighted diverse current and future uses for comics in education, patient care, and public health, along with challenges that lay ahead for the study of graphic medicine. Among an ever-expanding field of routes for education and connection, graphic medicine holds an evolving and promising place for the future.

References

Adamidis F, Kum L, Kitta A, Unseld M, Praschinger A, Koblizek R, Anvari-Pirsch A, Kutalek R, Melichar P, Zeilinger EL, Masel EK (2022) The potential of medical comics to teach palliative care skills: a cross-sectional study of 668 medical students. Ann Palliat Med 11:3436–3443. https://doi.org/10.21037/apm-22-637

Aleixo PA, Sumner K (2017) Memory for biopsychology material presented in comic book format. J Graph Nov Comics 8:79–88. https://doi.org/10.1080/21504857.2016.1219957

Alemany-Pagès M, Ramalho-Santos J, Azul AM, Tavares R (2020) A healthy liver will always deliver! Coimbra University Press, Coimbra

Alemany-Pagès M, Azul AM, Ramalho-Santos J (2022a) The use of comics to promote health awareness: A template using nonalcoholic fatty liver disease. Eur J Clin Invest 52. https://doi.org/10.1111/eci.13642

Alemany-Pagès M, Tavares R, Azul AM, Ramalho-Santos J (2022b) A healthy liver will always deliver: development of a NAFLD awareness comic. Health Promot Int 37:daac165. https://doi.org/10.1093/heapro/daac165

Alkureishi MA, Johnson T, Nichols J, Dhodapkar M, Czerwiec MK, Wroblewski K, Arora VM, Lee WW (2021) Impact of an educational comic to enhance patient-physician-electronic health record engagement: prospective observational study. JMIR Hum Factors 8: e25054. https://doi.org/10.2196/25054

Anderson PF, Wescom E, Carlos RC (2016) Difficult doctors, difficult patients: building empathy. J Am Coll Radiol 13:1590–1598. https://doi.org/10.1016/j.jacr.2016.09.015

Babaian CS, Chalian AA (2014) "The thyroidectomy story": comic books, graphic novels, and the novel approach to teaching head and neck surgery through the genre of the comic book. J Surg Educ 71:413–418. https://doi.org/10.1016/j.jsurg.2013.11.008

Brown T (2021) COVID-19 Conspiracies/Facts #3: COVID vaccines are safe, they have been prioritised not rushed through. https://teebsdoodles.wordpress.com/2021/02/04/covid-19-conspiracies-facts-3-covid-vaccines-are-safe-they-have-been-prioritised-not-rushed-through/

Callender B, Obuobi S, Czerwiec MK, Williams I (2020) COVID-19, comics, and the visual culture of contagion. Lancet Lond Engl 396:1061–1063. https://doi.org/10.1016/S0140-6736(20)32084-5

Canva M (2020) A New Yorker cartoonist got covid-19. So he drew this public warning. Washington Post

Charon R (2001) Narrative medicine: a model for empathy, reflection, profession, and trust. JAMA 286:1897. https://doi.org/10.1001/jama.286.15.1897

Chiang M, Reid-Varley WB, Fan X (2019) Creative art therapy for mental illness. Psychiatry Res 275:129–136. https://doi.org/10.1016/j.psychres.2019.03.025

Cimermanová I (2015) Using comics with novice EFL readers to develop reading literacy. Procedia Soc Behav Sci 174:2452–2459. https://doi.org/10.1016/j.sbspro.2015.01.916

Cohen SM, Dai A, Katz JT, Ganske IM (2022) Art in surgery: a review of art-based medical humanities curricula in surgical residency. J Surg Educ S1931-7204(22):00265–00263. https://doi.org/10.1016/j.jsurg.2022.10.008

Councilor K (2021) Queer comics. In: Oxford research encyclopedia of communication. Oxford University Press. https://doi.org/10.1093/acrefore/9780190228613.013.1194

Czerwiec MK, Williams I, Squier SM, Green MJ, Myers KR, Smith ST (2015) Graphic medicine manifesto, Graphic medicine. The Pennsylvania State University Press, University Park, PA

da Silva VR, Vieira ML (2022) Evaluation of student engagement through knowledge elaboration and the use of comics in Microbiology education. FEMS Microbiol Lett 369:fnac097. https://doi.org/10.1093/femsle/fnac097

Dunlap-Shohl P (2015) My degeneration: a journey through Parkinson's. The Pennsylvania State University Press, University Park, PA

Earle HEH (2021) Comics: an introduction. Routledge, New York

Eisner W, Eisner W, Eisner W (2008) Comics and sequential art: principles and practices from the legendary cartoonist, The Will Eisner library. W.W. Norton, New York

Engebretsen M, Kennedy H (2020) Data visualization in society. Amsterdam University Press

Engelberg M (2006) Cancer made me a shallower person: a memoir in comics, 1st edn. Harper, New York

Farinella M (2018) The potential of comics in science communication. J Sci Commun 17:Y01. https://doi.org/10.22323/2.17010401

Ghia J-E, Gaulin S, Ghia L, Garancher L, Flamand C (2020) Informing children citizens efficiently to better engage them in the fight against COVID-19 pandemic. PLoS Negl Trop Dis 14:e0008828. https://doi.org/10.1371/journal.pntd.0008828

Gillies PA, Stork A, Bretman M (1990) Streetwize UK: a controlled trial of an AIDS education comic. Health Educ Res 5:27–33. https://doi.org/10.1093/her/5.1.27

Green MJ (2013) Teaching with comics: a course for fourth-year medical students. J Med Humanit 34: 471–476. https://doi.org/10.1007/s10912-013-9245-5

Green MJ (2015) Comics and medicine: peering into the process of professional identity formation. Acad Med 90:774–779. https://doi.org/10.1097/ACM.0000000000000703

Green MJ, Myers KR (2010) Graphic medicine: use of comics in medical education and patient care. BMJ 340:c863. https://doi.org/10.1136/bmj.c863

Hague I, Ayaka C (2018) Representing multiculturalism in comics and graphic novels. Routledge, New York

Hamdy S, Nye C (2019) Comics and revolution as global public health intervention: The Case of Lissa. Glob Public Health 1–21. https://doi.org/10.1080/17441692.2019.1682632

Hamdy S, Nye C, Bao S, Brewer C, Parenteau M (2017) Lissa: a story about medical promise, friendship, and revolution, EthnoGRAPHIC. University of Toronto Press, North York, ON

Hollins S (2021) Having a vaccine for coronavirus. Books Beyond Words. https://static1.squarespace.com/static/551cfff9e4b0f74d74cb307e/t/60a3d632949154502805c844/1621350036393/Having+a+Vaccine+for+Coronavirus.pdf

Humphrey A (2014) Beyond graphic novels: illustrated scholarly discourse and the history of educational comics. Media Int Aust 151:73–80. https://doi.org/10.1177/1329878X1415100110

Joshi A, Hillwig-Garcia J, Joshi M, Lehman E, Khan A, Llorente A, Haidet P (2019) Comics as an educational tool on a clinical clerkship. Acad Psychiatry 43:290–293. https://doi.org/10.1007/s40596-018-1016-1

Kasthuri RR, Peter AM (2021) Twelve years of graphic medicine: a conversation with comic nurse on the future of comics and medicine. Configurations 29:97–106. https://doi.org/10.1353/con.2021.0004

Kaye J (2018) Super late bloomer: my early days in transition: an up and out collection. Andrews McMeel, Kansas City, MO

Kearns C, Kearns N (2020) The role of comics in public health communication during the COVID-19 pandemic. J Vis Commun Med 43:139–149. https://doi.org/10.1080/17453054.2020.1761248

Kearns C, Fisher D, Chong YS (2021a) The infective nurture of pandemic comics. Lancet 397:22–23. https://doi.org/10.1016/S0140-6736(20)32550-2

Kearns C, Kearns N, Braithwaite I, Shortt N, Eathorne A, Semprini A, Beasley R (2021b) Using comics and curiosity to drive pandemic research on a national scale. J Vis Commun Med 44:12–22. https://doi.org/10.1080/17453054.2020.1823206

Kellman R, Rott N, Seliger I (2021) COMIC: how one COVID-19 nurse navigates anti-mask sentiment. NPR

Kidd DC, Castano E (2013) Reading literary fiction improves theory of mind. Science 342:377–380. https://doi.org/10.1126/science.1239918

Kim J, Chung MS, Jang HG, Chung BS (2017) The use of educational comics in learning anatomy among multiple student groups: Anatomy Learning Comics. Anat Sci Educ 10:79–86. https://doi.org/10.1002/ase.1619

King AJ (2017) Using comics to communicate about health: an introduction to the symposium on visual narratives and graphic medicine. Health Commun 32: 523–524. https://doi.org/10.1080/10410236.2016.1211063

Klugman CM (2018) Medical humanities teaching in North American allopathic and osteopathic medical schools. J Med Humanit 39:473–481. https://doi.org/10.1007/s10912-017-9491-z

Liao H-C, Wang Y-H (2020) Storytelling in medical education: narrative medicine as a resource for interdisciplinary collaboration. Int J Environ Res Public Health 17:1135. https://doi.org/10.3390/ijerph17041135

Li-Vollmer M (2018) Medical countermeasure comics: visualizing a public health emergency response. Am J Public Health 108:935–936. https://doi.org/10.2105/AJPH.2018.304384

Maatman TC, Prigmore H, Williams JS, Fletcher KE (2019) Patient safety superheroes in training: using a comic book to teach patient safety to residents. BMJ Qual Saf 28:934–938. https://doi.org/10.1136/bmjqs-2018-009094

Maatman TC, Vugrnick B, Manak C, Wrzosek M, Usher C, Williams J, Fletcher KE (2020) Emotional content of comics drawn by medical students and residents. Acad Psychiatry J Am Assoc Dir Psychiatr Resid Train Assoc Acad Psychiatry 44:572–576. https://doi.org/10.1007/s40596-020-01261-6

Maatman T, Green MJ, Noe MN (2022a) Graphic medicine in graduate medical education. J Grad Med Educ 14:113–114. https://doi.org/10.4300/JGME-D-21-01107.1

Maatman TC, Minshew LM, Braun MT (2022b) Increase in sharing of stressful situations by medical trainees through drawing comics. J Med Humanit 43:467–473. https://doi.org/10.1007/s10912-021-09717-y

Marchetto MA (2006) Cancer vixen: a true story, 1st pbk ed. Pantheon Books, New York

McCloud S (2017) Understanding comics, reprint ed. William Morrow, an imprint of Harper Collins, New York

McNicol S (2017) The potential of educational comics as a health information medium. Health Info Libr J 34:20–31. https://doi.org/10.1111/hir.12145
McNicol S, Leamy C (2020) Co-creating a graphic illness narrative with people with dementia. J Appl Arts Health 11:267–280. https://doi.org/10.1386/jaah_00040_1
Merc A (2013) The effect of comic strips on EFL reading comprehension. Int J New Trends Educ Their Implic 4: 54–64
Myers KR, Goldenberg MDF (2018) Graphic pathographies and the ethical practice of person-centered medicine. AMA J Ethics 20:158–166. https://doi.org/10.1001/journalofethics.2018.20.2.medu2-1802
Natter M (2019) Annals graphic medicine—progress notes: tethered. Ann Intern Med 170:W114. https://doi.org/10.7326/G19-0001
Netter FH (1957) Medical illustration; its history, significance and practice. Bull N Y Acad Med 33:357–368
New York State Department of Mental Hygiene (1950) Chic young's blondie in: scapegoat, love conquers all, let's face it, on your own. New York State Department of Mental Hygiene, New York
Noe MN, Levin LL (2020) Mapping the use of comics in health education: A scoping review of the graphic medicine literature. Graphic Medicine
Obuobi S, Vela MB, Callender B (2021) Comics as anti-racist education and advocacy. Lancet 397:1615–1617. https://doi.org/10.1016/S0140-6736(21)00940-5
Ousager J, Johannessen H (2010) Humanities in undergraduate medical education: a literature review. Acad Med 85:988–998. https://doi.org/10.1097/ACM.0b013e3181dd226b
Park JS, Kim DH, Chung MS (2011) Anatomy comic strips. Anat Sci Educ 4:275–279. https://doi.org/10.1002/ase.224
Petersen RS (2011) Comics, manga, and graphic novels: a history of graphic narratives. Praeger, Santa Barbara, CA
Petrou L, Mittelman E, Osibona O, Panahi M, Harvey JM, Patrick YAA, Leedham-Green KE (2021) The role of humanities in the medical curriculum: medical students' perspectives. BMC Med Educ 21:179. https://doi.org/10.1186/s12909-021-02555-5
Pickering T (2017) Diabetes: year one. Pick-Art
Pickering T (2019) Diabetes year one. Drawing my pathography: comics, poetry and the medical self. Comics Grid J Comics Scholarsh 9:8. https://doi.org/10.16995/cg.147
Pincavage AT, Lee WW, Venable LR, Prochaska M, Staisiunas DD, Beiting KJ, Czerweic MK, Oyler J, Vinci LM, Arora VM (2015) "Ms. B changes doctors": using a comic and patient transition packet to engineer patient-oriented clinic handoffs (EPOCH). J Gen Intern Med 30:257–260. https://doi.org/10.1007/s11606-014-3009-4
Putnam GL, Yanagisako KL (1982) Skin cancer comic book: evaluation of a public educational vehicle. Cancer Detect Prev 5:349–356
Regev D, Cohen-Yatziv L (2018) Effectiveness of art therapy with adult clients in 2018-what progress has been made? Front Psychol 9:1531. https://doi.org/10.3389/fpsyg.2018.01531
Ronan LK, Czerwiec MK (2020) A novel graphic medicine curriculum for resident physicians: boosting empathy and communication through comics. J Med Humanit 41:573–578. https://doi.org/10.1007/s10912-020-09654-2
Sabin R (ed) (2010) Comics, comix & graphic novels: a history of comic art, 1. publ. repr. ed. Phaidon, London
Sethurathinam P (2018) Visual analysis of the challenges of care giving in graphic pathographies. Int J Commun Health 1–6
Sha Y, Li C, Xiong Y, Hazra A, Lio J, Jiang I, Huang H, Kerman J, Molina J, Li L, Liang K, Gong D, Li Q, Wu S, Sherer R, Tucker JD, Tang W (2022) Co-creation using crowdsourcing to promote PrEP adherence in China: study protocol for a stepped-wedge randomized controlled trial. BMC Public Health 22:1697. https://doi.org/10.1186/s12889-022-14117-5
Shapiro J, Rucker L, Beck J (2006) Training the clinical eye and mind: using the arts to develop medical students' observational and pattern recognition skills. Med Educ 40:263–268. https://doi.org/10.1111/j.1365-2929.2006.02389.x
Shwed A (2016) Crisis averted in infinite lives: utilizing comics as clinical art therapy. Intima J Narrat Med 1–11
Squier SM, Krüger-Fürhoff IM (2020) PathoGraphics: narrative, aesthetics, contention, community. Penn State Press, University Park
Stein D, Thon J-N (eds) (2013) From comic strips to graphic novels: contributions to the theory and history of graphic narrative, Narratologia. de Gruyter, Berlin
Sutherland T, Choi D, Yu C (2021) "Brought to life through imagery"—animated graphic novels to promote empathic, patient-centred care in postgraduate medical learners. BMC Med Educ 21:66. https://doi.org/10.1186/s12909-021-02491-4
Tan A, Yong Loo Lin School of Medicine (eds) (2022) The COVID-19 chronicles: Singapore's journey from pandemia to peri-pandemic limbo. Yong Loo Lin School of Medicine, National University of Singapore; World Scientific, Singapore
Thacker N, Wallis J, Winning J (2022) 'Capable of being in uncertainties': applied medical humanities in undergraduate medical education. Med Humanit 48:325–334. https://doi.org/10.1136/medhum-2020-012127
Thakkar D (2011) Teaching children through comics. BMJ. https://doi.org/10.1136/sbmj.d5964
Tigges S, Krupinski E, Luhanga U, Schulman D, Risk B (2021) Graphic narrative versus journal article for teaching medical students about P values: a randomized trial. J Am Coll Radiol JACR 18:1176–1178. https://doi.org/10.1016/j.jacr.2021.03.013
Vaccarella M (2013) Exploring graphic pathographies in the medical humanities. Med Humanit 39:70–71. https://doi.org/10.1136/medhum-2012-010209

Venkatesan S, Dastidar DG, Lewis AD (2022) Drawing pain: graphic medicine, pain metaphors, and Georgia Webber's dumb. Perspect Biol Med 65:356–372. https://doi.org/10.1353/pbm.2022.0031
Walrath D, Walrath D (2016) Aliceheimer's: Alzheimer's through the looking glass, Graphic medicine. The Pennsylvania State University Press, University Park, PA
Wang R, Houlden RL, Yu CH (2018) Graphic stories as cultivators of empathy in medical clerkship education. Med Sci Educ 28:609–617. https://doi.org/10.1007/s40670-018-0590-x
Wegner G (2020) Reflections on the boom of graphic pathography: the effects and affects of narrating disability and illness in comics. J Lit Cult Disabil Stud 14:57–74
Whiting J (2020) Comics as reflection: in opposition to formulaic recipes for reflective processes. Perm J 24:19.134. https://doi.org/10.7812/TPP/19.134
Wijaya EA, Suwastini NKA, Adnyani NLPS, Adnyani KEK (2021) Comic strips for language teaching: the benefits and challenges according to recent research. ETERNAL Engl Teach Learn Res J 7:230. https://doi.org/10.24252/Eternal.V71.2021.A16
Williams ICM (2012) Graphic medicine: comics as medical narrative. Med Humanit 38:21–27. https://doi.org/10.1136/medhum-2011-010093
Yang GL (2003) History of comics in education. https://geneyang.com/comicsedu/history.html
Yenawine P (2013) Visual thinking strategies: using art to deepen learning across school disciplines. Harvard Education Press, Cambridge, MA
Yu M (2018) Roles of graphic pathographies in clinical training. AMA J Ethics 20:115–121. https://doi.org/10.1001/journalofethics.2018.20.2.peer1-1802

2 Medical Graphics and Graphic Medicine

Shelley Wall

Abstract

The field of visual communication in healthcare and science is diverse and constantly expanding. The medium of comics offers visual communicators a powerful tool for medical and scientific communication, education, public outreach, and knowledge mobilization to add to their toolkit. Graphic medicine (comics for and about healthcare) has become firmly established as an area of creation and research in the past decade, and visual narratives in comic form are also used increasingly in the communication of basic science. This chapter examines the intersection of medical graphics and graphic science/graphic medicine through the lens of a graphic medicine syllabus used in the teaching of medical illustration graduate students at the University of Toronto, Canada.

Keywords

Graphic medicine · Science comics · Medical illustration · Visual narrative · Pedagogy

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2.1 Background

Since 2012, I have taught a course in graphic medicine—that is, the making, reading, and study of comics related to healthcare and illness—for students in the Master of Science in Biomedical Communications (BMC) program at the University of Toronto, Canada. The course (MSC2022H: Graphic Medicine Seminar) is offered in the second year of a 2-year professional graduate program designed to equip graduates with the competencies in biomedical sciences, communication, technology, illustration, and design that they will need to practice as medical illustrators, medical animators, or in other visual communication roles in healthcare or bioscience. The field of visual communication in healthcare and science is diverse and constantly expanding. Graduates may work in any number of domains, such as public health, patient education, undergraduate or medical education, pharmaceutical advertising, basic science, data analysis, public outreach, or knowledge translation. Their subject matter is wide ranging, encompassing fields as diverse as paleontology and contemporary health policy. The technological landscape in which they practice is shifting constantly and rapidly, as analogue and digital drawing and painting are joined by 3D modeling and animation, data-driven visualizations, information graphics, user experience design, augmented and virtual reality, and, most recently, the possibilities offered by artificial intelligence. While a degree from a

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medical or scientific illustration program can introduce students to domain-, content-, or technology-specific skills, the most enduring and adaptable competency we can instill in them is a flexible, platform-agnostic approach to thinking about visual problem-solving for communication in science and healthcare. Through the lens of this graphic medicine course syllabus, I will look at the intersections between biomedical communication and comics and at how reading and making comics can help to build those visual problem-solving competencies.

When I first proposed the graphic medicine elective course it seemed, on the one hand, like an obvious complement to our existing course offerings, in that it involved combining image and text to address topics in science and medicine. At the same time, it seemed like a strange outlier in a curriculum devoted to rigorous training in human anatomy, molecular biology, pathology, surgical illustration, data visualization, and advanced digital technologies, in that it proposed bringing the populist language and subversive history of comics into serious disciplinary spaces. Comics still receive pushback as a "frivolous" form in disciplines such as medicine; in 2011, that pushback was even stronger than it is today. Nevertheless, the course proposal went through governance and was endorsed within the Institute of Medical Science in the Faculty of Medicine. Enrolment in the early years was small—it is one elective offering among several, in a program with a cohort of 18 students per year—but in recent years has grown to a steady state of over half the registered Biomedical Communications students in a given cohort.

This chapter presents some reflections on what didactic comics—their techniques, their contexts, their ethos—can offer to scientific and medical visualization. My reflections follow the structure of this particular syllabus. Specifically, I consider the burgeoning field of graphic medicine—"the intersection of the medium of comics and the discourse of healthcare" (Czerwiec et al. 2015: 1)—in relation to medical graphics—"drawing and organizing lines and shapes to communicate a specific bit of science-related information to another person" (Christiansen 2023: 13). While graphic medicine includes memoirs of illness and caregiving and addresses the ways in which reading and creating comics might build empathy in medical professionals, this chapter focuses on didactic graphic medicine and science as areas that are closer to the more instrumental roles of biomedical visualization. Medical illustration is not a graphic medicine, but they share exciting and productive points of intersection that deserve exploration.

2.2 Introduction to the Course

The graphic medicine (GM) course begins with an overview of the field. The term "graphic medicine" was coined by physician and artist Ian Williams in 2007 as the name of a website where he posted examples of, and notes on, comics dealing with illness and healthcare (Czerwiec et al. 2015: 116). Through this website, scholars and creators with an interest in comics and medicine came together, and a graphic medicine community was born. The article "Graphic medicine: Use of comics in medical education and patient care," published in the *British Medical Journal* (Green and Myers 2010), marked the first time that comics had been discussed in a major medical journal. Five years later, the *Graphic Medicine Manifesto* defined the term and surveyed the scope of the field. Graphic medicine has now grown into a rich interdisciplinary area of study and creation, encompassing graphic "pathographies" (illness narratives), information comics for patient education and public outreach, and comics used in medical education and for research mobilization. A sister field, science comics, has also burgeoned during this time, with work by, for example, cartoonist and neuroscientist Matteo Farinella, cartoonist and biologist Jay Hosler, cancer-researcher-turned-cartoonist Argha Manna, and many others. Medical illustrators work in these same domains: science communication, patient education, public health, medical education, and research mobilization. They share the same target audiences: patients and caregivers, medical trainees, clinicians, researchers, science students, and the wider public. As we look at some of these domains during the GM course, we consider how comics' visual and narrative strategies operate in a given context, how these strategies overlap with those of biomedical visualization in other forms, and how the language of comics might be adopted or adapted within the medical illustration field.

"Comics" are not necessarily comic. Comics about health often deal with profoundly serious topics such as illness, death, and trauma. As Scott McCloud notes in his seminal *Understanding Comics: The Invisible Art* (a treatise on comics, in comic form), "The artform—the medium—known as comics is a vessel which can hold any number of ideas and images" (McCloud 1993: 6). Jessica Abel and Matt Madden, in *Drawing Words and Writing Pictures*, propose the following questions when considering whether something is a comic: "Are there multiple images that are intended to be read in a certain order? If there's only a single image, does it have a kind of narrative to it? Is there a combination of both text and images?" (Abel and Madden 2008: 5). Note that these criteria are met by many (non-comic) medical and scientific illustrations as well: a sequential illustration of a surgical procedure, a signaling pathway, or an injection technique, for example. The language of comics and the language of biomedical visual communication are cognate in many ways.

2.3 Anatomy and Physiology of Comics

As in an anatomy and physiology course, we begin with the naming of parts and a description of how they function. When it comes to the basic "anatomy" of a comic, anyone who grew up with comics will recognize the panels that often mark the narrative units of a story, and the gutter—the gap—that separates the panels; they will also understand the different forms of discourse represented by speech balloons (utterance), thought bubbles (unspoken thought), and text boxes (a kind of "voice-over" narration) (Fig. 2.1).

As with the anatomy of organisms, variations in the shape, size, number, quality, position, disposition, relationships, and presence or absence of these elements shape the unique character of each work.

Under "physiology" of comics, we look at panel-to-panel transitions, pacing, page layout, and point of view; these elements are bound up with each other and cannot always be completely teased apart. Scott McCloud notes that it is in the gutter—the transition between panels—that "human imagination takes two separate images and transforms them into a single idea" (McCloud 1993: 66). The reader, in other words, forges the meaningful connection between separate panels, achieving "closure" by "observing the parts but perceiving the whole" (McCloud 1993: 63), and thus co-creating the story. While McCloud does not reference reader-response theory, this concept is central to a phenomenological theory of the reading process articulated by Wolfgang Iser: "The convergence of text and reader brings the literary work into existence" (Iser 1980: 50). According to McCloud, different types of panel-to-panel transitions demand different degrees of closure, that is, lesser or greater efforts of interpretation, from the simple moment-to-moment (e.g., an image of a person with eyes open, then closed) to transitions involving shifts in time, place, and actors. Making meaning out of comics demands the active participation of the reader. As a demonstration of the power of designing meaningful transitions, students are asked at the beginning of class to create a simple three-panel story with a beginning, middle, and end; after we have looked at and discussed different types of transitions, they are invited to re-tell the same story, again in three panels, but using different kinds of transitions. This simple exercise is often a powerful demonstration of how intentional choices about transitions, and about the kind of "closure" demanded of the reader, can shift the feeling and even the meaning of a narrative.

When introducing students to the choreography of page layout, I rely on a "Grids and Gestures" exercise developed by comics artist and scholar Nick Sousanis, who observes that "[t]ime, in this static medium, is necessarily

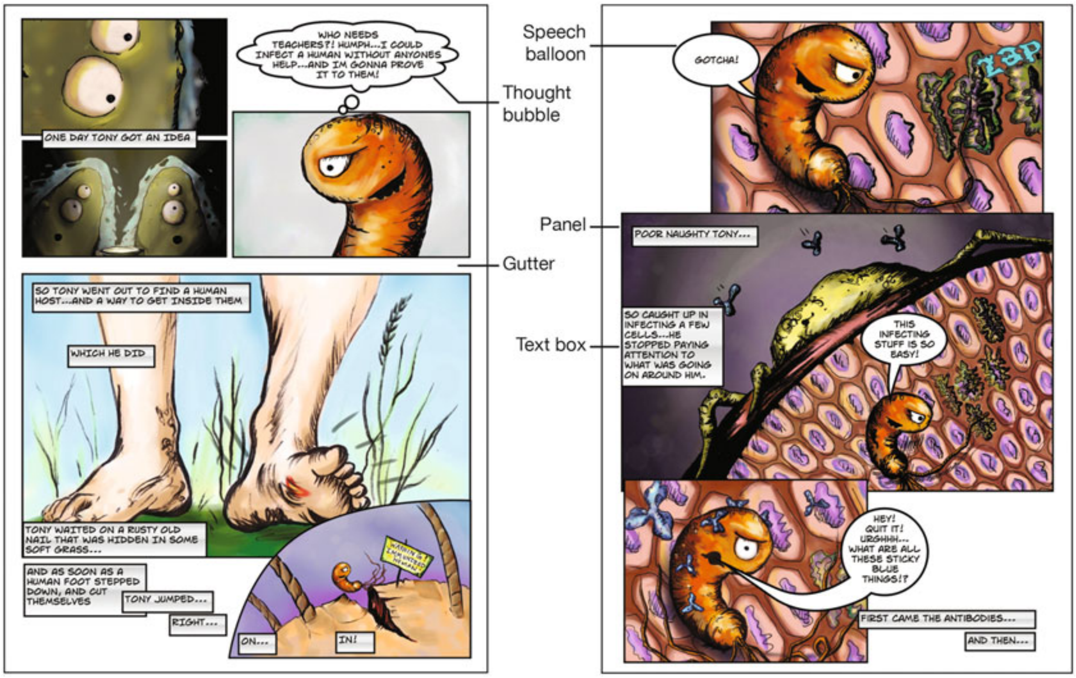

Fig. 2.1 Anatomy of a comic. Work completed in the context of the Graphic Medicine Seminar. Digital illustration by Natalia Burachynsky (2012), annotations by the author. Used with permission

encoded in space" and that, even as the comics reader follows a linear visual narrative, they take in the page as a single visual field, making for an "interplay of sequential reading and simultaneous viewing modes in a single form" (Sousanis 2015a: 1). Sousanis suggests that the architecture of the built environment offers a way to appreciate the rhythm of a comics page: the regular, steady pacing of ceiling tiles, for instance, punctuated by the speedier staccato of an air vent. In the "Grids and Gestures" exercise, students are invited to create a page of panels that represent "the shape of their day," then to fill those panels with non-representational marks that evoke the feeling of each moment/panel. I find that biomedical communication students, attuned as they are to the precise visual representation of empirical information, experience both a challenge and a release in this free-form, non-figurative exercise. At the same time, it offers an object lesson in the message-shaping power of page design.

In conjunction with this exercise, we analyze examples of varying page layout. In the following excerpt from a comic by Emily Taylor, for instance, a regular grid of "small multiples" conveys the protagonist's experience with ineffective acne medications: the passage of time is indicated in text boxes and time codes; the sameness of routine is conveyed through the repetitive, uniform grid structure of the panels (which evoke the protagonist's view in a mirror); and the temporal progression from hope to despair is signaled by the darkening gradient and the protagonist's changing facial expressions (Fig. 2.2).

Information design theorist Edward Tufte writes of small multiples: "As our eye moves from one image to the next, this constancy of design allows viewers to focus on changes in information rather than changes in graphical composition" (Tufte 1990: 29), and we see this "economy of perception" at work in Taylor's comic.

In contrast to the meaningful regularity of this comic, we look at examples of comics that engage the reader in a more complex experience of

Fig. 2.2 Excerpt from "Vulgaris." Work completed in the context of the Graphic Medicine Seminar. Digital illustration by Emily Taylor (2020). Used with permission

layout, such as Nick Sousanis's "Against the Flow" (Fig. 2.3).

This virtuosic piece leads the reader's eye in a complex dance across the page, at first in a regular, linear pattern beginning at the top left, then diving diagonally and hooking upward, then in a double spiral that leads to the center of the page and back out again, ending in the bottom right-hand corner. Overall, conventional Western reading gravity is observed (upper left to bottom right), with a gravity-defying performance in the middle—a visual that embodies the conceptual content of the piece, which is the progression of entropy and the counter-eddies that defy it. This comic demonstrates the strategies an artist can use to guide the reader's eye in a precisely determined order through a dense array of information, as well as the ways in which the visual form of a narrative can profoundly enhance the reader's understanding of its content.

Finally, we consider point of view: Who is the "agent of perception" (Bal 2017: 12)—that is, through whom or what is the narrative focalized? In illness narratives, focalization can be a means of conveying subjective experience, as in this excerpt from Matthew Jang's story of the protagonist's mother's surgery (Fig. 2.4).

A recognized function of reading such illness narratives, in the context of medical education, is to encourage healthcare trainees and practitioners to empathize with the patient's perspective (Green and Myers 2010; Anderson et al. 2016; Myers and Goldenberg 2018; Ronan and Czerwiec 2020; Sutherland et al. 2021); here, for example, the reader appreciates the patient's apprehension about what might be simply the unremarkable tools of the trade to a surgeon. In patient education, a shift in narrative point of view can encourage the reader to take a different perspective on the material being presented. Natalia Burachynsky's comic "Germageddon," for example, tells the story of immunity and vaccination from the perspective of a virus and a bacterium (Fig. 2.5).

Not only does this reversal of the usual point of view in vaccine education add humor, but it also encourages the reader to translate the narrative back into human terms—that is, to reverse the germs' message that "vaccines are a tragedy" into the human-centered message that "vaccines are beneficial," thereby giving the reader an active share in forging a positive public health message. Narratologist Mieke Bal notes the importance of distinguishing between the narrator (the "speaker" of the text) and the focalizer—the "agent of perception" (Bal 2017: 12). In the case of Jang's comic, for example, the narrator is the patient's son, while the patient herself is the agent of perception. Recognizing these nuances in *how* a story is told can expand the repertoire of a visual biomedical communicator and provide them with strategies to enhance the messages they seek to convey. We return to these aspects of the physiology of comics—transitions, page layout, and point of view—throughout the course, as we delve into the use of comics in various domains related to healthcare and science.

2.4 Didactic Comics for Patient Education and Public Health

Patient education and public health outreach are core domains of practice in medical and scientific visualization. Introducing students to the use of comics in these domains allows them to gain an overview of some general principles of visual communication in patient education and public health, as well as insights into the medium-specific features that comics have to offer. Well-designed visuals in any media can enhance patient comprehension and help to mitigate language, literacy, and health literacy barriers (Houts et al. 2006; Osborne 2006; Pratt and Searles 2017; Haragi et al. 2019; Hollingdrake et al. 2022). Comics, specifically, have been demonstrated to be an informative and appealing format for health communication for both children and adults (Muzumdar and Pantaleo 2017; Mendelson et al. 2017; Hanson et al. 2017; Brand et al. 2019a, b; Kearns and Kearns 2020; Cuauhtemoc 2021). Comics bring the tools of narrative, dialogue, relatable characters, humor (when appropriate), and visual metaphor to the communication of health information. (All of these features can be seen in the "Germageddon" excerpt above.)

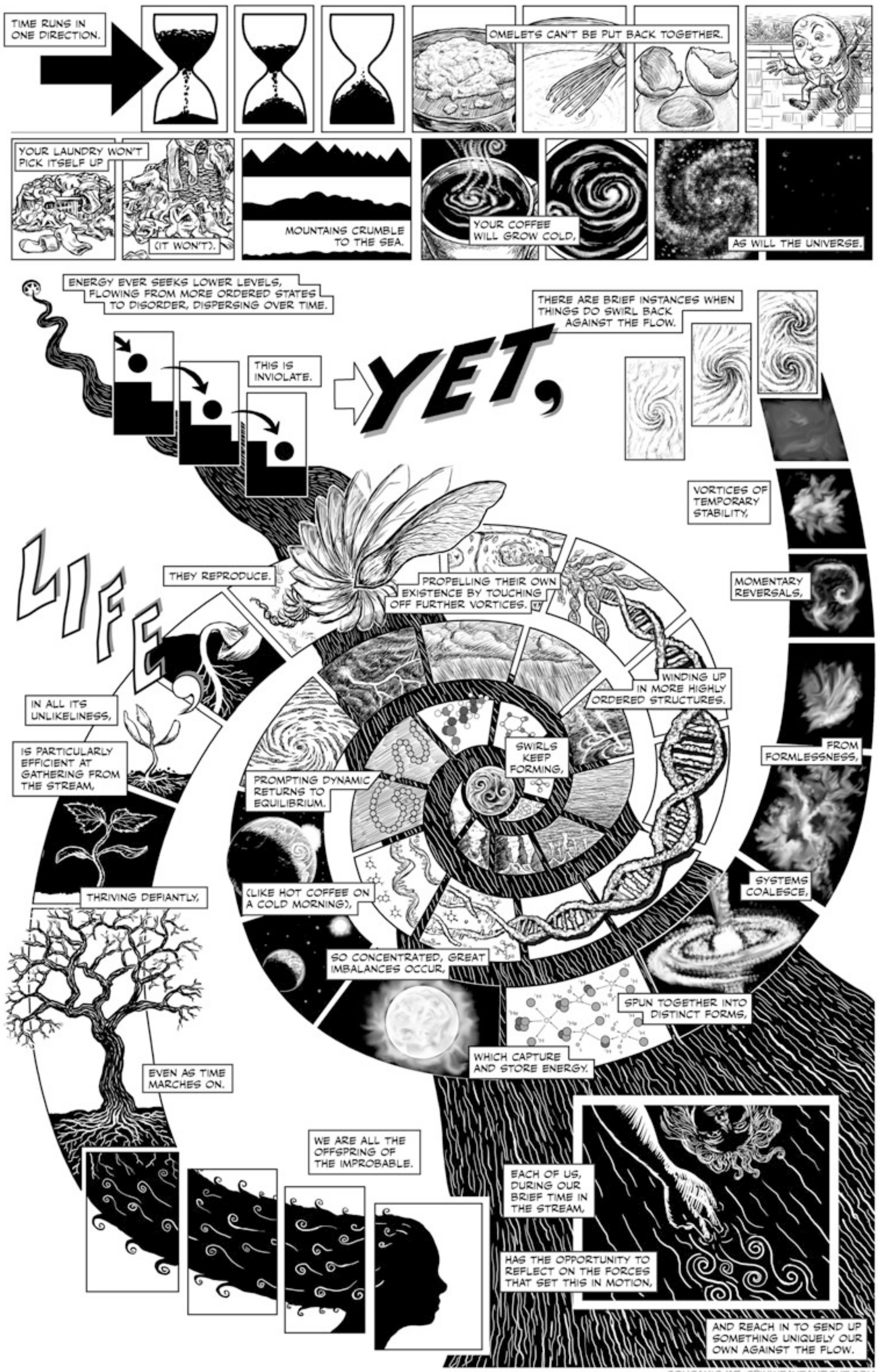

Fig. 2.3 "Against the Flow." Digital illustration by Nick Sousanis, first published in *The Boston Globe*, 4 October 2015. Used with permission

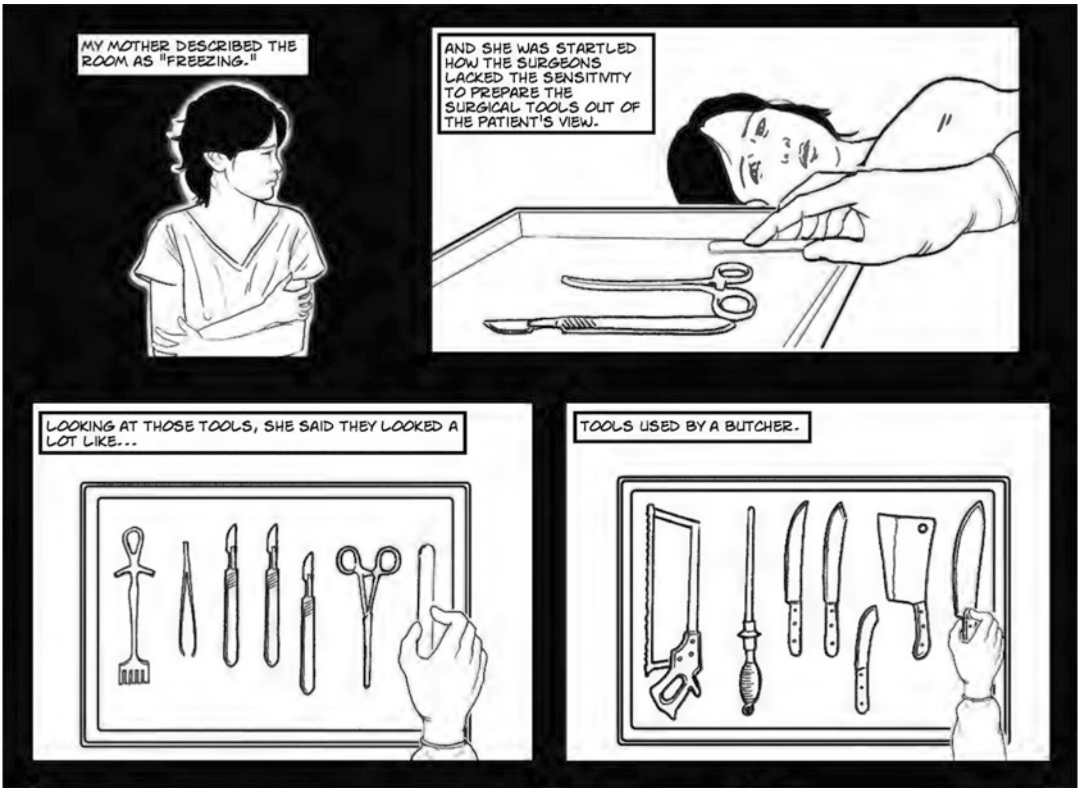

Fig. 2.4 Excerpt from "If You Just Smile." Work completed in the context of the Graphic Medicine Seminar. Digital illustration by Matthew Jang (2012). Used with permission

Patient education works across a number of dimensions. One obvious purpose is to inform—to convey information on a cognitive level. But patient education works on an affective level as well: it influences engagement and can therefore shape behavior, through appeals to patients' emotions, values, and social relationships (Roter et al. 1998). Comics have something unique to offer in addressing this affective dimension. As Sarah McNicol notes, "While a straightforward patient information leaflet can convey factual information, a comic can also help patients (and carers) understand much more about the fears, anxieties and expectations a patient may need to deal with" (McNicol 2014: 50).

Comics for patient education offer a study in the importance of tailoring a message to its specific target audience. For patients to be engaged by the material they are given it is essential that the visuals reflect, at least broadly, their values and their lived experience. Indigenous Story Studio, based in British Columbia, produces comics and other media on health and well-being that reflect the history, social and geographical contexts, cultural practices, values, and determinants of health of Canada's Indigenous populations. *Silent Enemy* (Ryan et al. 2017), for example, tells a story of early cancer detection and treatment, interleaved with a story of the protagonist and his children becoming stranded in the bush in a snowstorm and working together to fight off a cougar. The comic emphasizes the fact that dealing with a cancer diagnosis is not the experience of one individual alone but also of their family and support system and that "working together" is a key part of recovery. As we see in the (non-contiguous) excerpts reproduced below, changes in color palette signal the shifts

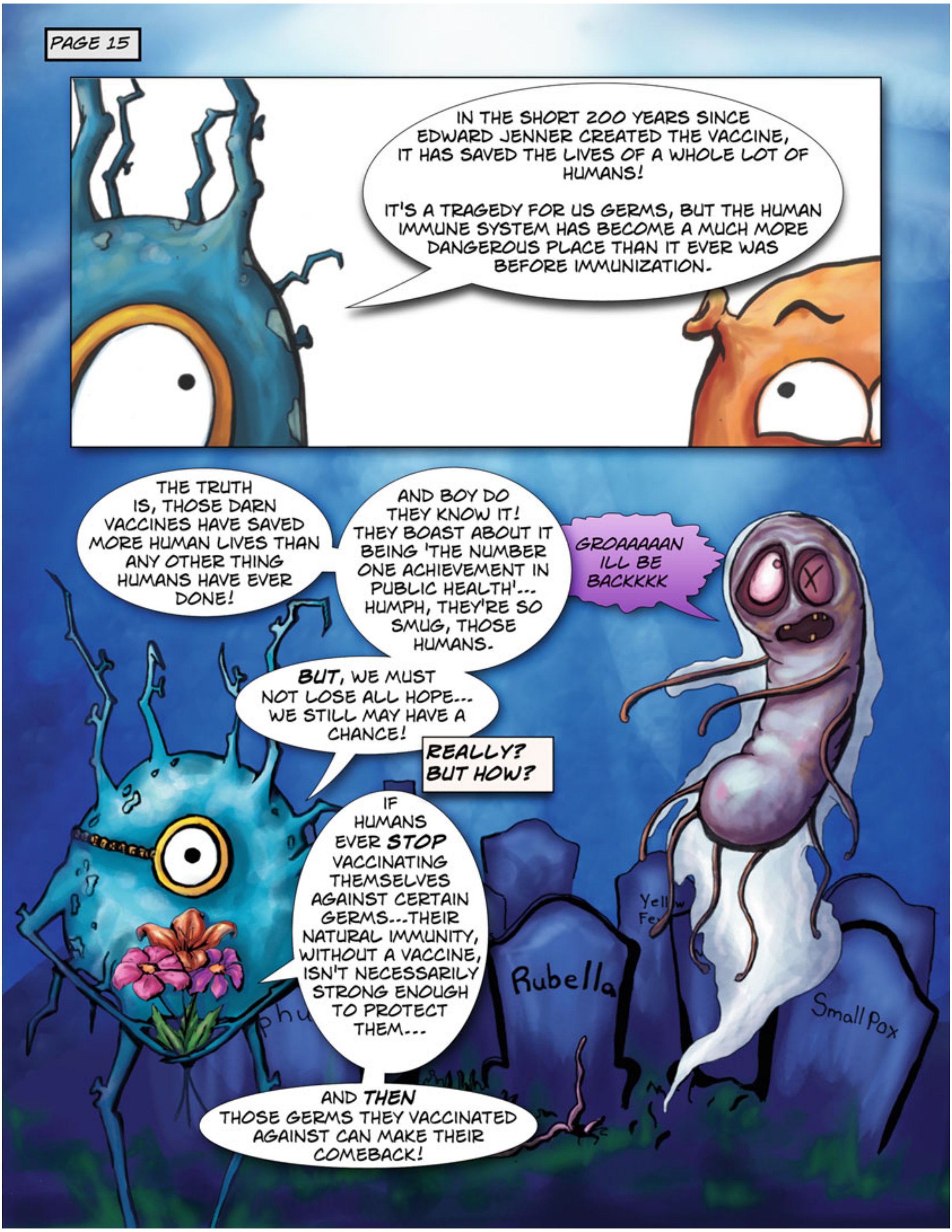

Fig. 2.5 Excerpt from "Germageddon." Work completed in the context of the Biomedical Communications graduate program. Digital illustration by Natalia Burachynsky (2012). Used with permission

between storylines (the hike, in an earlier time; the cancer treatment in the narrative present); changes in typography and a shift to what McCloud would call "aspect-to-aspect" transitions signal the didactic portion of the narrative (Fig. 2.6).

When information is embedded in a narrative, readers can see themselves reflected in the situation. A pilot study assessing the effectiveness of a comic as supplementary patient information before coronary angiography in comparison with the standard textual intervention, for example, found a significant increase in patient comprehension and satisfaction and a decrease in anxiety in patients who received the comic (Brand et al. 2019a) (Fig. 2.7).

These excerpts demonstrate the embedding of typical patient-education materials (e.g., simplified diagrams of the heart and arteries) within a narrative of the informed consent process and the medical procedure itself. They provide a sense, not only of what the procedure *is*, but also of what the patient will experience (e.g., how he will be positioned; elsewhere in the comic the protagonist experiences the warmth of the contrast medium and the chest pressure as the balloon catheter is inflated). Because the narrative is focalized through the patient (the patient as the agent of perception in receiving information), these excerpts capture the patient's affective responses as well: his dismay at the density of textual information in the consent form, and his anticipation of activities he will be able to engage in as a result of having the procedure.

Sometimes, however, a non-specific, purely metaphorical visualization is most appropriate. In the case of visuals for trauma therapy, for instance, the depiction of specific situations, even specific physical features, can be re-traumatizing. In the following example of the "parallel lives" model of trauma, based on a model by Deirdre Fay and co-created by an artist and a team of trauma therapists, an almost wordless comic describes the way in which, when an individual with a history of trauma "is triggered, material from the past explodes or implodes into the present in the form of thoughts, feelings, sensations, impulses, or behaviors" (Hershler et al. 2021: 34). The visual metaphor (tripping and falling into a body of water, becoming entangled in weeds, carrying those weeds back to the surface) is complemented by the use of page layout: the upper and lower panels signify present and past; the breaking of the panel frame as the individual falls through the gutter signifies the breaching of the barrier between present and past. The character itself is amorphous, providing a presence into which readers may project themselves as they map their specific history onto the metaphorical model (Patricia Nguyen, the artist, is a medical illustrator and an alumna of the Graphic Medicine Seminar.) (Fig. 2.8).

A key feature of these examples is their attention to context of use. As with all good medical and scientific visualization, the creator considers not only the target audience—their cognitive and emotional needs—but also where and when they will encounter the information. While "Silent Enemy" does not have a specified context of use, it is a free-standing narrative that can convey a public health message without commentary or guidance. The patient-informed consent comic was designed specifically as a supplement to consultation with a healthcare professional. "Parallel Lives" is intended to be shared and discussed in an individual or group therapy session; the comic is accompanied by a guide for clinicians, suggesting how a client might be encouraged to interact with the model under the guidance of a therapist.

The COVID-19 pandemic made the need for accurate, effective, engaging public health education more urgent than ever. The accessibility and affordances of comics made them a natural medium for this purpose. Medical artist and illustrator Ciléin Kearns calls attention, not only to the virtues of image/text synergy, narrative, and visual metaphor noted above, but also to the value in using simplified characters, even anthropomorphic animal characters, to allow identification with the narrative across many demographics, while also "disrupt[ing] associations between ethnicity and COVID-19" in the wake of a pandemic upsurge in anti-Asian racism (Kearns and Kearns 2020: 140).

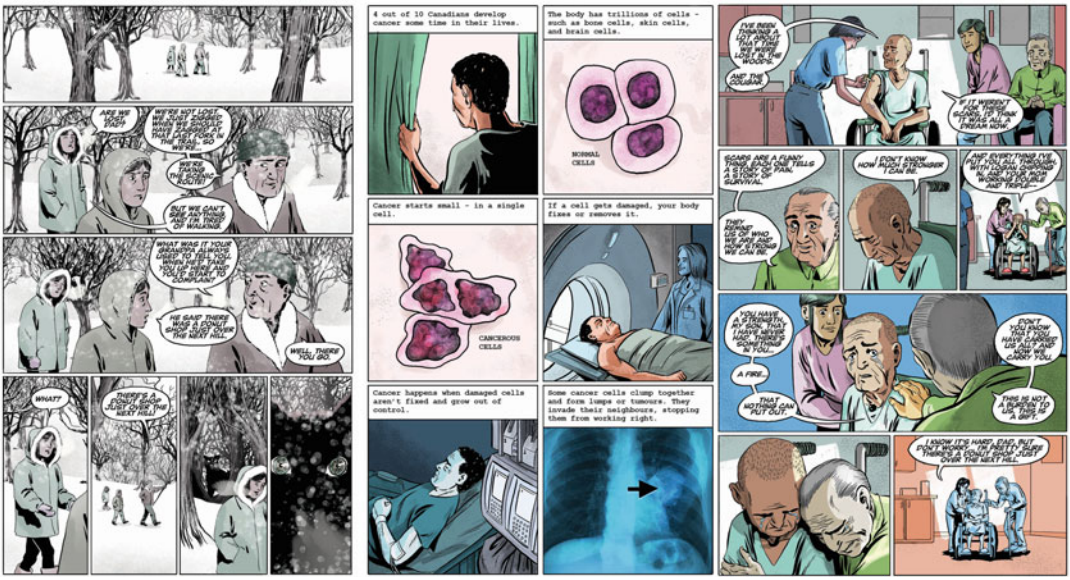

Fig. 2.6 Excerpts from "Silent Enemy" 2017. Cancer Care Ontario and The Healthy Aboriginal Network. Used with permission

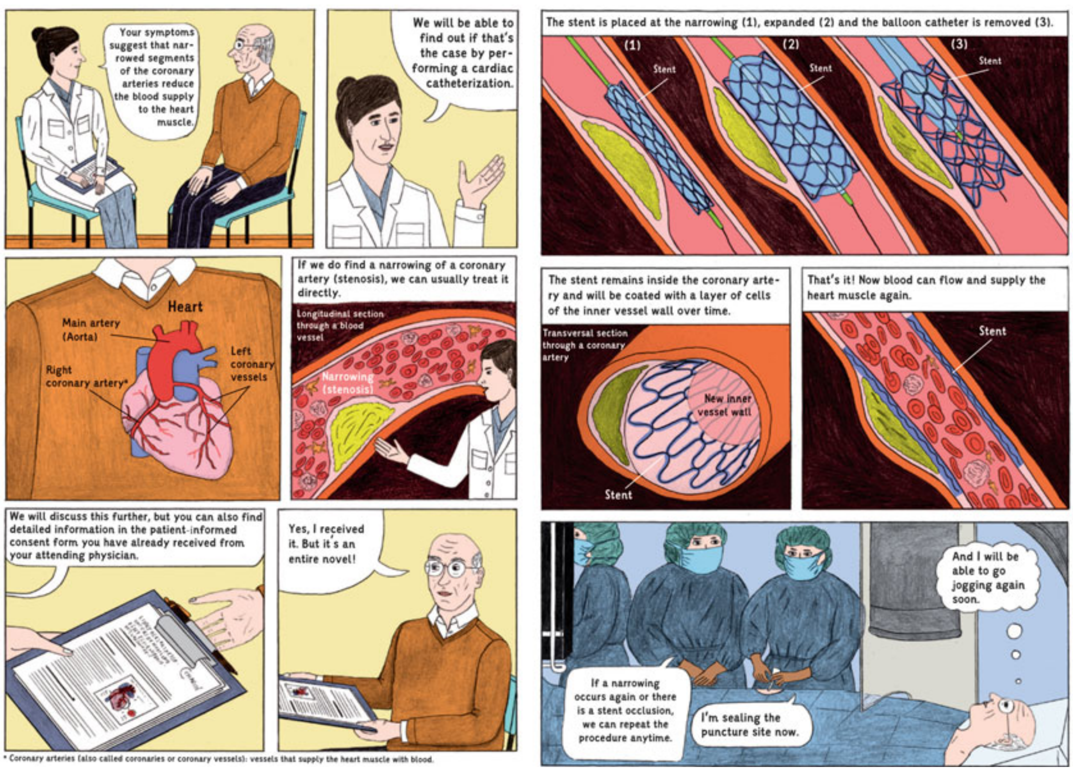

Fig. 2.7 Excerpt from "Patient-Informed Consent" by Brand et al. (2019b). Used with permission

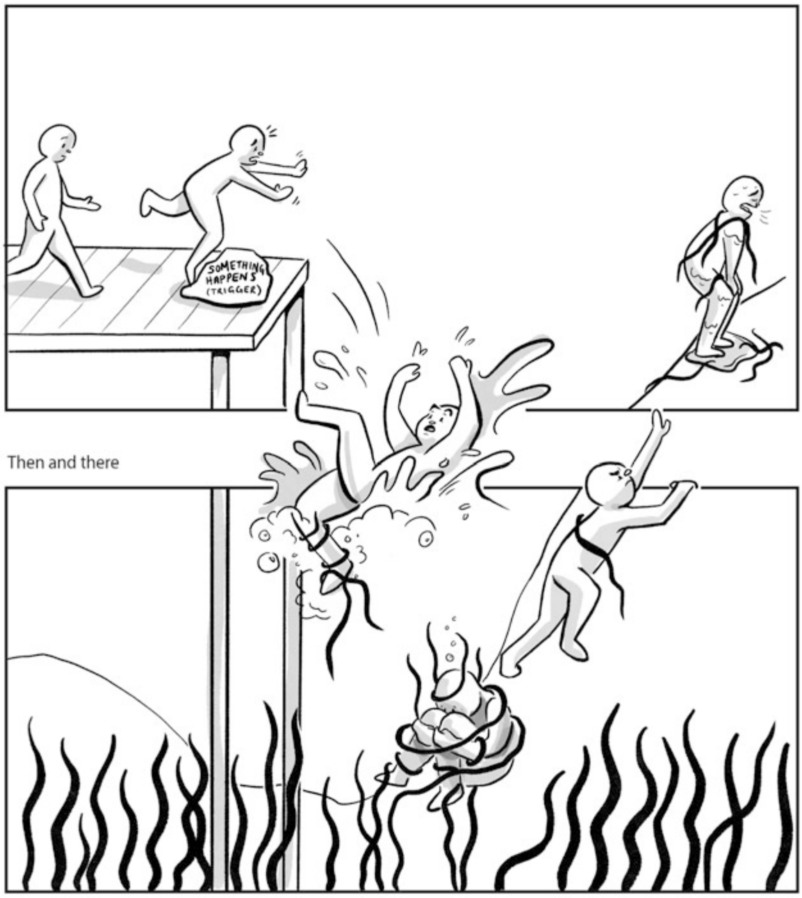

Fig. 2.8 "Parallel lives," reproduced from *Looking at Trauma: A Toolkit for Clinicians* (Hershler et al. 2021). Digital illustration by Patricia Nguyen. Used with permission

2.5 Comics for Science Communication

Comics are inherently multimodal, working as they do with the interplay between image and text. The text can comprise different modes of discourse: dialogue, reported dialogue (e.g., quotations), unspoken thoughts, exposition, labeling, or even representations of sound effects. The visuals, too, can be multimodal, incorporating the discourse of medical illustration (e.g., a diagram of the arteries, an image of cells in a microscopic field) into narrative panels, as seen in the examples above. This discursive flexibility comes to the fore in didactic comics about science, to which we turn in the next phase of the Graphic Medicine Seminar curriculum.

Visualizing scientific information for diverse audiences is also a core domain of practice for biomedical communications graduates. Audiences may include not only patients (as in patient education), but also students, the general public (as in public health and science outreach), and researchers. Empirical data on the effectiveness of comics in science, technology, engineering, and mathematics (STEM) outreach are limited (Farinella 2018b), in part because of the many variables involved: engagement and information acquisition require different measures; studies conducted with students may not reflect the efficacy of science comics among the general public; and the narrative strategies and aesthetics of comics for science communication are highly variable. What follows is an overview of some of the strategies we consider in the course, given all of these factors. The employment of a particular narrative/expository strategy will vary depending on target audience, subject matter, and context of use, but examining an array of examples provides students with tools in their visual communication toolkit, to be used according to the context.

We begin with the question "Who is speaking?" Despite the assumed objectivity of science, there is always a seeing eye, a speaking "I": knowledge is always situated. Identifying the narrator and the agent of perception (focalization) in science comics can be a means either to engage the reader in creative interaction with the information or to establish credibility, or both.

One approach to science communication in comics is the use of an omniscient narrator—the impersonal "voice-over" afforded by text boxes. This approach is perhaps closest to the more typical textual discourse of science communication, in which non-embodied speech serves as a marker of objectivity. Caitlin Chang employs this approach in a comic describing the physiology and psychological implications of hypervigilance (Fig. 2.9).

The images in this comic are supplementary to the text, which may be read without the illustrations and still make sense (but with significantly reduced impact). They illustrate the text, using visual metaphor and humor to provide supplementary explanation and commentary—for example, the individual crushed by the word "hypervigilance," or the succession of figures with their bodies literally separated from their heads. The "narrative" is the story of the biological origins, physiology, and treatment of hypervigilance, but sequential visual narrative—the longitudinal relationship among panels—is less important than the "cross-sectional" relationship between image and text within each panel.

Some expository comics employ an embodied narrator, a character who speaks directly to the reader and guides them through the information. The presence of an identifiable narrator provides an explicit conduit between text and reader. If we imagine a comic narrative as a drama played out on a stage, the inclusion of an embodied narrator "breaks the fourth wall," speaking directly to the reader while also interacting with the constructed world of the comic. Scott McCloud provided an early and significant example of such a character in *Understanding Comics*, which begins with his avatar introducing himself, describing his early experience with comics and the questions that led him to write the book. A more recent example appears in "A Comic Strip Tour of the Wild World of Pandemic Modeling" (Weinersmith et al. 2020; https://fivethirtyeight.com/features/a-comic-strip-tour-of-the-wild-world-of-pandemic-modeling/), a webcomic that appeared on 13 April 2020 as people around the world were contending with a daily flood of statistics and projections. In this comic, the figure of an unnamed data journalist walks us through the ways in which data are collected and analyzed to project fatality and infection rates, and the many variables and unknowns that make pandemic modeling a moving target. Rather than being situated within a stable, real-world space, she inhabits the world of information—standing on a world map as she discusses international variability, for example, or addressing the reader from the deck of the Diamond Princess in describing what that closed system might, or might not, tell us about statistics in the wider population. *FiveThirtyEight*, the journalism website where the comic appears, specializes in data-driven journalism. In keeping with their stated mission to "use data and evidence to advance public knowledge—adding certainty where we can and uncertainty where we must" (FiveThirtyEight 2023), the embodied narrator presents what is known about pandemic modeling while acknowledging the many gaps and ambiguities and acknowledging the frustration in trying to find stability on such shifting ground. A loose narrative through-line is provided by the character's journey through the information as she presents it to the reader and models the activity of meaning-making.

Other didactic comics employ narrative explicitly, using story, characters, and situations to impart information and to model behavior. The Wellcome Centre for Integrative Parasitology (WCIP), for example, has a program of using comics for public engagement. "Helminths: The Secret World of Parasitic Worms" tells the story

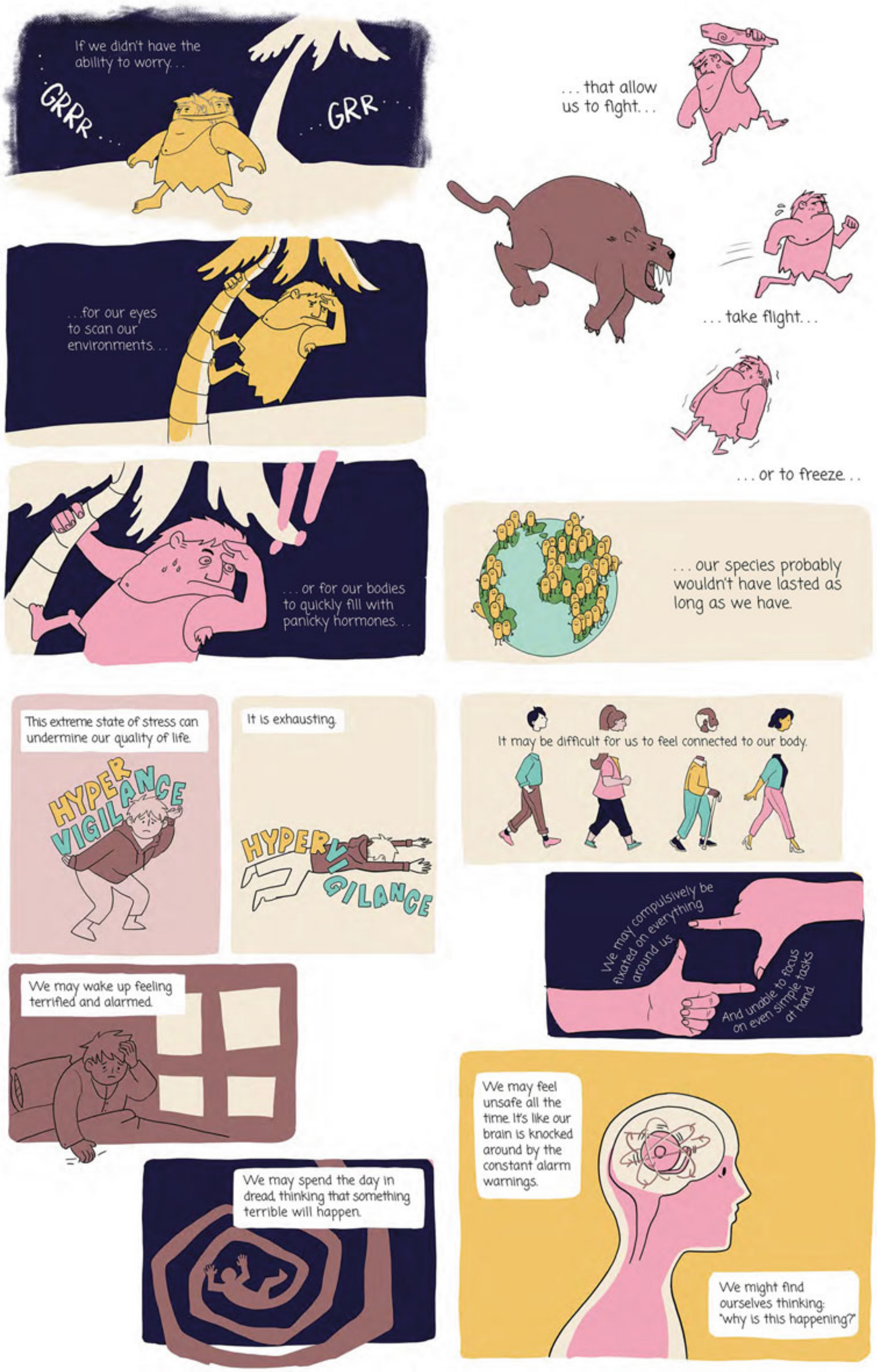

Fig. 2.9 Excerpts from "Hypervigilance." Work completed in the context of the Graphic Medicine Seminar. Digital illustration by Caitlin Chang (2021). Used with permission

Fig. 2.10 Excerpts from "Helminths: The Secret World of Parasitic Worms." Comic by Jamie Hall and Edward Ross (2020). Wellcome Centre for Integrative Parasitology. Used with permission

of a Scottish researcher traveling to Uganda, where she meets local researchers and community members who explain to her, and to each other, the biology of helminths as well as the social, economic, and medical contexts in which they exist and are studied (Fig. 2.10).

This comic and others on topics such as malaria, toxoplasmosis, and sleeping sickness are distributed around the world, including the UK and Africa. In a blog post about the Centre's comics program, they write: "Our comics link what we do every day in our labs, to the experiences of those living in regions where parasitic diseases are endemic. This is what makes them so powerful" (WCIP 2016).

Another approach to comics-based science communication is the Socratic method—a dialogue between teacher and student—which lends itself well to narrative dramatization. Biologist, comics artist, and researcher Jay Hosler uses the characters of Wilbur (a fly) and Ant Edna (an ant) to enact dialogues about basic concepts in biological science for undergraduate teaching. This provides opportunities for humor, appropriate for Hosler's primary audience (Fig. 2.11).

Wilbur is the "ignorant" character, giving voice to exaggerated versions of the kinds of questions a novice student might ask. These questions can then be explored as Edna provides instruction and Wilbur works through the problems for himself. Visual analogy is a powerful, indeed essential, tool in scientific thinking: "scientific practice fundamentally rests on models and metaphors" (Farinella 2018a: 5). Farinella notes the "deeply metaphorical" nature of comics, with their "rich vocabulary of marks and symbols" (much like medical and scientific illustration), which "make comics an ideal format to build extended conceptual metaphors" (Farinella 2018a: 8). Hosler's comic is openly self-

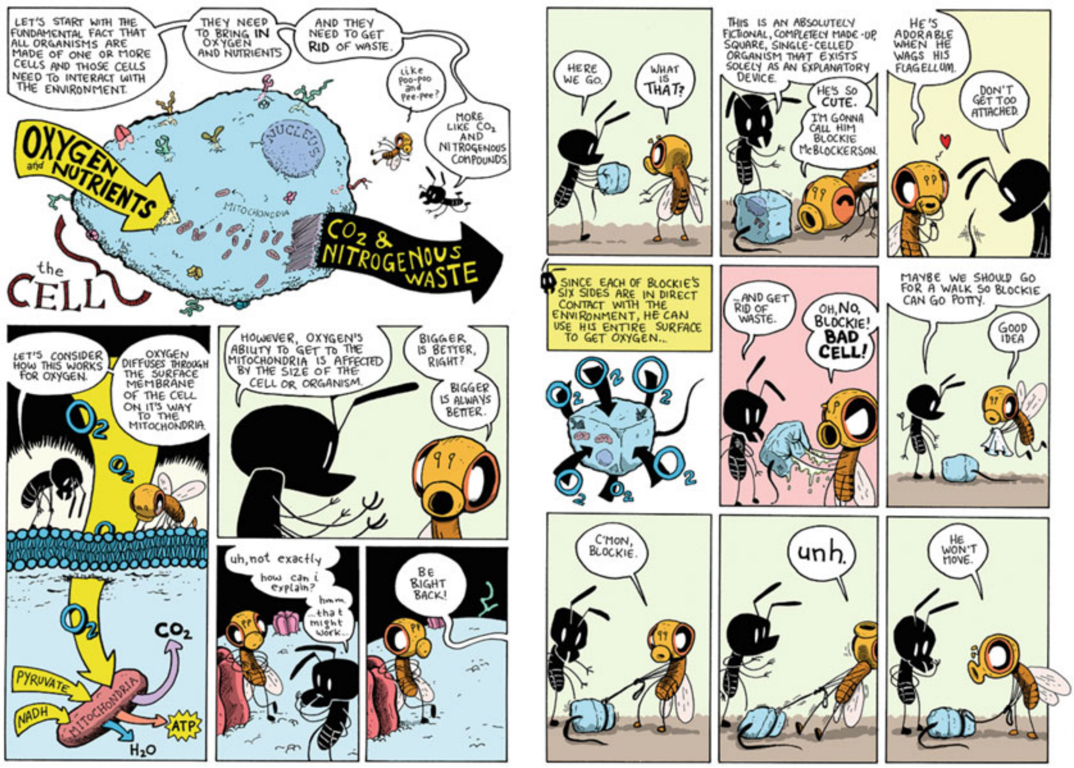

Fig. 2.11 Excerpts from "Big Ideas About Surface Area and Volume." Comic by Jay Hosler (2015). Used with permission

conscious about this use of visual analogy: "This is an absolutely fictional, completely made-up, square, single-celled organism that exists solely as an explanatory device." This self-referentiality makes for an additional source of humor, while also reminding the student of the necessarily simplified nature of explanatory models. The fly and ant characters (one order of visual discourse) actually interact with scientific diagrams (another order of visual discourse) as, for example, they stand on an image of the cell membrane to observe oxygen diffusion. This self-reflexivity and mixing of visual languages makes the comic not only engaging and thought-provoking, but also a sophisticated commentary on the constructed nature of conceptual models.

In analyzing medical and scientific comics to develop a taxonomy of narrative strategies, biomedical visualization students enhance their appreciation of the fact that the *how* of a narrative is as crucial to conveying information as the content of the message. The students' own work for the course is wide ranging, spanning personal and didactic narratives and sometimes exploring the relationship of comics to other media such as animation and "scrollytelling" (scrolling web animations). Learning and practicing the language of comics allows them to expand their visual repertoire, exercise their creativity, and acquire strategies that they can carry over into their non-comics illustrative work.

2.6 Conclusion

Medical illustrators are storytellers. Whether it be a protein binding event, a surgical procedure, instructions on insulin injection, or surfacing the stories embedded in data, illustrators take the raw material of processes/structures/events and package them in narrative. Words and images work together to tell the story. Mieke Bal proposes the distinction between the *fabula*— "a series of logically and chronologically related events that are caused or experienced by actors"—and a *story*—"a particular manifestation, inflection, and 'colouring' of a fabula" (Bal 2017: 5). In other words, there is the raw material (the steps in a surgical procedure, for example), and the selection, emphasis, pacing, etc., that determine how the story is told. Comics offer a playground to explore the ways in which a story can be told, in which authority can be situated relative to information, and in which readers can be engaged in a message. For biomedical communicators, comics can be an end in themselves; they can also be a fruitful learning tool for thinking through the ways in which choices about emphasis, pacing, narrators, framing, focalization, and style can shape and color the visual stories we tell in other media as well.

References

Abel J, Madden M (2008) Drawing words & writing pictures. First Second, New York

Anderson PF, Wescom E, Carlos RC (2016) Difficult doctors, difficult patients: Building empathy. J Am Coll Radiol 13(12PB):1590–1598

Bal M (2017) Narratology: introduction to the theory of narrative, 4th edn. University of Toronto Press, Toronto

Brand A, Gao L, Hamann A, Crayen C, Brand H, Squier SM, Stangl K, Kendel F, Stangle V (2019a) Medical graphic narratives to improve patient comprehension and periprocedural anxiety before coronary angiography and percutaneous coronary intervention: A randomized trial. Ann Intern Med 170(8):579–581

Brand A, Gao L, Hamann A, Martineck S, Stangl V (2019b) Annals graphic medicine—patient-informed consent. Ann Intern Med (Web exclusive). Available at https://doi.org/10.7326/G19-0008

Burachynsky N (2012) Germageddon (unpublished comic). Created in the context of the Biomedical Communications Graduate Program, University of Toronto

Chang C (2021) Hypervigilance (unpublished comic). Created in the context of the Biomedical Communications Graduate Program, University of Toronto

Christiansen J (2023) Building science graphics: an illustrated guide to communicating science through diagrams and visualizations. CRC, Boca Raton, FL

Cuauhtemoc L-N (2021) Exploring the impact of online graphic narratives in consumer health promotion: A type 2 diabetes study. Health Market Q 38(4)

Czerwiec MK, Willams I, Squier SM, Green MJ, Myers KR, Smith ST (2015) Graphic medicine manifesto. Pennsylvania University State Press, University Park, PA

Farinella M (2018a) Of microscopes and metaphors: Visual analogy as a scientific tool. Comics Grid J Comics Scholarsh 8(1):1–16

Farinella M (2018b) The potential of comics in science communication. J Sci Commun 17(1)

Farinella M. Cartoon science (website). www.cartoonscience.org

FiveThirtyEight (2023) About us (website). https://fivethirtyeight.com/about-us/. Accessed 23 Jan 2023

Graphic Medicine International Collective. Graphic Medicine (website). www.graphicmedicine.org.

Green MJ, Myers KR (2010) Graphic medicine: Use of comics in medical education and patient care. BMJ 340(7746):574–577

Hall J, Ross E (2020) Helminths: the secret world of parasitic worms. University of Glasgow, Wellcome Centre for Integrative Parasitology. https://www.gla.ac.uk/research/az/wcip/engage/centrenews/theparasiteblog/headline_459057_en.html. Accessed 3 Jan 2023

Hanson A, Drendel AL, Ashwal G, Thomas A (2017) The feasibility of utilizing a comic for education in the emergency department setting. Health Commun 32(5):529–532

Haragi M, Ishikawa H, Kiuchi T (2019) Investigation of suitable illustrations in medical care. J Vis Commun Med 42(4):158–168

Hershler A, Hughes L, Nguyen P, Wall S (2021) Looking at trauma: a toolkit for clinicians. The Pennsylvania State University Press, University Park, PA

Hollingdrake O, Howard C, Liu C-W, Mutch A, Dean J, Fitzgerald L (2022) HIV health literacy beyond the biomedical model: an innovative visual learning tool to highlight the psychosocial complexities of care. AIDS Care 34(120):1489–1498

Hosler J (2015) Surface area, volume and the meaning of life (webcomic). https://www.jayhosler.com/jshblog/?p=1875. Accessed 8 Sept 2016

Hosler J. Research website. http://jayhosler.com

Houts PS, Doak CC, Doak LG, Loscalzo MJ (2006) The role of pictures in improving health communication: A review of research on attention, comprehension, recall, and adherence. Patient Educ Couns 61:173–190

Iser W (1980) The reading process: A phenomenological approach. In: Tomkins JP (ed) Reader-response criticism from formalism to post-structuralism. The Johns Hopkins University Press, Baltimore

Jang M (2012) If you just smile (unpublished comic). Created in the context of the Biomedical

Communications Graduate Program, University of Toronto

Kearns C, Kearns N (2020) The role of comics in public health communication during the COVID-19 pandemic. J Vis Commun Med 43(3):139–149

Manna A. Drawing history of science (website). https://drawinghistoryofscience.wordpress.com

McCloud S (1993) Understanding comics: the invisible art. HarperCollins, New York

McNicol S (2014) Humanising illness: Presenting health information in educational comics. Med Humanit 40: 49–55

Mendelson A, Rabinowicz N, Reis Y, Amarilyo G, Harel L, Hashkes PJ, Uziel Y (2017) Comics as an educational tool for children with juvenile idiopathic arthritis. Pediatr Rheumatol 15:69

Muzumdar JM, Pantaleo NL (2017) Comics as a medium for providing information on adult immunizations. J Health Commun 22(10):783–791

Myers KR, Goldenberg MDF (2018) Graphic pathographies and the ethical practice of person-centered medicine. AMA J Ethics 20(2):158–166

Osborne H (2006) Health literacy: How visuals can help tell the healthcare story. J Vis Commun Med 29(1): 28–32

Pratt M, Searles GE (2017) Using visual aids to enhance physician-patient discussions and increase health literacy. J Cutan Med Surg 21(6):497–501

Ronan LK, Czerwiec MK (2020) A novel graphic medicine curriculum for resident physicians: Boosting empathy and communication through comics. J Med Humanit 41:573–578

Roter D, Hall J, Merisca R, Norstrom B, Cretin D, Svarstad B (1998) Effectiveness of interventions to improve patient compliance: a meta-analysis. Med Care 36(8):1138–1161

Ryan C, Daniels EC, Muir S (2017) Silent enemy. Healthy Aboriginal Network, Courtenay, BC. Available at https://istorystudio.com/graphicnovels/silent-enemy-living-with-cancer/

Sousanis N (2015a) Grids and gestures: a comics making exercise. SANE J Sequential Art Narrat Educ 2(1): unpaginated

Sousanis N (2015b) Against the flow (comic). First published in The Boston Globe, 4 Oct 2015. https://www.bostonglobe.com/ideas/2015/10/03/sousanis/XOMd3JBYnEdzQCWHM6twTJ/story.html. Accessed 10 Oct 2015

Sutherland T, Choi D, Yu C (2021) "Brought to life through imagery"—animated graphic novels to promote empathic, patient-centred care in postgraduate medical learners. BMC Med Educ 21(1):66

Taylor E (2020) Vulgaris (unpublished comic). Created in the context of the Biomedical Communications Graduate Program, University of Toronto

Tufte ER (1990) Envisioning information. Graphics, Cheshire, CT

Weinersmith Z, Koerth M, Bronner L, Mithani J (2020) "A comic strip tour of the wild world of pandemic modeling" (webcomic). FiveThirtyEight. https://fivethirtyeight.com/features/a-comic-strip-tour-of-the-wild-world-of-pandemic-modeling/. Accessed 2 June 2020

Welcome Centre for Integrative Parasitology, University of Glasgow. "Using comics to illustrate our research" (webpage). First published 9 May 2016. https://www.gla.ac.uk/research/az/wcip/engage/centrenews/theparasiteblog/headline_459057_en.html. Accessed 25 Jan 2023

3 Decolonising Visual Narratives in Global Health: The Case for Equitable and Ethical Imagery Use

Raabia Farooqi, Alexandra M. Cardoso Pinto, Sameed Shariq, Marc Mendelson, and Esmita Charani

Abstract

As we endeavour to make global health more equitable, it is imperative to understand the skewed narratives and stereotypes that underpin modern health practices and to promote interventions that address and challenge these principles. Such notions and imbalances are often founded within the colonial, hegemonic roots of global health. Increasingly, the power held by the photographs and images used within global health paraphernalia as a means to perpetuate such narratives has been identified, and the need for more intentional and ethical use of imagery elucidated. In this chapter, we trace the origins of global health imbalances back to colonial and tropical medicine, in which medicine was used as a tool to facilitate colonial expansion and subjugation of native peoples. We outline how the rise of epidemic orientalism shifted the blame of disease burdens to the Global South, the impacts of which transcend into the modern day. We further outline the manifestations of these imbalances within global health practice in the twenty-first century. We then introduce imagery as a powerful tool to propagate and shift narratives and discuss the historically problematic use of photography within global health. Based on the findings of a recent study aiming to promote more ethical practice in global health photography, we discuss key concepts that must be upheld when capturing and distributing images; in particular, the need for consent, integrity and relevance.

Keywords

Global health imagery · Global health photography · Decolonising global health · Colonial narratives · Ethics · Inequity

Raabia Farooqi and Alexandra M. Cardoso Pinto contributed equally with all other contributors.

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3.1 Introduction

Global health is widely defined as the area of study aiming to promote health improvements and health equity globally (Beaglehole and Bonita 2010; Chen et al. 2020). As egalitarianism and reduction of disparities represent a fundamental goal of global health, reflection upon how to best implement ethical and equitable practice remains vital by virtue of the work undertaken. The recent calls to decolonise global health are the natural evolution of this reflection. Failing to include host actors in policy development and implementation, cultivation of imbalanced power relationships in Global North-South collaborations, and refusing to understand the significance of culture and context in issues are the result of systemic biases within global health infrastructures, rooted in the colonial origins of global health (August et al. 2022). Direct intervention to undo these practices is necessary, but in order to fully tackle such issues we must also challenge the perpetuation of underlying skewed narratives and ideologies that have dominated the field since its colonial beginnings. The governing structures and power dynamics that have manifested from such outdated, racist and imbalanced ideologies continue to devalue and underserve vast swaths of the global population to this day (Khan et al. 2021).

To challenge such notions, the use of imagery within global health warrants particular attention. Over the years, photographs and images utilised within global health publications and paraphernalia have cumulatively embedded stereotypes founded in such narratives, fuelling white saviorism, exoticism and alienation of global populations. Tropes frequently depict Global South populations exclusively as the recipients of aid—vulnerable, distressed and helpless—and Global North populations as their saviours—progressive, intellectual and strong (Graham et al. 2019). Considering the visual medium is the most potent in its storytelling power, Global Health Imagery use can be extremely damaging, disempowering individuals, exacerbating existing inequalities and perpetuating harmful stereotypes. However, its potency is invaluable in subverting dominant narratives in the public consciousness, and it should thus remain a key area of focus as we strive to make global health more equitable.

This chapter will outline the origins of the imbalances and problematic ideologies that are deeply embedded within global health institutions, illustrate how their manifestations continue to disadvantage the Global South in the modern day, discuss the relevance of person-centred visualisations and global health imagery in propagating damaging narratives and highlight necessary considerations for visualisations to subvert imbalances. This work serves as a deeper exploration of our work on developing ethical guidelines for imagery use in Global Health (Charani et al. 2022).

3.2 A Historical Overview of Global Health Power Imbalances

In order to fully appreciate the importance of such efforts in promoting equity in global health, including ethical and equitable visualisation and representation of individuals, an understanding of the imbalances deeply embedded within the colonial and hegemonic roots of global health institutions is necessary.

3.2.1 The Roots of Global Health: Imperialism and Colonial Medicine

Though ‘global health’ did not appear within mainstream literature until the 1990s, it was not a novel concept; rather, the term replaced several predecessors utilised throughout history (Holst 2020). It is widely accepted that modern global health evolved from colonial medicine of the nineteenth century, which was primarily created to control colonised populations and facilitate colonial expansion by European and North American powers (Hirsch 2021).

Imperialism and overseas conquest produced a huge transmission of disease in all directions as populations became exposed to unfamiliar diseases. The most fatal and devastating impacts of such exchanges were often demonstrated within indigenous populations when exposed to novel pathogens carried by colonisers. European colonial powers spread diseases such as smallpox and measles to the native people of the Americas and Africa from the times of Columbus to the nineteenth century; the population of Native Americans declined by around 75–95% upon European contact (Collen et al. 2022). This pattern is considered attributable to an innate susceptibility to colonial-introduced pathogens; potentially exacerbated by the inhumane conditions imposed by colonists including enslavement, killings, forced labour, famine and mass displacement (Collen et al. 2022). Evidence further proves the blatant weaponisation of disease and this apparent susceptibility by European powers. Records from 1763 attest to British troops distributing blankets deliberately infected with smallpox to Native Americans to produce a 'desired effect', highlighting the intentional exploitation of increased indigenous susceptibility for colonial gain (Lane and Summer 2009). The excessive mortality of native peoples during colonisation led to the formulation of early racist theories of White European superiority over 'savage' indigenous bodies. Such notions underpinned much of colonial medicine and were utilised to justify the correctness of European occupation and oppression of indigenous peoples (Green et al. 2013). The impacts of such ideas persisted, later forming the basis of scientific theories and racial hierarchies.

Whilst those colonised were disproportionately impacted, it remains that disease transmission was bidirectional and caused substantial morbidity and mortality. Within the so-called scramble for Africa throughout the nineteenth century, the vast majority of the African continent was occupied and controlled by different European colonisers seeking territorial and financial gain. However, European settlers suffered extremely high susceptibility to diseases such as malaria to which natives were relatively immune, causing high mortality and failure of colonial expansion; one such example is the so-called white man's grave of West Africa in which Europeans died in huge numbers (Havik 2016). European powers therefore employed medicine as a tool to overcome such barriers. Once quinine, an ingredient used to treat and prevent malaria for centuries in South America, was successfully isolated and made widely available in Europe, it was quickly exploited for use by European troops in Africa. This intervention ultimately facilitated the colonial occupation of much of Africa through mitigating the initial disease barrier. Similar use of quinine later enabled British colonisation in India (Cohen 1983). Such examples elucidate the hegemonic aims of colonial medicine in procuring additional expansion into tropical areas and protecting colonising military armies, at the cost of the health and lives of native populations.

We can thus learn that the roots of global health are in colonial medicine, which was primarily utilised as a tool for empirical advancement and a weapon of oppression. It provided a means to subjugate indigenous populations, protect European militia in overseas colonies without helping natives and conquer new regions. Representation and portrayal of natives as inferior 'savages' fuelled ideals of White superiority and legitimised European colonial projects. Such imbalances are ingrained into the fabric of colonial medicine and, by extension, global health.

3.2.2 Tropical Medicine, Epidemic Orientalism and International Coordination

With much of the globe conquered by colonial powers by the late nineteenth century, colonial medicine had increasing applications. In an increasingly interconnected world, the spread of disease across and between colonies posed a threat not only to European invaders and settlers, but also to indigenous slaves and labour forces undertaking work in plantations and mines vital to sustaining empirical production and trade. Epidemics such as cholera, yellow fever and sleeping sickness spread throughout colonies, eventually reaching Europe throughout the nineteenth and twentieth centuries (Green et al. 2013). As such, efforts were directed to understanding disease, the causes of its spread and the implementation of measures to protect settlers and labour forces. Referring to parts of the colonised world as 'the tropics' became customary, and the study of disease and health concerns specific to overseas colonies by European powers was termed 'tropical medicine'. The field of tropical medicine flourished beyond the late nineteenth century, with many advances in identifying pathogens and vectors for a diverse range of diseases present within the colonial world. During this time, a certain shift took place as the study of tropical medicine moved from practitioners in the colonies towards research institutions within Europe, with the first school of tropical medicine constructed in Britain in 1899. Funds to establish and run this school derived from the British government ministry in charge of British colonies and from colonies themselves through exploitation of resources and labour. Whilst this marked an era of thriving scientific study and advancement, the ultimate aims remained to sustain colonial rule. Diseases were tackled due to the threat they posed to trade and economic growth, and measures were implemented primarily to preserve and defend European bodies.

Alongside understanding disease mechanisms and microorganisms, much of tropical medicine research centred upon developing theories; notions conceived during the colonial medicine era were formalised into pseudoscientific hypotheses regarding race and health. Some research centred upon establishing the primitiveness and backwardness of native peoples and their practices; the invasion and exploitation of regions was thus justified as a means of providing social and economic 'advancement' to the colonised world (Birn 2018). Other research was utilised to prove differences in racial characteristics and differential disease susceptibilities. For instance, an 1835 epidemiological investigation commissioned by the British Empire highlighted the excessive mortality of European soldiers employed in West Africa as compared to African-born soldiers; this was interpreted as evidence for the enhanced suitability of the black bodies for work in hot climates over white bodies. Such beliefs justified the use of 'brown labour' throughout the colonies and ultimately provided the basis of the Atlantic Slave trade, leading to the enslavement of over 15 million men, women and children. In this way, research formed the basis and justification of continued oppression and racist attitudes propagated by imperial powers (Green et al. 2013).

Furthermore, terming the study of colonial health and disease as 'tropical medicine' shifted the locus of disease burden and blame far away from 'temperate' European regions, and towards foreign, 'dangerous' and culturally distinct tropical sites. In many instances, blame was placed upon the 'filth' in the colonies for generating disease (Birn 2018). For instance, epidemics of cholera were seen to spread from India across Asia and eventually into Europe, causing immense morbidity and fatalities. The generation of these waves was blamed on the uncleanliness of natives, despite no widespread cholera epidemics having occurred historically in the subcontinent prior to initiation of colonial military projects (Williams 2021). In particular, British physicians blamed traditions such as Hindu pilgrimage for cholera spread, with claims that 'the most riotous imagination could scarcely exaggerate the filth of India and... of the Hindoo pilgrims' (Jain 2020). In this manner, disease was utilised for the 'othering' of the native population, for instance portraying natives as 'inferior' and sources of disease, despite growing scientific knowledge regarding disease transmission. Such perceptions further justified the 'civilising mission' of colonialism in helping to bring sanitation to colonies classed as unclean, diseased and primitive by the foreign gaze. Not only did these notions shape disease responses, but they also dominated public attitudes and stereotypes within Europe. Individuals native to Africa and Asia were persistently depicted as dangerous reservoirs for disease that posed a threat to European bodies and were held as the sole culprits of disease spread. This narrative prevailed throughout popular culture and media, in which the 'diseased native' stereotype was ubiquitously portrayed in a racialised manner fuelling exoticism, stigmatisation and blame (Green et al. 2013).

Predominance of these attitudes caused the propagation of a so-called epidemic orientalism, in which the colonies were situated as the sole source of all disease and Europe as the perpetual victim, and the colonies as posing a persistent threat to imperial expansion and trade from which Europe required protection (White 2023). Increasing concerns about emerging disease threats in the colonies and their spread to Europe galvanised the formation of a coordinated international sanitary system. The International Sanitary Conferences, which would later form the basis of the modern World Health Organisation (WHO), centred upon the orientalist standpoint of protecting European bodies and dominance from the danger originating in the colonies without impacting international travel and trade. The conferences began in the late nineteenth century, focusing on the control of three specific diseases: plague, cholera and yellow fever, due to their threat to European trade and potential for infection in the subcontinent (Swanson 1977).

The well-established Eurocentrism of the International Sanitary Conferences meant that discussion often centred around the national trade priorities of member states as opposed to scientific evidence regarding the transmission and prevention of disease, hindering any meaningful progress. When measures were introduced, they were largely aggressive sanitary controls imposed upon the colonial world, with no emphasis on the policing of disease spread from Europe to other countries. This led to an associated racialised surveillance of non-Europeans. For instance, a 1901 epidemic of bubonic plague in Cape Town resulted in the forced eviction of the African urban population from the city, who were then placed into hastily established racially segregated quarantine camps. Similarly, Muslim pilgrims attending Hajj were subjected to extensive scrutiny under the action International Sanitary Conferences, with aggressive controls and quarantines imposed due to fears of disease spread by pilgrims returning to Europe (White 2020; Swanson 1977). Such measures furthered the 'diseased native' narrative, inflicting oppressive measures onto non-European populations and creating imbalances and racist stereotypes of disease blame and burden.

In 1947, the authority over the conventions passed to the WHO. Operating under the same orientalist perspective, the WHO ultimately reproduced this perspective towards disease threat. The WHO and its origin convention would decide who would be the subject of surveillance, which spaces required protection and which spaces required sanitary domination in order to protect others. The designation of a Public Health Emergency of International Concern (PHEIC) to a disease was done by the WHO through a deliberative process mandated by the International Health Regulations (IHR) 2005 (World Health Organization 2005). The process does not solely justify designations via epidemiological context or pathology—many diseases appear to meet the PHEIC threat level but not all receive the designation. Alexandre White (2018) outlines the role of perceived geopolitical implications and collateral economic impact from Global North member states as being of significant influence on designations (White 2018). This demonstrates that organisational structures in Global Health continued to operate on the Global North's terms and bend according to their priorities.

3.2.3 Manifestations of Imbalanced Narratives in the Twenty-First Century

We must recognise these disturbing roots of global health within colonialism. Through an examination of the historical context, it is evident that colonisation was not 'simply an act of accumulation and acquisition', but that it was 'sustained by an almost metaphysical obligation to rule subordinate, inferior or less advanced peoples' (Harrison 1996). The imbalances established during this period still persist today.

Firstly, we still continue to localise disease threats to specific regions of the world, propagating damaging stereotypes and stigma rooted in the epidemic orientalist ideals of the colonial era. The COVID-19 pandemic set the stage for the latest case of disproportionate and unjustified leveraging of Western power which came in the form of a travel ban on several southern African states including South Africa, Namibia, Lesotho, Botswana, Eswatini and Zimbabwe by the European Union and the United States of America (Africa 2020). This travel ban was placed after South African scientists rapidly and transparently shared the findings of mutation and genomic sequences of the latest SARS-CoV-2 variant in November 2021, with the justification that this would curb the spread of the new variant. This rationale went in opposition to the official advice (World Health Organization 2020) given by the World Health Organisation and the International Health Regulations to keep borders open and was widely believed to be a sign of continuing discrimination and scapegoating of the continent by the West. As discussed already, colonisation saw race-based segregation imposed across African regions in order to keep ‘white’ officials separate from ‘carriers’ of diseases, such as plague, smallpox, syphilis, sleeping sickness, tuberculosis, malaria and cholera. Travel bans serve as modern versions of these policies (Kagumire 2021).

We now know that in this period, African states were world-leading in their handling of the COVID-19 pandemic with the global share of COVID-19 deaths to share of global populations being only 0.26 as compared to North America’s 5 and Europe’s 2.3 (Phillips 2020). Furthermore, it was only due to South Africa’s sophisticated infrastructure of immunological expertise, genome sequencing and health research capacities built over decades in their fights against AIDS and Ebola, that it was able to detect the new Omicron variant. This knee-jerk rush to punish South Africa was founded on the basis that African countries are the epicentre of infectious diseases and must be marginalised (Business Insider South Africa 2020; Calain 2007). This idea was reflected in visualisations accompanying media stories around this development. Perhaps most notable was the example of Spanish newspaper La Tribuna de Albacete, which published a cartoon of brown coloured viruses on a boat with the South African flag heading for Europe.

Secondly, the majority of global health actors are headquartered in the Global North which further perpetuates the historical structural imbalances, and practices continue to be paternalistic and prescriptive upon the Global South.

According to the 2022 report from Global Health 50/50, Global Health continues to be governed by the Global North (Global Health 50/50 2022). Among more than 2000 board seats of organisations active in Global Health, analysis reveals that 75% are held by nationals of high-income countries (home to just 16% of the global population). The report also found that 94% of Global Health organisations were headquartered in high-income countries. The domination of the Global North in these organisations that control the distribution of billions in funding and determine agendas means global health projects are shaped by those foreign to the sites at which they are conducted.

Studies have shown that funding for each of the different disease categories from these Global North-based organisations do not match closely to the health priorities of the aid recipients or reflect the most cost-effective interventions (Baccini et al. 2022). For example, childhood diseases are considered as a prominent case of misalignment, since they attract little health aid relative to the loss of disability-adjusted life years (DALYs) caused by them, despite the availability of highly cost-effective interventions (Dieleman et al. 2014). It has been found that donors act based on beliefs on the relative importance of health issues (as opposed to more ‘objective’ indicators) and that individual biases and perceptions present within the social networks of global health actors and policy makers influence such beliefs (Baccini et al. 2022). This illustrates that agenda setting in the global health sector is ultimately inequitable and subject to the dominant narratives that shape biases and beliefs.

Furthermore, as a consequence of the status quo, academics from low- and middle-income countries (LMICs) where there is weak research infrastructure often need to rely on global North-South partnerships for resources, funding, recognition, and the chance to be published in high impact journals by affiliation (Ashuntantang et al. 2021; Olusanya et al. 2021). Unfortunately, they often suffer marginalising behaviour from their collaborators, as a result of being held in lower regard. Such behaviour has included:

– Continual questioning of the ability and technical skills of the staff from low-income countries
– Travelling to the site without prior communication with the low-income country's principal investigator
– Publishing papers or deciding authorship without the knowledge of the low-income country's principal investigator
– Directly communicating with the field staff undermining the site principal investigator
– Communicating unsubstantiated allegations against the principal investigator to the low-income country's university leadership as a means of coercive influence (Rasheed 2021)

This is part of a wider phenomenon experienced by global south professionals across industries, who deal with increased scrutiny and paternalistic partnerships when engaging with agencies based in the North (Higgins 2018). This elucidates that imbalances also persist within the academic and research spheres of global health.

3.3 The Role of Global Health Imagery in Decolonising Global Health

3.3.1 The Storytelling Power of Images

Imagery use as a Global Health communications tool in particular warrants significant emphasising the fight to decolonise global health. This is because the visual medium holds unrivalled power in shaping narratives in the public consciousness.

The picture-superiority effect dictates that, thanks to evolutionary mechanisms, imagery is far more likely to be retained in our memory than text (Defeyter et al. 2009). Quick processing of visual information was favourable for early humans constantly relying on hunting and foraging for food and hiding from predators. These primitive behaviours continue to shape and dictate our thought processes in modern life. Consequently, the messaging generated by the imagery used in global health communications is very likely to shape people's perceptions and lasting impressions, more so than the information presented in textual format.

Research has also shown that visual evidence enhances storytelling by making readers more likely to believe and relate to what is being read (Newman et al. 2012). Audiences are less likely to be aware of the subtle meanings in photos as they are of those in written texts, which makes visual framing powerful in terms of transmitting implicit ideas of difference (Messaris and Abraham 2001). This reality requires global health actors to utilise visuals in their communications in a responsible way in order to effectively and ethically educate about health work. This includes the way it represents the different parties in healthcare projects and the work itself.

Images can also strongly influence the way we act. Because we process visual stimulation at lightning speed, images are likely to prompt strong emotion, which in turn can lead to action. The visual cortex has recently been found to have independent decision-making capacity demonstrating the high impact of the visual medium on our perception (Ho et al. 2009). Considering that it is through global health communications that donors and stakeholders often appreciate health challenges and the way they are managed, the very way global health programmes are formulated and run can be affected by imagery use.

Deborah Poole describes images as being part of a 'visual economy', where it is not just the content of an image but its production, circulation, and consumption that cause it to get incorporated into the international power dynamics. These in turn are embodied in the relationships of photographer, subject, consumer, and publisher (Poole 1997).

Bearing all this in mind, it becomes clear that the perpetuation of problematic narratives in image production as well as the use of those images should be given particular attention when aiming to decolonise global health.

3.3.2 The Current State of Global Health Imagery

Global health photography includes any image taken as part of a global health programme (for instance, humanitarian aid, disaster relief, vaccination programmes) or one which represents its providers or beneficiaries. Global Health photography has been subject to ethical scrutiny, both historically and in modern day criticisms. Such comments are widespread within both academic publications and sources of grey literature, defined as documents not controlled or published by commercial publishers, including articles and social media posts. Numerous sources continue to highlight concerns with practice of photography deemed insensitive and unethical in the context of media and humanitarian settings (Chesterton 2017; Stewart and DiCampo 2019; Devakumar et al. 2013; MSF Child Protection Inquiry 2022; Graham et al. 2019). Many Global Health photographers themselves have also shared their concerns about field work, discussing the ethically grey areas encountered due to pressure to use images as commodities that offer both visual evidence of the ground realities and a means of organisational marketing for global health actors (Graham et al. 2019).

Unfortunately, the drive to photograph harsh realities in order to encourage financial aid and awareness has often led to the dehumanisation and disrespect towards individuals photographed and communities represented. Images continue to show individuals in conditions of poverty, pain and suffering in order to evoke pity and awareness. This can perpetuate imbalances and the conception of communities as being helpless and entirely dependent on foreign aid (Graham et al. 2019).

As the extent to which media campaigns garner attention often translates into funds, organisations may engage in a race-to-the-bottom of suffering and seek to portray their cause as the most deserving. This promotes the depiction of populations in increasingly pitiable and undignified states in order to leave a lasting impression and leads to the practice of a myopic form of Global Health in which less sensational forms of problems that tend to be more common among global South populations are ignored. Even where campaigns do highlight a condition that affects significant proportions of a population, it is often the most extreme manifestations of it that are given coverage.

For example, a recent CNN health campaign on obstetric fistulas labelled the condition a ‘fate worse than death’ (Winsor 2013), with the articles accompanied by photographs of women depicted in a depressed and dishevelled state. The article focused on stories of young women who had been divorced, ostracised and labelled ‘witches’ for having debilitating complications from untreated fistulas. The need to share identifiable pictures of these women was likely unnecessary and unlikely to be in their best interests. Furthermore, such complex cases are far from typical with many women continuing to lead fulfilling, well-supported, relatively normal lives albeit with the drawbacks of having to deal with the physical and emotional discomfort of the far more common complication of urinary incontinence. Though the typical African woman’s experience of an obstetric fistula lacks the dramatics of those highlighted by media campaigns, they still deserve to be told and resolved. The choice to give disproportionate representation to extreme cases of mistreatment of women by their communities serves the narrative that there is significant disparity between the civilised Global North readers of the article and the primitive cultural practices of the Global South. This stands as a continuation of the colonial ideology of the need for civilisation of indigenous peoples, encapsulated in Rudyard Kipling’s poem ‘The

White Man's Burden' (Kipling 1940) that viewed intervention and interaction between coloniser and colonised as a necessary civilising mission.

Generalisations can also be detrimental; the use of single individuals to represent entire communities is not only inaccurate, but unethical, as it often leads to stereotyping. Additionally, in some cases images and stories are published that publicise sensitive, confidential information, including medical diagnoses, which can lead to stigma and further suffering, and exploitation, of the individual represented (Chesterton 2017; MSF Child Protection Inquiry 2022; Stewart and DiCampo 2019). Some of these photos have won awards—but rarely are the subjects of the images themselves remunerated, or otherwise benefitted.

It is important to remember, however, that this does not need to be the case. Photography can be used for the opposite effect: to empower communities and counter stereotypes. They can be used to raise awareness of pressing concerns in a way that is respectful and dignifying for the individuals represented.

Many international organisations have published their own codes of ethics for photography. For example, the Confederation for Cooperation of Relief and Development NGOs (CONCORD) published a code of conduct on images and messages, which specifically mentions truthful representation, avoidance of stereotypes and recording subjects' identification preferences, amongst several other points (CONCORD 2012). Similarly, Photographer Without Borders highlights the importance of voicing the community being photographed, allyship and consent (Photographers Without Borders n.d.).

However, it is too often that these guidelines are not followed: despite wide acknowledgement of the need for respect, equity and integrity, the issue of unethical global health photography persists. There is also a lack of guidelines specific to healthcare—which may require particular considerations regarding privacy and confidentiality, consent and coercion, as well as respect towards the dignity of individuals in vulnerable situations.

3.4 Creating a Framework of Good Practice for Global Health Imagery

Driven by negative experiences surrounding the use of global health photography—that is, the overwhelming number of examples of disempowering, undignified photos of individuals, particularly from low-income settings used in wide-reaching published resources in the field of global health—led a group of researchers to design a study to evaluate this issue (Charani et al. 2023). The aim of the study was to analyse images published in global health reports within the field of infectious disease to explore the extent to which they were used appropriately and respectfully, and design a Framework of Good Practice based on these findings (Charani et al. 2023). To ensure as much objectivity as possible, the analysis was based on four key criteria derived from some of the aforementioned, pre-existing guidelines: relevance of images to their report and its subject; integrity and respect for individuals in images; evidence of consent; equity and appropriateness of individuals represented.

The work highlighted issues in all four criteria of analysis. These findings informed a Framework of Good Practice. Whilst this framework still needs to be validated by global health actors and trialled on a greater range of images, it is based on a substantial sample size of images and includes specific examples with justifications. It is therefore our hope that Global Health actors engage with this framework—evaluate it, adapt it, and above anything, implement it into standard practice.

3.4.1 Relevance and Representation

Images provide a snapshot of time for audiences. A singular scene can certainly provide a great deal of information but rarely can that information comprehensively communicate the entire story behind the image. A graduation portrait may do well at communicating whether the person in question has passed a certain stage of their studies but can it tell you how long it took, what challenges one needed to face along the way, or even indeed what that degree is in? And that's assuming that the photo isn't trying to mislead us; that the scroll of paper in the person's hands is indeed an academic certificate; that the photo was indeed taken at a graduation ceremony and not in a photo studio as part of an elaborate cover up. To get the full story behind any image we need additional details that contextualise the scene—the who, what, why and when. If instead we are only exposed to limited information, our brain is forced to jump to conclusions, often fuelled by assumptions informed by unconscious bias.

Image use is certainly justified, but to have a positive impact on the storytelling of communications material they must be relevant to the broader messaging and act as a supplement to the text. In Global Health, images often are used to illustrate stories with significant complexity. The committee meeting to decide next steps for virus surveillance, the mother whose child died of preventable causes, the barriers faced by the vaccine delivery team in a village with low uptake. These stories warrant detailed explanation in order to sufficiently communicate the role of the individuals and activities being depicted in the scene. Without this, the storytelling can underserve individuals involved and the work that is carried out.

In our review of global health imagery, it was found that portrait imagery of populations from LMICs was used frequently without any accompanying caption or obvious relation to the body of text (Charani et al. 2023). This caused viewers to make broad associations between the visual characteristics of the individual depicted and the subject of the document. Such associations have been found to shape people's beliefs about entire ethnic and racial groups, as well as the regions they are from (Midberry 2017). In the context of global health, this often meant an association with an identified disease or health issue. Furthermore, environments and activities set in LMICs, such as rural villages and cultural dances and rituals, that were seemingly unrelated to the health subject matter were often depicted without contextual aids, resulting in confusion about the link between the focus of the scene and the intended messaging. Often, these images were employed for their decorative value, depicting scenes that would be of interest to foreign audiences who were unfamiliar with these. This practice, when exclusively applied to global South people and places, serves to appeal to the foreign gaze and perpetuates orientalist exoticisations of groups rather than serving any purpose in supplying information or conveying the experiences of those photographed.

There is a balance to strike. Person-centred images can help remind viewers about the human stakes of a healthcare issue and serve as a positive platform to represent them. However, this must be done on their terms. This requires photographs to depict scenes with a direct link to the subject matter or topic of discussion and where that link is not immediately obvious, the photograph should be accompanied with contextual details.

It has been argued that images serve a decorative function as well as being to illustrate and inform. However, there is an additional element of responsibility in the healthcare context (Mavroforou et al. 2010; Segal and Hansen 2021; Devakumar et al. 2013). An individual's health is a deeply personal and sensitive matter, therefore depicting an individual in relation to a health problem has significant consequences for the way they are perceived and treated in society. Being associated with diseases can result in stigmatisation, social isolation and prejudice. This is why there are extreme consequences in the UK for breaking confidentiality. Imagery enables a much easier means of identification and can very easily be misused in the future. It is therefore vital that images have a clear and pre-defined purpose which is vetted for being ethically appropriate and appropriately conveyed in its presentation.

Extracts from the 'Framework for the use of imagery in global health' summarising key points under the principle of relevance and equitable

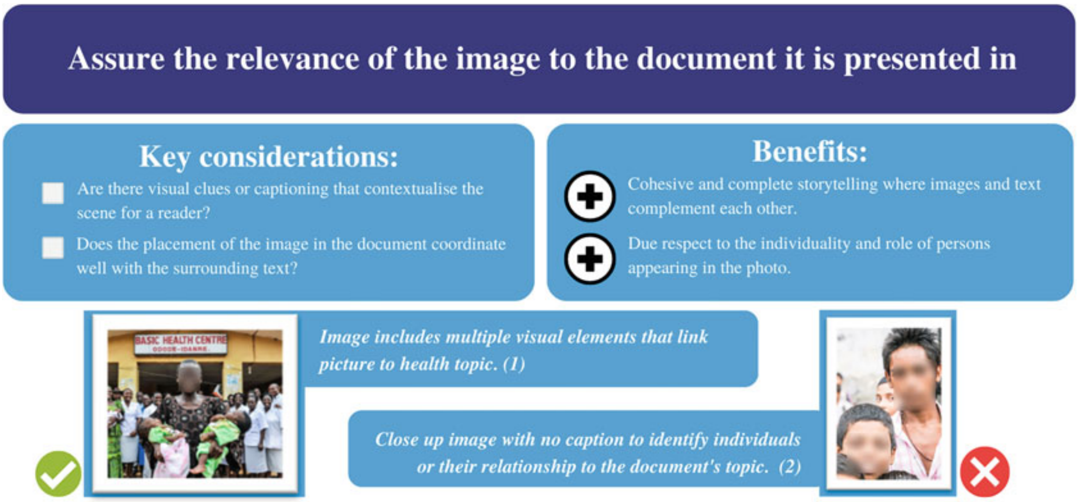

Fig. 3.1 Extract of 'Framework for the use of imagery in global health' detailing key considerations and associated benefits on the principle of ensuring relevance (Charani et al. 2023)

representation can be found in Figs. 3.1 and 3.2, respectively.

3.4.2 Integrity

It was also identified that promoting the integrity of subjects is paramount to ethical global health photography (Charani et al. 2023). This was defined as upholding the dignity and privacy of individuals being photographed and is particularly pertinent to vulnerable groups and those depicted within difficult conditions.

The use of shocking, emotionally evocative imagery in order to produce outrage and promote action and mobilisation is long-standing. As early as the nineteenth century, evidence supports the use of photography for the purposes of 'social

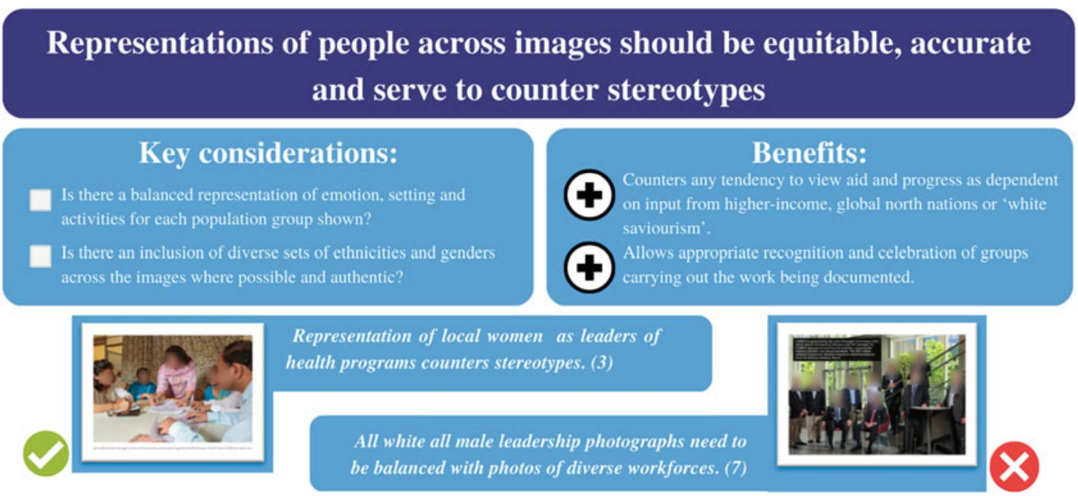

Fig. 3.2 Extract of 'Framework for the use of imagery in global health' detailing key considerations and associated benefits on the principle of equitable representation (Charani et al. 2023)

documentation'; for instance, numerous photographers depicted injustices and deprivations within America such as the New York slums and child labour within coal mines and factories. These images depicted vulnerable subjects in squalid conditions, truthfully depicting the suffering inflicted and harsh reality of the situations. Such images produced the necessary emotions to influence public perception and contributed to driving the action to improve living conditions and advocate for human rights (Hfbauer 2003). Throughout history, many instances have occurred in which imagery has widely impacted public opinion and driven subsequent political action and change, illustrating the powerful capacity of imagery in influencing minds and driving narratives. This power persists today; as recently as 2020 images and videos of the police brutality experienced by George Floyd, a man murdered by an officer in Minneapolis triggered widespread public outrage and awareness and mobilised thousands to rally in the pursuit of change (Christián et al. 2022).

As such, the depiction and publication of human suffering may be argued as being justified, and necessary to produce the awareness and outrage necessary for intervention. Imagery use and dissemination has certainly proved to be an invaluable tool to facilitate change and political influence. However, an ethical dilemma is brought forward with this use: where do we draw the line? At what point does raising awareness of suffering and difficulty breach into the realms of disrespect and the so-called poverty porn? Many have recently highlighted the exploitative connotations of displaying suffering and the generation of stereotypes, objectification and dehumanisation (Graham et al. 2019). The need for respect, dignity and sensitivity in the depiction of human beings is important across all contexts, but is paramount within the global health sphere with significant power dynamics and historical imbalances still present.

Within global health, imagery is similarly employed by actors to produce emotion and compassion to raise funds and drive intervention. It is further utilised by organisations as a means to shape campaigns, display progress made and appeal to donors. However, global health photography frequently utilises the aforementioned tropes; visuals such as emaciated children and crying women continue to be plastered across media and paraphernalia by actors to achieve goals. Furthermore, images have been consistently accused of propagating white saviorism narratives, depicting aid-workers from the Global North 'saving' Global South populations who appear distressed and impoverished (Christián et al. 2022).

Within our study and the analysed images, it was found that such damaging practices persist (Charani et al. 2023). Depiction of individuals appearing distressed, scared or confused within difficult conditions was seen to impinge on dignity and respect. In many instances, such photographs were inserted somewhat thoughtlessly and without context, at times without any relevance to the subject matter. Images were often non-specific to the context and centred around the distressed faces of men, women and children rather than the situation on the ground, offering limited insight and shifting the focus onto the aid recipients rather than the aid itself. Children in particular were deliberately exploited to emotionally charged images and were shown in depictions of excessive vulnerability, often alone and in poor conditions; little regard was demonstrated for privacy and sensitivity whilst photographing young children. Such practices show a lack of consideration for the subjects depicted and tend towards the dehumanisation and commodification of human suffering. Images that centred around the situational conditions and context as opposed to placing distressed faces at the forefront, and those showing local people happily receiving aid were deemed more appropriate, informative and mindful of dignity.

Furthermore, portrayal of individuals as constantly and excessively scared, distressed, and vulnerable places them within a position of constantly needing aid. In most cases, faces were depicted without any associated story, meaning or understanding, further contributing to alienation and imbalance. This is extremely damaging and perpetuates the 'white saviour' narrative which has persisted over the course of history, situating the actors headquartered in the Global North as the necessary means to rescue vulnerable individuals in the Global South from perceived self-inflicted difficulties. There were also several images identified in which visibly distressed aid recipients from LMICs were depicted adjacent to a white-skinned person delivering aid to them. In these cases, stark imbalances and similarities to the colonial past were particularly striking. In contrast, images showing individuals happily engaging with local workers of their own backgrounds and utilising the resources given to them were deemed as more dignified and suitable.

It was also found that privacy was a key point of consideration, as plastering the faces of individuals from LMICs upon global health publications without explicit consent impinges upon the rights of those photographed. Subjects may unknowingly or unwillingly have their face and identity broadcast to thousands across many countries for no real purpose. Some images even showed blatant confidentiality breaches, in which visible hospital patients were seemingly unaware of being photographed, and showing decipherable medical identification cards. This is unacceptable, showing a blatant disregard for dignity and privacy, and it is clear that such practices would never be permissible within HICs. Images in which unnecessary exposure of faces or identifiable information were avoided were preferred; such images often included individuals engaging in other activities, directing attention away from the face and identity of the subject. It was also found that measures such as manipulating the image can be helpful in maintaining dignity in some instances. For instance, anonymising subjects using blur where relevant helped to uphold privacy and integrity.

An extract from the 'Framework for the use of imagery in global health' summarising key points under the principle of integrity can be found in Fig. 3.3.

3.4.3 Consent

In its simplest form, consent involves ensuring that individuals agree and give evidential permission, for a photograph of themselves to be taken and shared. Every image should have clear evidence of consent when used in global health documents or made available in public mediums.

Consent links closely to the concepts of integrity and equitable representation. Even if a photograph is deemed respectful by the audience or photographer, the permission of the subject to be photographed and for their image to be widely disseminated must be considered. Examples of how photography has been used without consent and to the detriment of its subjects stems as far back as the mid-nineteenth century, soon after the very start of photography. Louis Agassiz was a Swiss-American scientist who believed in the theory of 'separate creation'—that is, that humans with different skin colour, or race, were each of a different species (Wallis 1996). In 1850, seven human slaves in South Carolina were photographed, largely naked, for Agassiz. The purpose of these photographs was to highlight physical differences between White Europeans and Black Africans and hence prove Agassiz's belief of white superiority. These identified differences were later adopted by popular culture to produce pejorative and depreciatory images of Black African individuals, later including images of beaten-up bodies in erotic positions. These early examples of how photography can be used in a cruel, exploitative way against its subjects highlights the importance of codes of ethics for photographers and publishers, and ensuring consent, free from coercion, from its subjects.

There are multiple layers in the concept of consent. Explicit consent happens if a person is directly asked if they would accept a photograph of them to be taken and directly confirms its dissemination would be acceptable to them. However, some might argue that in the absence of explicit consent, an individual smiling or otherwise acknowledging a camera acts as implicit consent for their photograph to be taken, which might be acceptable under certain circumstances. The clearest limitation of this approach is that this is merely an assumption—there can be acknowledgement of a camera but no consent. Furthermore, no information has been provided as to where the photograph will be displayed, the

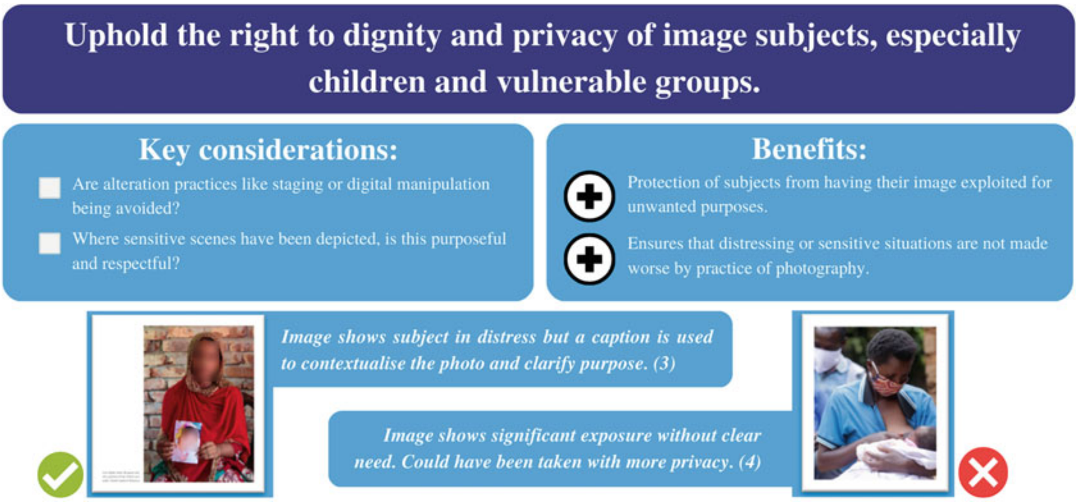

Fig. 3.3 Extract of 'Framework for the use of imagery in global health' detailing key considerations and associated benefits on the principle of integrity (Charani et al. 2023)

manner in which it will be distributed and what message it will be used to convey. Consent prior to taking the photograph can involve the photographer introducing themselves and explaining these key details; consent afterwards may involve showing the photographs to the subjects and confirming they are still happy with the final image. Other individuals may alter behaviours in the presence of a camera and therefore, arguably, make the photograph less authentic. Nevertheless, this raises an important question: who should define the *authenticity* of a moment, or place?

In the photographs analysed in our study (Charani et al. 2023), all images from high-income nations were staged (and most taken in healthcare settings), whereas the majority of photographs in low-income settings were not staged (including those taken in healthcare settings but also in communities). Staging photographs allows settings, individuals and communities to be depicted in a pre-defined way. The staging of individuals in high-income settings ensured that these were portrayed in a respectful, professional way without any confidential information being revealed.

Although staging has potential to aid persuasion and manipulation, it can also be used as a tool to empower subjects in deciding how they would like to be portrayed. The opposite may lead to individuals not feeling respected. The photograph 'Migrant Mother' taken by Dorothea Lange in 1936 as she worked for the US Farm Security Administration aimed to highlight the difficult circumstances of American farmworkers in support of President Roosevelt's 'New Deal' to promote economic recovery (Hodge 2015). The image shows a mother (Florence Owens Thompson) looking into the distance with two of her children resting on her shoulders, looking away from the camera, and a third laying on her lap. Staging is not always deliberate; the presence of a camera, and the interaction between photographer and subject can itself lead to changes in the moment being photographed. As Lang later explained, '[Thompson] seemed to know that my pictures might help her, and so she helped me' (Lange 1960). The image became a symbol of the Great Depression. However, years later Thompson wrote to her local newspaper revealing her identity and expressing her frustrations towards the image (Dunn 1995)—the story shared in the caption was incorrect and the portrayal of herself and her family as a symbol of hardship was undignified. Thompson was also not aware that the photograph would be sold, nor of the full extent of its possible dissemination; she felt exploited. This example not only highlights the importance of thorough consent practices—

including information on dissemination and captioning—but also the power of images to tell a biassed story.

Individuals should have a right to decide how they are represented in photographs—and be asked for consent. At the same time, however, it is unrealistic to demand entirely unbiased photographs—both the subject and photographer will portray parts of themselves and their ideologies in photography. Ultimately, individuals must be respected as photographic subjects and feel as though their story is shared authentically, but photographers must also feel as though the story they are reproducing aligns with reality. In some ways, both the subjects and photographer must consent to a photograph being shared.

Therefore, implicit consent in the context of global health work is unlikely to be sufficient—the focus should instead be on *informed consent*. In order to provide informed consent, individuals need to understand all relevant details of the photograph and its dissemination, including who is taking this photograph and why; where it will be used; how it will be shared; what the caption is going to be. When a photograph is taken in the context of global health work, it does not rest within the photographer's camera roll forever—it is shared with organisations, placed in documents and at times even put for sale online. Individuals need to be aware of these possibilities and provide consent—or not—for this to happen. Evidence of this consent should be documented and mentioned alongside the relevant photographs.

It is also important to include processes to withdraw consent, including instructions or contact details to make this request. Removal of photographs, however, is likely to only be possible for a certain time period of time following submission, or within specific mediums as, once a photograph is shared to a public medium online it becomes challenging, and in some cases impossible, to remove all existing copies. Nonetheless, these factors should be explained when describing withdrawal of consent. It is also important to consider whose responsibility it is to remove these photographs and keep track of withdrawal of consent; this is likely to change at different stages of photographic development and dissemination.

There are instances where seeking explicit informed consent is not possible. For instance, in very large group settings or large-scale emergencies. In these instances, it is important to start by considering whether the photograph is necessary—and if sharing this is in the best interests of those photographed or their community. If so, judgement of how to depict individuals in the photograph rests with the photographer and should be guided by clear codes of ethics. For example, it is likely to be challenging to seek explicit informed consent for photographs taken during a natural disaster—but sharing these photographs may be valuable historical documentation and serve to raise awareness. Therefore, even greater focus should be given to the remaining pillars of this framework: respecting the privacy of individuals by anonymising identifiable features, preserving dignity by avoiding portrayal of extreme suffering and ensuring authenticity by depicting harsh realities as well as local efforts of recovery.

Consent processes must also be made accessible to everyone. For instance, if written consent cannot be provided, verbal consent may be appropriate; if a non-verbal child cannot provide consent but appears unsettled or uncomfortable with a photograph being taken—even if parents have given consent—then it is likely in their best interests for the photograph not to be taken. Special consideration should also be given to children. If children are capable of providing informed consent, they should be consulted. However, a parent or guardian should ideally be present throughout the consent process and photograph. In cases where children cannot consent, the parent or guardian should be consulted instead. In any situation, photographs should only be taken if they are in the best interests of the child—and should never be photographed, or shared, if this puts the child at risk in any way.

Furthermore, considering the appropriateness of moments for photography to take place is also essential; consent must be free from coercion. Arguably, a patient about to be given life-saving treatment by an organisation will not feel capable of denying consent for a photograph to be taken. *Should these photographs be taken at all?* On the one hand, they showcase important efforts and disseminate efforts not only to encourage further financial aid, but also to provide evidence to past donors. However, the inability to say no in these circumstances may lead to long-term detriment of subjects. Within healthcare settings in particular, it may also lead to sharing of information that individuals would prefer to maintain private. One example involves a photograph of a 16-year-old girl, gang-rape survivor from the Democratic Republic of Congo, who was treated by the non-governmental organisation, Médecins Sans Frontières (MSF). Her photograph was captured by a photographer working with MSF and placed online as a stock image for sale, fully identifiable, alongside a caption of her story. The photograph has since been removed after substantial criticism on Twitter (Batty 2022), with claims that the image was not only exploitative in nature, but also placed the child's safety at risk. This is a pressing example of how even explicit consent for photography may be insufficient justification for an image to be published. Photographers and publishers continue to have a duty to consider if images are in the best interests of their subjects and ensure that no one is put at harm through the dissemination of imagery.

The topic of consent is by no means a simple one. Not only are there practical challenges with documentation and language but previous work has highlighted additional subtleties in consent, including different personal and cultural interpretations of consent (Devakumar et al. 2013). Regardless of these challenges however, one finding in the study was particularly concerning: individuals in low-income settings cannot be treated with less respect, or dignity, than those in high-income countries. In other words, global health photography cannot continue to accept double standards; this goes directly against the definition of achieving *global health*. Therefore, even if practicalities of achieving consent differ in order to adapt to local populations—the requirement for informed consent must be universal.

An extract from the 'Framework for the use of imagery in global health' summarising key points under the principle of informed consent can be found in Fig. 3.4.

3.5 The Next Steps in Decolonising Global Health Visual Narratives

The framework has been received well and has been promoted in numerous international forums including news outlet 'Newzroom Afrika', the 'Every Breath Counts' coalition and 'One Health Trust'. Perhaps its biggest impact so far, however, has been a policy change implemented across all Lancet journals to strive for more equitable imagery use which was cited as a direct consequence of this work (The Lancet Global Health 2023). It is clear that there is a significant drive to redress the imbalances that exist in global health imagery; it is vital that these efforts are built upon, in order to refine the framework and assess its feasibility for widespread use. The current plan to do this involves working in collaboration with a range of stakeholders including actors, photographers and the public. Interviews and surveys will be conducted in a Delphi process that enables the co-development and validation of a Framework for Good Practice in Global Health Imagery Use. In their paper, Graham et al. (2019) outline the importance of engaging with the entire photographic process including image commissioning, production, publication, distribution and redistribution (Graham et al. 2019). It is therefore vital to appreciate the roles played by all the stakeholders involved.

Our work will involve a particular emphasis on the needs and voices of indigenous actors. An excellent model of such practice includes the work of the South African non-governmental organisation Eh!woza, which directly engages students and young adults from areas with high HIV and TB rates with local biomedical research. The local youth are empowered to produce documentaries, films and media that reflect individual experiences on disease and raise public awareness regarding disease burdens. Through the use of workshops, documentaries, school

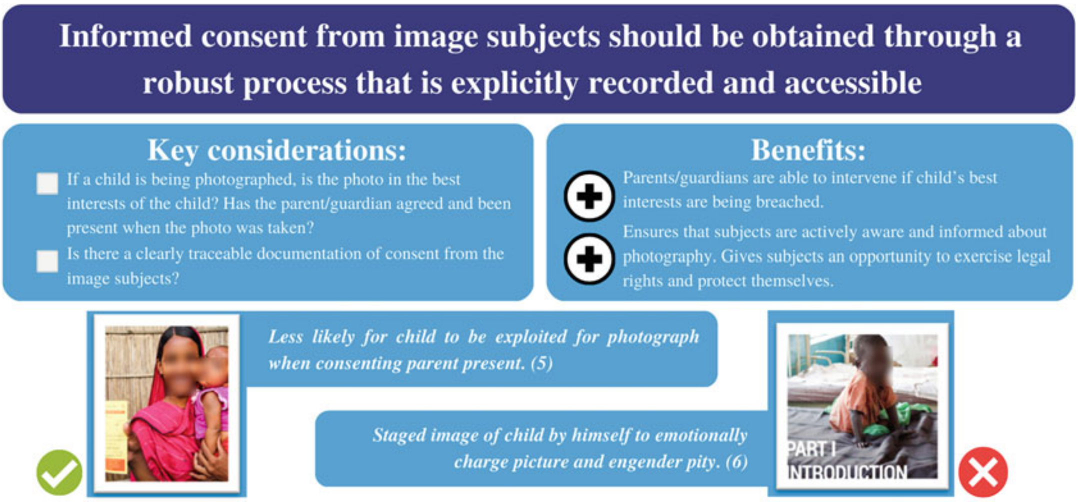

Fig. 3.4 Extract of 'Framework for the use of imagery in global health' detailing key considerations and associated benefits on the principle of ensuring informed consent (Charani et al. 2023)

programmes and science communication, Eh! woza facilitates public engagement and interaction with research that directly impacts them and serves to create a more balanced representation of health and disease. Placing local people at the forefront of their work, amplifying local voices and prioritising storytelling serve to reduce stigma, emphasise individual experiences and empower those affected most; we hope to take inspiration in order to implement similar practices whilst undertaking our work.

Global Health Institutions: Including Publishers and Editors

As most global health organisations are headquartered in the Global North, they are deemed to hold the most power—including financial assets, decision-making, capacity and influence. Therefore, it is they who often determine the broader agendas that the photographic process will be in service to. It is thus imperative that these centres of power are engaged in the promotion of ethical practice in global health photography, and the taking of a positive stance on a global scale—only then will meaningful change begin to be seen.

In December 2022, MSF released a statement of better and improved commitment to more appropriate representation in its work, moving away from colonialist-based white saviour narratives to honest, empowering portrayals of local teams. This statement is an important step forward—however, it does not address issues related to the dissemination of images that impinge upon integrity or lack of consent from the subjects of photographs. Images taken by photographers for this organisation are often put for sale online, as stock images; a recent letter by a group of academics and photographers, including current and former MSF staff, highlighted the exploitative nature of the sale of such photographs. Most notably, a photograph of a 16-year-old rape survivor, identifiable, which is still found for sale online.

Photographers might be following the codes of conduct, but often have no control over how images are then used and disseminated. It is the responsibility of institutions to foster a space of ethical photography. More practically, publishers, communication officers and editors also need to ensure that any images taken—and the way these images are used—follow an appropriate code of ethics. Identifiable photographs that do not respect the dignity of individuals should not be made available online for sale. It is difficult to justify the sale of such images; not only do they infringe the dignity and at times privacy of individuals, but profits from these sales do not reach the photographed individual. In other words, these photographs do not benefit them in any way. Understanding what barriers and facilitators exist for global health actors in pursuing more controlled and ethical distribution of the photographs they commission will also be necessary going forward.

Photographers

Before reaching any institutions, photographers possess the power to decide what images are worth capturing, and which images are worth sharing. They are also the ones who can ultimately ensure that photographs are taken with consent from subjects visualised in them and preserve the dignity of those involved. Photographers must balance artistic expression with the subject's dignity and rights, as well as institutional demands. If the purpose of global health photography is to support local communities and promote health and equity, then these three concepts should be aligned.

It is the responsibility of photographers to ensure that informed consent is sought from individuals who are photographed, before disseminating photographs in any format. This should be documented and evidence shared with institutions—who have a responsibility to confirm that there is evidence of consent. In this way, institutions and photographers on the ground may work in tandem to uphold an ethical framework for image production and dissemination.

Additionally, photographers (and subjects themselves) are also best-placed to provide the true context surrounding an image. Many photographers who strive to follow ethical standards provide captions alongside their images, outlining the context in which an image was taken and details of the subjects involved, in an attempt to ensure that the importance of context and subject voice is respected. Engaging with photographers to reveal the nuances behind these decisions and practices will be key for providing reasonable standards for them to adhere to and ensure they are feasible for those capturing scenes on the ground of global health campaigns.

The Public

Finally, images are shared with the ultimate purpose of informing and influencing public perception—raising awareness of issues, portraying a reality and encouraging them to make donations. If we continue to react, endorse and reproduce images that are problematic, we are inevitably contributing to the progression of a cycle of unethical photography production. Simultaneously, involvement of the public in the reform of global health photography will hugely influence change and shift narratives.

Social media provides strong platforms to amplify messages. There is clear outrage at unethical global health photography and dissemination of such. The sharing of personal encounters with these images sparks discussions between members of the social media community. The writing and publication of the letter to MSF, for instance, was disseminated through these platforms. This level of collaboration and dissemination is a vital driver of change. It will therefore be important to understand the mechanisms behind these feedback loops and how the role of the audience can cause a transformation in what communication strategies are deemed acceptable and marketable.

3.6 Conclusion and Next Steps

This chapter has highlighted the ethical challenges underlying current use of imagery in global health, highlighting the need for more respectful, equitable representation of individuals in this field. Through an examination of the field's colonial origins, we are able to understand the associated stereotypes, biases and imbalanced narratives utilised to legitimise oppression of native peoples across the world, and the manner in which disease was weaponised to alienate and shift blame onto indigenous peoples. Such imbalances continue to shape modern day global health structures, attitudes towards disease and stigmatisation towards communities bearing high disease burdens. The importance of prioritising adequate representation is thus emphasised as we endeavour to decolonise global health and enhance equitability.

We present imagery as a powerful storytelling tool frequently employed by global health actors to raise awareness and funds. Throughout global health imagery, damaging portrayal of local peoples continues to be practised, perpetuating aforementioned stereotypes and imbalances. As such, the imminent implementation of an ethical framework for use of imagery in global health is crucial, with focus on consent processes, relevance of photographs, dignity towards the individual and community and equitable representation. Recognition of the importance of representation, and implementation of measures to monitor and uphold ethical image dissemination within global health is imperative.

Such change requires all relevant stakeholders to be involved in its design and implementation. Therefore, it is vital to cooperate with global health institutions, photographers, global health report producers, publishers and locals, to gain deeper insight into the issues underlying global health photography from the perspective of each stakeholder and barriers that need to be overcome. This is likely to require analysis of published guidelines within institutions, briefings for photographers, publishing agreements, as well as discussions with representatives from each of these groups. It is also important to highlight the value of working in partnership with locals or, in other words, individuals within communities that have been photographed by global health institutions. Gaining their perspective of the issue, their view of proposed guidelines and suggestions on how they would prefer to be represented, involved and informed of the processes within global health imagery is essential to ensure these guidelines do indeed respect and benefit those who they are aiming to support.

Additionally, our study focused on global health reports. However, the issue is much broader than this: indeed, photography shared on media platforms may well be even more sensationalist. Therefore, wider implementation of our proposed framework would require evaluating it in these other mediums.

References

Africa BIS (2020) England bans flights from South Africa, as well as SA visitors, from today due to new Covid variant. https://www.businessinsider.co.za/england-bans-flights-from-sa-2020-12. Accessed 28/12/2022

Ashuntantang G, Luyckx V, Naicker S, Venkatapuram S (2021) Reform of research funding processes could pave the way for progress in global health. Lancet Glob Health 9(8):e1053–e1054. https://doi.org/10.1016/s2214-109x(21)00207-2

August E, Tadesse L, O'Neill MS, Eisenberg JNS, Wong R, Kolars JC, Bekele A (2022) What is global health equity? A proposed definition. Ann Glob Health 88(1):50. https://doi.org/10.5334/aogh.3754

Baccini L, Heinzel M, Koenig-Archibugi M (2022) The social construction of global health priorities: an empirical analysis of contagion in bilateral health aid. Int Stud Q 66(1):sqab092. https://doi.org/10.1093/isq/sqab092

Batty D (2022) Médecins Sans Frontières pulls images of teenage rape survivor after outcry. The Guardian. https://www.theguardian.com/world/2022/may/23/medecins-sans-frontieres-pulls-images-of-teenage-survivor-after-outcry. Accessed 12/12/2022

Beaglehole R, Bonita R (2010) What is global health? Glob Health Action 3. https://doi.org/10.3402/gha.v3i0.5142

Birn A (2018) The historical origins of modern international (and global) health. In: Textbook of global health, 4th edn. Oxford University Press, New York, pp 1–42

Business Insider South Africa (2020) England bans flights from South Africa, as well as SA visitors, from today due to new Covid variant. https://www.businessinsider.co.za/england-bans-flights-from-sa-2020-12. Accessed 30/12/2022

Calain P (2007) From the field side of the binoculars: a different view on global public health surveillance. Health Policy Plan 22(1):13–20. https://doi.org/10.1093/heapol/czl035

Charani E, Shariq S, Cardoso Pinto AM, Farooqi R, Nambatya W, Mbamalu O, Abimbola S, Mendelson M (2022) The use of imagery in global health: an analysis of infectious disease documents and a framework to guide practice. Lancet Glob Health 2023 11(1) e155–64 December 1, https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(22)00465-X/fulltext

Chen X, Li H, Lucero-Prisno DE 3rd, Abdullah AS, Huang J, Laurence C, Liang X, Ma Z, Mao Z, Ren R, Wu S, Wang N, Wang P, Wang T, Yan H, Zou Y (2020) What is global health? Key concepts and clarification of misperceptions: Report of the 2019

GHRP editorial meeting. Glob Health Res Policy 5:14. https://doi.org/10.1186/s41256-020-00142-7
Chesterton B (2017) I wish you'd listened to your heart. Duckrabbit. https://www.duckrabbit.info/blog/2017/05/photography-world-still-need-talk/. Accessed 29/10/2022
Christián L, Erdős Á, Háló G (2022) The Background and repercussions of the George Floyd case. Cogent Soc Sci 8(1):2082094. https://doi.org/10.1080/23311886.2022.2082094
Cohen WB (1983) Malaria and French imperialism. J Afr Hist 24(1):23–36
Collen EJ, Johar AS, Teixeira JC, Llamas B (2022) The immunogenetic impact of European colonization in the Americas. Front Genet 13:918227. https://doi.org/10.3389/fgene.2022.918227
CONCORD (2012) Code of conduct on images and messages. https://concordeurope.org/2012/09/27/code-of-conduct-on-images-and-messages/. Accessed 05/01/2023
Defeyter MA, Russo R, McPartlin PL (2009) The picture superiority effect in recognition memory: A developmental study using the response signal procedure. Cogn Dev 24(3):265–273. https://doi.org/10.1016/j.cogdev.2009.05.002
Devakumar D, Brotherton H, Halbert J, Clarke A, Prost A, Hall J (2013) Taking ethical photos of children for medical and research purposes in low-resource settings: an exploratory qualitative study. BMC Med Ethics 14(1):27. https://doi.org/10.1186/1472-6939-14-27
Dieleman JL, Graves CM, Templin T, Johnson E, Baral R, Leach-Kemon K, Haakenstad AM, Murray CJ (2014) Global health development assistance remained steady in 2013 but did not align with recipients' disease burden. Health Aff (Millwood) 33(5):878–886. https://doi.org/10.1377/hlthaff.2013.1432
Dunn G (1995) Photographic license. San Jose Metro. https://www.newtimesslo.com/archive/2003-12-03/archives/cov_stories_2002/cov_01172002.html. Accessed 10/01/2023
Global Health 50/50 (2022) Boards for all? A review of power, policy and people on the boards of organisations active in global health. Cambridge, UK
Graham AP, Lavery JV, Cook-Deegan R (2019) Ethics of global health photography: a focus on being more human. Health Hum Rights 21(1):49–62
Green J, Basilico MT, Kim H, Farmer P (2013) Colonial medicine and its legacies. In: Farmer P, Kleinman A, Kim J, Basilico M (eds) Reimagining global health an introduction. University of California Press, Berkeley, CA, pp 33–73
Harrison M (1996) "The tender frame of man": disease, climate, and racial difference in India and the West Indies, 1760–1860. Bull Hist Med 70(1):68–93
Havik PJ (2016) Hybridising medicine: illness, healing and the dynamics of reciprocal exchange on the upper Guinea coast (West Africa). Med Hist 60(2):181–205. https://doi.org/10.1017/mdh.2016.3
Hfbauer S (2003) The visualisation of dignity: photography from an ethical perspective. Danish Institute for Human Rights, Copenhagen, Denmark
Higgins A (2018) Is poverty porn a necessary evil? BRIGHT Magazine. https://brightthemag.com/is-poverty-porn-necessary-evil-aid-charity-humanitarian-donor-donation-c96739a1f311. Accessed 03/01/2023
Hirsch LA (2021) Is it possible to decolonize global health institutions? Lancet 397(10270):189–190. https://doi.org/10.1016/s0140-6736(20)32763-x
Ho TC, Brown S, Serences JT (2009) Domain general mechanisms of perceptual decision making in human cortex. J Neurosci 29(27):8675–8687. https://doi.org/10.1523/jneurosci.5984-08.2009
Hodge D (2015) Migrant mother, Nipomo, California. Tate. https://www.tate.org.uk/art/artworks/lange-migrant-mother-nipomo-california-p13115. Accessed 10/01/2023
Holst J (2020) Global Health—emergence, hegemonic trends and biomedical reductionism. Global Health 16(1):42. https://doi.org/10.1186/s12992-020-00573-4
Jain S (2020) Anti-Asian racism in the 1817 cholera pandemic. JSTOR. https://daily.jstor.org/anti-asian-racism-in-the-1817-cholera-pandemic/. Accessed 20/12/2022
Kagumire R (2021) The colonial undertones of Omicron travel bans. Al Jazeera. https://www.aljazeera.com/opinions/2021/12/6/the-colonial-roots-of-western-responses-to-omicron. Accessed 25/3/2023
Khan M, Abimbola S, Aloudat T, Capobianco E, Hawkes S, Rahman-Shepherd A (2021) Decolonizing global health in 2021: a roadmap to move from rhetoric to reform. BMJ Global Health 6(3):e005604. https://doi.org/10.1136/bmjgh-2021-005604
Kipling R (1940) Rudyard Kipling's verse (definitive edn). Doubleday, Garden City, NY, pp 321–323. OCLC 225762741
Lane JM, Summer L (2009) Smallpox as a weapon for bioterrorism. In: Fong IW, Alibek K (eds) Bioterrorism and infectious agents: a new dilemma for the 21st century. Springer, New York, pp 147–167
Lange D (1960) The assignment I'll never forget. Popular Photogr 46(2):42–43
Mavroforou A, Antoniou G, Giannoukas AD (2010) Ethical and legal aspects on the use of images and photographs in medical teaching and publication. Int Angiol 29(4):376–379
Messaris P, Abraham L (2001) The role of images in framing news stories. In: Reese S, Gandy O, Grant A (eds) Framing public life: perspectives on media and our understanding of the social world. Routledge, New York
Midberry J (2017) Only image I ever see. Journalism Stud 18(7):925–942. https://doi.org/10.1080/1461670X.2015.1088399
MSF Child Protection Inquiry (2022) Letter to the Board of Médecins Sans Frontières/Doctors Without Borders. WordPress. https://msfchildprotect.wordpress.com/2022/05/24/letter/. Accessed 10/10/2022

Newman EJ, Garry M, Bernstein DM, Kantner J, Lindsay DS (2012) Nonprobative photographs (or words) inflate truthiness. Psychon Bull Rev 19(5):969–974. https://doi.org/10.3758/s13423-012-0292-0

Olusanya BO, Mallewa M, Ogbo FA (2021) Beyond pledges: academic journals in high-income countries can do more to decolonize global health. BMJ Glob Health 6(5). https://doi.org/10.1136/bmjgh-2021-006200

Phillips S (2020) Why Africa leads the world in COVID-19 performance. The Hill. https://thehill.com/opinion/healthcare/520901-why-africa-leads-the-world-in-covid-19-performance/. Accessed 28/12/2022

Photographers Without Borders (n.d.) Code of ethics. https://www.photographerswithoutborders.org/code-of-ethics. Accessed 05/01/2023

Poole D (1997) Vision, race, and modernity: A visual economy of the Andean image world. Princeton University Press, Princeton

Rasheed MA (2021) Navigating the violent process of decolonization in global health research: a guideline. Lancet Glob Health 9(12):e1640–e1641. https://doi.org/10.1016/s2214-109x(21)00440-x

Segal JP, Hansen R (2021) Medical images, social media and consent. Nat Rev Gastroenterol Hepatol 18(8): 517–518. https://doi.org/10.1038/s41575-021-00453-1

Stewart J, DiCampo P (2019) Should use of online photographs be exempt from ethical guidelines? Lancet Infect Dis 19(9):933–934. https://doi.org/10.1016/s1473-3099(19)30433-5

Swanson MW (1977) The sanitation syndrome: Bubonic plague and urban native policy in the Cape Colony, 1900–1909. J Afr Hist 18(3):387–410. https://doi.org/10.1017/S0021853700027328

The Lancet Global Health (2023) The future of global health research, publishing, and practice. Lancet Glob Health 11(2):e170. https://doi.org/10.1016/s2214-109x(23)00010-4

Wallis B (1996) Black bodies, white science: The slave daguerreotypes of Louis Agassiz. J Blacks Higher Educ 12:102–106. https://doi.org/10.2307/2963000

White A (2018) Epidemic orientalism: social construction and the global management of infectious disease. Boston University, Boston

White AIR (2020) Historical linkages: epidemic threat, economic risk, and xenophobia. Lancet 395(10232): 1250–1251. https://doi.org/10.1016/s0140-6736(20)30737-6

White A (2023) Epidemic orientalism: race, capital, and the governance of infectious disease. Sanford University Press, Sanford

Williams JN (2021) Public health, authority, and the colonial state: cholera in India. Harv Libr Bull. https://nrs.harvard.edu/URN-3:HUL.INSTREPOS:37368752. Accessed 15/12/2022

Winsor M (2013) A fate worse than death for scores of African women. CNN. https://edition.cnn.com/2013/05/23/health/end-obstetric-fistula-day/index.html. Accessed 12/10/2022

World Health Organization (2005) International health regulations, 3rd edn. World Health Organization, Geneva

World Health Organization (2020) Updated WHO recommendations for international traffic in relation to COVID-19 outbreak. https://www.who.int/news-room/articles-detail/updated-who-recommendations-for-international-traffic-in-relation-to-covid-19-outbreak. Accessed 28/12/2022

Medical Illustration in Anatomy

4

Jade Naicker

Abstract

History portrays the important role that art plays in anatomy and medicine, with its ability to preserve and articulate human dissections and physiological concepts. Throughout time, we see an evolution of medical illustration from elaborate and dramatized compositions during the Renaissance era to more refined and naturalistic depictions of anatomical concepts and procedures by the pioneers of art and medicine. These greats such as the Flemish "father of anatomy" Andreas Vesalius and Leonardo da Vinci gained their accolades through intricate investigation of the human body and valued the importance of practical, embodied dissection while striving for its accurate presentation. Today, medical illustrations are described as simple, clear infographics which interpret details of human dissection for a more conceptualized understanding of anatomy and are an efficient tool to ensure ease of learning and improved health care. Further progression is seen in the field of medical art with the integration of innovative imaging techniques such as three-dimensional rendering and virtual and augmented realities, which engages students while forging a true comprehension of context. Medical illustration expands beyond anatomy and can be used to convey and simplify useful information to the public and therefore acquires the responsibility of depicting diverse communities and inclusive representation. Although medical art is ever-evolving and becoming an integral part of medical curricula, the initial melding of art and anatomy had solidified its significance in science and its ability to elevate teaching and learning.

Keywords

Medical illustration · History · Anatomy · Teaching · Diversity · Digital imaging

4.1 The History of Medical Illustration

Even with the expansion of analytical and detailed textual information, images have remained a more enticing and engaging medium of communicating content that may otherwise be considered laborious. Medical illustrations allow for a more comprehensive and logical understanding of anatomy, as it superimposes a visual aid with theory in a contextual manner. As such, art has always maintained an intricate role in anatomy and medical teaching throughout time by documenting anatomical findings and supplementing concepts. The ideology of functional representation is dominant in the realm of

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medical illustration, enhancing the pedagogical impact of medical teaching and learning, while slowly imprinting its stance as an individual niche of medicine and anatomy.

Art as a concept began as a means of observational reporting of early humankind and later progressed into an outlet of creativity and imagination as modern human behavior progressed. The first indication of art has been theorized to have originated in Middle Stone Africa with evidence of the crafting of beads, engravings, and frequent use of color (d'Errico and Henshilwood 2007; Marean et al. 2007).

Historically, medical illustration has served an integral role in medical teaching and training, especially during periods of heightened scientific interest and intellectual advances. Anatomical knowledge was minimal and limited to textual resources, as human dissection was frowned upon in Ancient Greece, as the human body was accepted as the vessel for the soul and desecration of such would incite retaliation from the deceased (Calkins et al. 1999). However, the Greek physician Herophilus (350–280 B.C.) was a pioneer in anatomical study, as he was the first to base his treatise on sanctioned cadaveric dissection (Bay and Bay 2010). His extensive dissection of the brain and nervous system augmented the premise that the brain is the source of intellect and emotion, which the heart was commonly perceived to have conveyed (Bay and Bay 2010). His body of work authenticated fundamental anatomical findings and facilitated the supplementation of human dissection in medical teaching and eventual anatomical illustrations.

Claudius Galen (129–200 A.D.) was a formidable force in medical history, documenting reputable anatomical script that was referenced in medical teaching for close to 15 centuries (Marx 2013). Galen comparatively depicted human anatomy according to his multiple animal dissections, which were readily available, unlike human cadaveric material that was still considered taboo in early Greek society. As admirable as his impact was on human anatomy and medicine, the accuracy of his findings would later be challenged due to them being substantiated by animal dissections (Hajar 2011). Regardless, his intense research and expertise interpreted the functionality of associated anatomical structures, advancing theoretical anatomical knowledge and its significance in pathology and medical treatment, as he classified disease as the imbalance of anatomical functions (Rajkumari 2015). Even though his text had not been supported by illustration, his fundamentals of anatomy enticed curiosity of human anatomical concepts, and his establishment of anatomy as an ethos of medicine inspired further investigation and a desire for human dissection (Rajkumari 2015).

One of the many anatomists who actively tried to discredit many of Galen's theories and overthrow his powerful influence on medical principles was physician and anatomist, Mondino De Liuzzi (1270–1326). However, Galen's grip on functional medicine was too indomitable to sway the medical society of that time, despite the extensive study and documentation of anatomical findings with the appropriate use of human specimens (Olry 1997). Regardless, his efforts were not in vain as his body of work ignited the approval and interest of human dissection in driving the pursuit of intricate and accurate anatomy, which coaxed the introduction of medical illustration (Calkins et al. 1999). A student, and follower of De Liuzzi's research, Guido da Vigevano (1280–1349) spearheaded the use of illustrations and is said to be one of the first to document anatomical observations as images, extending the boundaries of anatomy and interlinking the concept of medicine and art (Di Ieva et al. 2007).

The multi-faceted works of Leonardo da Vinci (1452–1519) remain some of the most celebrated works of art to this day. Irrespective of his lack of treatise and textual guides, da Vinci produced extraordinarily precise renditions of anatomical dissections, which can attest to his endeavor to unite all disciplines (Netter 1956). The artist was one of very few to illustrate his own human dissections and challenge many of Galen's longstanding concepts, which were concluded to be inaccurate (O'Malley and Saunders 1952). His illustrations melded spatial anatomical structures with the accompanying functionality and anatomical physiology and was one of the few to successfully do this (Keele 1979). His keen observational skills allowed him to document details that surpassed the investigation and findings of reputable anatomists of his time and was only later acknowledged by subsequent anatomists, contributing to the advanced and innovative nature of da Vinci (Bulbulian 1961). An example of this is da Vinci's depiction of the spine with its exaggerated curvatures and its application to supporting posture and gait as seen in Figure 4.1, which also displays da Vinci's shorthand notes regarding his dissections and his interpretation of findings. Due to his comprehensive and complex dissection and study of the human body, da Vinci reformed the presentation of anatomical views due to the detail they possessed, as well as maintaining the functional representation of structures (Tsafrir and Ohry, 2008). Therefore, da Vinci birthed the exploded view of multiple dissections and the depiction of anatomical structures from multiple perspectives of orientation, creating spatial awareness and understanding of key and complex concepts (Kemp 1998).

The Belgian anatomist and physician, Andreas Vesalius (1514–1564), was a renowned teacher of anatomy and medicine in Padua, Italy where he extensively utilized human dissection in his teaching and training of medical students (Ghosh 2015). Vesalius revolutionized printed manuscripts of anatomical illustrations when he commissioned the talents of local artists, in particular Jan Stephan van Calcar (1500–1546) to recreate his intricate dissections, which were compiled and published in the famed *De Humani Corporis Fabrica* in 1543 (Mumford 1908). This served as the first concrete atlas of human anatomy to be created and distributed, initiating the role of medical illustration in medical training and accustoming human dissection to an otherwise conservative scientific audience, attuning them to refined anatomical investigation. Andreas is dubbed the father of modern anatomy, with his text having consolidated, refined, and novel anatomical findings. This ignited a climate of innovative medical thinking and the acceptance of medical illustrations in enhancing anatomical text. While human dissection had been an accepted practice at this time, there was still a broad disconnect between human investigation and teaching, with many still relying on the pedagogies of Galen who concluded his teachings primarily based on animal studies. It was Vesalius who challenged these theories via his thorough consolidation with anatomical study and dissection. Indeed, Vesalius challenged the ideals which saturated medical teachings in the 1500s, including the reliance on textual material without supplementing it with proactive dissection. The Flemish physician highlighted his enthusiasm for dissection on the illustrated cover of *Fabrica* depicting an anatomical demonstration with Vesalius utilizing a dissected corpse and multiple observers surrounding him (Massey 2016). The illustrations depicted in *De Humani Corporis Fabrica* portrays a collection of dissected "muscle men" posing against an elaborate backdrop of the Italian city of Padua. This inclusion of decorative and fanciful landscapes was due to the artistic license awarded to the illustrators employed by Vesalius, as the convention of beautifying figures irrespective of its content radiated through the images and is now one of the key and memorable features of Vesalius's *De Humani Corporis Fabrica* (Fig. 4.2). In order to publish the now famed textbook, the drawings were hand engraved into wood after which they were inked and hand-printed onto paper using a woodcut press. The illustrations depicted in *De Humani Corporis Fabrica* are the result of a collaborative refinement of accurate depictions of human anatomy, irrespective of the elaborate landscapes which often added to the aesthetic appeal of the material (Vesalius, 1543). This led to the famed atlas becoming the gold standard of medical illustration, on which many anatomists and physicians based their teachings.

4.2 Transition in the Aesthetic of Medical Illustration

The development and evolution of mechanized printing set the tone for many of the anatomical textbooks and atlases essential for anatomical and medical education today, with the visual aid and

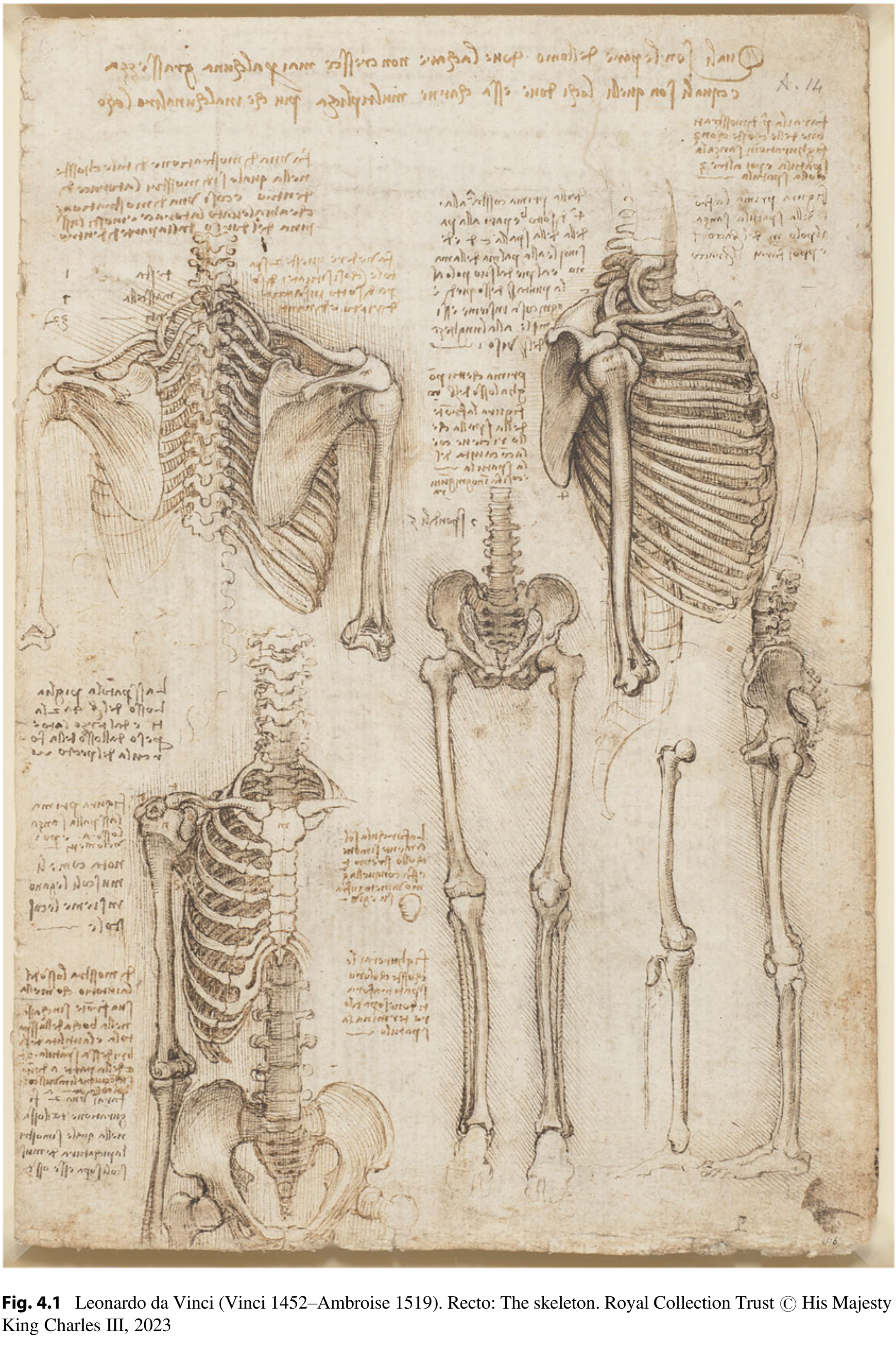

Fig. 4.1 Leonardo da Vinci (Vinci 1452–Ambroise 1519). Recto: The skeleton. Royal Collection Trust © His Majesty King Charles III, 2023

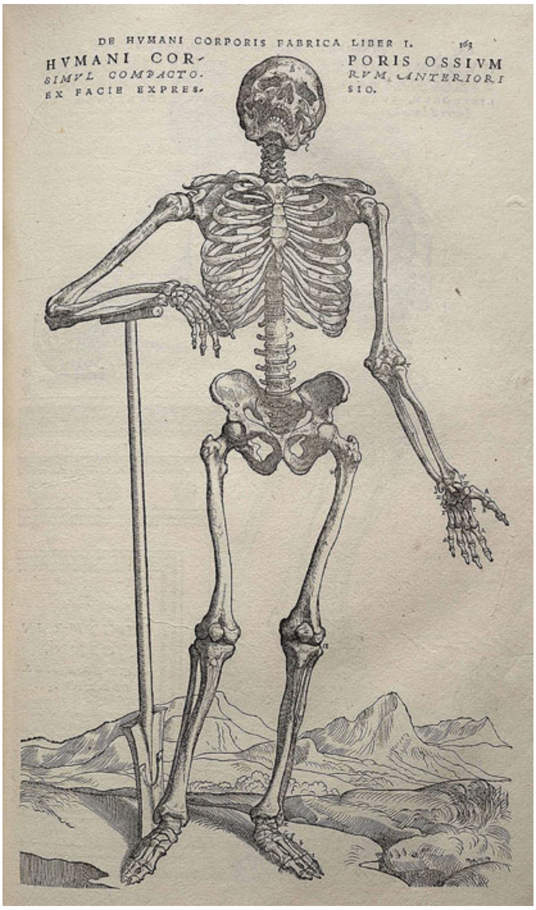

Fig. 4.2 Andreas Vesalius (De Humani Corporis Fabrica, 1543). p. 163. History of Medicine collection, David M. Rubenstein Rare Book & Manuscript library, Duke University

schematic presentation of structures and concepts being a pertinent tool in anatomy education. Contemporary anatomical illustrations shifted in style, from more aesthetically vibrant and unnecessarily elaborate images to simplified depictions of anatomically accurate and conceptualized images resulting from detailed examination and erudition. This was a departure from the whimsical interpretation of structures where dissected bodies were generally presented in regal or dramatized poses against backgrounds of detailed landscapes with the inclusion of arbitrary details (Ghosh 2015). These details were often meant to glamorize the idea of human dissection as it removed the gore of blood and putrefying flesh which it was associated with, although some may argue that artists were merely evoking their artistic discretion (Riva et al. 2010).

Hieronymus Fabricius ab Acquapendente (1533–1619) was a distinguished academic of anatomy and surgery in Italy and often facilitated the transition of illustration from ornate to clean and clinical portrayal (Riva et al. 2010). With the awakening of the simplification of anatomical illustrations in an effort to be conducive to comprehension and learning, Fabricius compiled a collection of 300 illustrations of human and animal dissections which were published in the *Tabulae Pictae* (Riva 2004). Fabricius was said to be a forerunner in the evolution of medical illustration as he resisted the trend of overdramatized positioning of dissections and opted for unpretentious, singular representation of structures without distracting backgrounds. Therefore, making his resource more suitable for the study of anatomy and medicine (Riva et al. 2010).

The eighteenth century ushered in the age of Naturalism, which resulted in photorealistic depictions of intricate dissections and minimal artistic embellishments, in turn initiating and redefining clinical aesthetics. William Hunter (1718–1783), although ethically questionable in his investigations and exploration in science, was nevertheless a formidable name, especially in the world of gynecology (Shelton 2013). In 1741, Hunter moved to London and shortly after became an assistant to Doctor James Douglas, an obstetrician who exemplified competence and influence in his field, wielding many accolades and expertise. Douglas' experience in midwifery had a major influence on Hunter who in turn adopted the discipline remarkably, and it propelled Hunter in his field, making him a handsome candidate in his institution with the knowledge he had acquired. Hunter was an ardent teacher and prioritized anatomical study in his lectures and relied heavily on anatomical figures, specimens, and cadavers during his academic sessions.

Hunter's most accomplished work was his *Human Gravid Uterus* which he initiated in 1750 and completed in 1774 during his

Fig. 4.3 William Hunter (the anatomy of the human gravid uterus, 1774). Table IV. Engraving by Jan van Rymsdyk. Courtesy of the National Library of Medicine

professorship at the Royal Academy of Arts (1768–1783) (Fig. 4.3). This work featured a collection of detailed engravings which highlighted gynecological and fetal in utero anatomy which Hunter had immense exposure to and proficiency with during his time in midwifery (Andrews 1915). The thirteen specimens which were dissected overall confirmed anatomical debates and theories and solidified the cumulative knowledge of the anatomy of gestation with regard to both the mother and fetus. Hunter strayed from the path of outdated assessments and often reported progressive and evolutionary pedagogies stemming from his extensive research and life's work (Andrews 1915). This resulted in his text and teaching having dependable accuracy and detail in their features which were not previously reported by studies. The collection included skilled engravings by various artists employed by Hunter, the primary artist being Jan van Rymsdyk (1730–1790) who was responsible for replicating these dissections in the most realistic and clinical form which was demanded by Hunter.

Hunter pressed the need for accurately portraying these anatomical specimens in the most minute of details, absent from any artistic or unique branding which may have distracted from the illustration. Artists like van Rymsdyk were strictly enforced to illustrate in real time and as a result, faced some ridicule as to the legitimacy of their artistic capabilities, due to the restraint expressed in his illustrations which was attributed to the lack of extravagant flare employed (Mount 2006). Although unpopular, this artistic style which Hunter had instructed his illustrators to adopt had highlighted imperative observations and articulated a progressive, minimalistic aesthetic. Hunter, much like his iconic predecessors, reiterated the significance of practical knowledge and demonstration in these illustrations, allowing these exposed dissections to be at the forefront of the viewer's attention, and it was these practices which propelled his scientific discoveries (Massey 2016). Hunter was also one of the few anatomists and physicians to initiate the concept of regional anatomy which initiated an organized understanding of the body as a whole by compartmentalizing it and allowing for an efficient learning experience.

John Bell (1763–1820) had a profound influence in medicine and was a strong advocate for this transition in medical illustration. Bell was an anatomist and surgeon who was labeled the father of surgical anatomy, as he fortified the importance of anatomical study in facilitating and developing surgery, as well as enticing student interest in it (Kaufman 2005). His ardent passion for anatomy and his impressive research led to the publication of his knowledgeable treatise, the *Anatomy of the Human Body*, which presented his anatomical observations while melding the disciplines of anatomy and surgery (Bell and Bell 1794–1804). Bell supplemented his text with simple and conceptual self-made illustrations and extensively motivated for the pertinence and reliance on medical illustration in anatomy as a guide to the understanding and integration of concepts (Bell 1794; p. iii). His illustrations lacked the elaborate and fanciful visuals of his predecessors, but maintained accuracy and simplicity, in turn making them easier to comprehend and follow as they were meant as a practical guide for surgeons (Bell 1794).

One of Bell's brothers, who cannot be overlooked due to his exceptional illustrative skills and understanding of the importance of art in anatomy, is Charles Bell (1774–1842). Charles Bell had an immense passion for the study and inquiry into the human body and spearheaded the concept of using art as a tool for study. Charles advocated the link between the perception gained by the eye and the movement produced by the hand and emphasized this as an important learning tool for the complexities of the human body. He implored students to stimulate their observational skills when in the dissection lab and attune their senses to intricate detail, nuances and spatial awareness of the specimens by replicating them in real time on paper. By emphasizing this he essentially created a curriculum where students studied anatomy through an art-based practice. In 1806, Bell began his treatise for painters, *Essays on the Anatomy of Expression in Painting*, which allowed Bell to reimagine the change in aesthetics which medical illustration had undergone, with its naturalistic depiction devoid of imaginative poses or trappings which would otherwise showcase an artist's unique flare. Bell posited that the simplicity of a medical illustration was a favorable and more appealing aesthetic and went so far as to associate nuances of restraint and lucidity with beauty (Bell 1870).

Bell, however, was not opposed to the inclusion of decorated human components in his artwork as a means of spurring enthusiasm for learning amongst students (Bell 1801). Bell leaned toward illustrations which exhibited the various components of anatomy, while at the same time conveying the personal experience of the artist. This allowed the viewer to comprehend the artist's approach and visual techniques which complemented their interaction with and interpretation of the dissection which inhabits the image.

The transition into the eighteenth century also birthed the age of enlightenment, where new technological discoveries were being made and innovation and industrialization were prioritized over expressive and poignant art. Bernhard Siegfried Albinus (1697–1770) worked with the eminent Dutch artist, Jan Wandelaar (1690–1759), who was able to skillfully and creatively marry concepts of art and anatomy during the age of enlightenment, and ensured the rapid development of technical skills and scientific concepts at the turn of the eighteenth century. Albinus contributed toward their partnership by planning each illustration and exploring the anatomical and scientific concepts linked to the artwork such as the mechanical and physiological properties of the human body, to ensure understanding and accuracy. Albinus ensured that a thorough anatomical investigation of multiple samples was conducted in order to reproduce the truest depiction of the anatomy and sought to adjust and fine-tune a subject to produce a consistent final sketch.

Wandelaar was one of the first artists to utilize dimensions and ratios to ensure proportionality which was found lacking in many other illustrations of that time. Wandelaar utilized a grid method of illustration whereby a grid was superimposed onto the physical subject in order to replicate it as an illustration onto his sketch surface. This method enabled the close correlation between the subject and the illustration. It also allowed for the maintaining of reference points throughout the observation and illustration process and ensured that the artist was able to accurately scrutinize the symmetry of the subject as well as preserve the proportions of the subject in the illustration itself (Cazort et al. 1996). This methodology allowed for an accurate depiction of the anatomy using advanced artistic methods which contrasted greatly with the detailed and elaborate landscapes surrounding the anatomy, which at that time seemed regressive with regard to the shift in aesthetics from eccentric to straightforward. Their most famous example of this being the fourth-order muscle man with the detailed depiction of the so-named "Clara," the first Indian rhinoceros to be sent to Europe in over 150 years (Clarke 1986). The landscape background in Wandelaar's illustrations was intentionally added to enrich the image and to ensure that the anatomical illustration stood out. Without the landscape background, the lightest parts of the anatomical structures would fade into the white background of the paper and not be easily discernible (Fig. 4.4). The landscape background also ensured dimension and spatiality (Elkins 1986; Roberts and Tomlinson 1992). Albinus was criticized by many anatomists and physicians of the eighteenth century, including John Bell, and as a result the 1777 Edinburgh publication of the artworks replaced the background with a more contemporary one (Wilson-Pauwels 2009).

Max Brödel (1870–1941) was a talented German-born artist who inaugurated the establishment of medical illustration as a profession and created a course at the John Hopkins School of Medicine in 1911 which sprouted new, young medical illustrators and melded scientific and artistic teaching and in turn substantiated illustration as a form of science in itself and certainly its significance in medicine (Hajar 2011). Brödel, who is renowned for his artworks and collaboration with Doctor Frank Netter in his anatomy atlas compositions, started his career by illustrating for many clinicians based at the John Hopkins School of Medicine in 1894. Brödel expanded his interests beyond art and valued scientific investigation, making his own clinical discoveries in Urology which aided him in becoming a proclaimed medical illustrator. In this way, Brödel embodied the blended concept of "art in medicine" and took it upon himself to master both fields by observing clinical practice and studying human tissue via various methods of investigation (Brödel 1901). This artist also broke ground in his specialized field by establishing creative art techniques and mediums such as the "carbon dust"[1] and "stipple board"[2] method which later became widely used.

Brödel's methods aimed to convey the feel and look of fresh tissue in his illustrations, by maintaining realism and detail while still ensuring that the illustration is didactic and comprehensible. This was achieved by planning the illustration thoroughly (Brödel 1915).

The need and eminence of a medical illustrator was significant and Brödel sought not only to nourish the skills and training of young

[1] Carbon dust is an artistic technique whereby fine shavings of carbon pencil are applied to a surface using dry art brushes (Crosby and Cody 1991).

[2] Stipple or coquille board is a drawing paper with a textured surface that provides a stippling effect when crayon or pencil is applied to the paper (Hodges 2003).

Fig. 4.4 Bernhard Siegfried Albinus (Tabulae sceleti et musculorum corporis humani, 1747). Plate 4. Engraving by Jan Wandelaar. Courtesy of the National Library of Medicine

illustrators but also to corroborate their role in science and medicine, thus melding their proficiency in art and science in one profession. In 1959, the Department of Arts and Applied Medicine was forged at John Hopkins Medical Institution and laid the path for many to follow. Currently, multiple institutions cater to the study and training of students in medical illustration. Medical illustrators are in high demand, as academics were previously required to rely on graphic designers prior to the establishment of this specialized vocation.

The training of medical illustrators evolved in its own right, with the implementation of innovative imaging techniques and digital technologies in addition to traditional illustration methods, ensuring illustrators meet the demand of a steadily emerging digital climate. These include training in digital artwork using software programs, three-dimensional (3D) rendering and animations.

From the year 1850, the focus in medical art shifted from interpretive to fully factual and objective depictions, keeping in mind the functional representation of illustrations amongst scholars and academics (Ghosh 2015). This also solidified the scientific importance of medical illustration and its necessity in medicine.

4.3 Medical Illustration Today

Henry Gray's (1827–1861) *Anatomy: Descriptive and Surgical* was originally created to assist physicians with the practical application of anatomical concepts in medicine. The textbook was first published in 1858 and initially contained 363 illustrations created by Henry Vandyke Carter (1831–1897), who was a profound teacher of anatomy and physiology (Kemp 2010). Carter's illustrations are still featured in the renowned *Gray's Anatomy* textbook, which has been integrated into the curriculum of medical students globally. This vastly prescribed textbook has become a reputable reference for anatomical study while highlighting a multitude of skillfully drawn illustrations. Henry Gray was a physician and anatomist who also taught anatomical concepts to medical students including Henry Carter. Gray valued accuracy and intelligibility with regard to his pedagogy and required these same properties in the illustrations which supported his text. Gray was one of the few anatomists of his time to effectively utilize "sectional anatomy" in his text, a term commonly used to describe anatomy which has been divided according to the sections of the body (Kemp 2010).

Although Henry Gray was awarded most of the recognition for his work in *Anatomy: Descriptive and Surgical*, Carter produced the art which reinforced Gray's findings. Carter's illustrations were clinical and distinct, as it allowed the viewer to clearly integrate the significant components of systemic anatomy in order to conceptualize its function. This artistic style highlighted the clinically relevant anatomy, making it an ideal learning tool and dissection guide (Hiatt and Hiatt 1995). This concept and sequence of content was seen as innovative, as it strayed from the normal treatises available during this era which were saturated with content, and is the reason that *Gray's Anatomy* textbook is still in demand and in print. Carter was also one of the first artists to include structural annotations of his illustrations on the image itself, allowing improved accessibility to information and systematic learning (Burch 2008). These editorial decisions were the result of Gray and Carter's vast dissection experience which they acquired during their teaching responsibilities at Saint George's Hospital Medical School. These tasks imparted an understanding for the practical needs of a student and dissector and directed their creative process. The current editions of *Gray's Anatomy* incorporate various modalities of imaging for visual aid including photography, radiographs, and endoscopic images of patients, while the illustrations have been enhanced to digitized, color figures. The illustrations do more to inform the reader as an annotated figure than to replicate a cadaveric dissection, with many of the illustrations having been produced and edited using the Adobe Creative Suite.

The *Atlas of Human Anatomy* by Doctor Frank Netter (1906–1991) has become a greatly popularized anatomical guide and is said to be the gold standard of clinically orientated atlases of human anatomy. The name "Netter" is synonymous with the formidable collection of intricate, watercolor illustrations that has served as one of the primary resources in anatomy education for anatomists and clinicians alike. Netter was an artist and physician who graduated from New York University Medical College, where he funded his studies by selling his medical art to his professors and later large pharmaceutical companies, before fully pursuing his artistic passion as a medical illustrator. Netter's medical training paired with his artistic abilities had proven to be a considerable advantage as the artist was not only able to illustrate with accuracy, but also from an astute clinical perspective. In addition, Netter also enlisted the help of many collaborators with clinical and anatomical backgrounds during the composition of his anatomical illustrations to ensure it conveyed an accurate and realistic narrative. Subsequently, Netter became a favored profile in both the anatomical and clinical niches, and the demand for his artwork rose during the emergence of contemporary surgical procedures. One of these notable procedures is the first artificial heart transplant in 1982 which was conducted by Doctor Willem DeVries (Reverón 2014). Currently, Netter's vivid and hyper-realistic images, which amount to more than 4000, are some of the most recognizable and celebrated medical illustrations. Netter's earlier illustrations included clinical patient scenarios. This visual conveyed a sense of humanity and empathy for these individuals which reminded many of the tangible human connection one has with patients, and that it is the person which one treats not the condition. Netter was also not opposed to technological advances in illustration techniques and appreciated its usability and innovation in print and media (Netter 2013).

Doctor Carlos Machado now inherits the legacy of Doctor Frank Netter, as his successor and the main illustrator for the present editions of the *Atlas of Human Anatomy* which still preserves the discernible aesthetic which Netter attained. Machado also shares the same medical training as his predecessor which allows him to project the same patient care principles which Netter exuded through his illustrations, while maintaining acute clinical insight. His illustrations contain the same artistically appealing and realistic attributes as the original artwork, while offering its own aesthetically striking visuals.

During the 1700s, anatomists experienced a scarce supply of cadaveric material and difficulty with sourcing legitimate human tissue which still maintained a preserved condition, enough for its dissection. This limitation inspired experimentation with 3D wax models as a way of implementing alternatives to human remains. Cadaveric material would rapidly decay, especially in warmer climates, as methods of refrigeration and chemical preservatives had not been perfected at this time. This led anatomists and physicians to replicate these dissections using 3D models, sculpted from wax, which would eventually replace cadaveric tissue. The composition and construction of wax models led to the mastering of technical skills and craftsmanship. Most of these models presented female anatomy placed in feminine poses, with the most popular being a seven-layer model by Clemente Susini (1754–1814) which could be disassembled and featured a pregnant womb. Although these models provided a sterile and less gory alternative to dissection, the art form lacked the technology needed for it to be sustainable and was dissociated from real human dissections as it did not convey the same detail and accuracy. The realism which came with cadaveric interactions prepared students for patient interaction and these wax models were lacking not only the imperative detail but also a realistic portrayal of human tissue.

Although 3D models are still frequently used in anatomy laboratories and classrooms, they have been replaced by more durable plastic models which display complex and detailed structures which far surpass the original wax models used in the 17th century. The plastic models available currently, like the SOMSO® anatomy models, also provide comprehensive displays of anatomical structures which would often be difficult to visualize during cadaver dissection. These models offer an alternate and interactive learning material as it allows students to disassemble and reassemble part of the model which contains accurate presentation of anatomical structures. These plastic models provide a visual aid for teaching and learning and can be particularly useful during anatomy sessions hosted for larger academic groups where a shortage of cadaveric specimens may arise. These alternatives also reduce the amount of physical contact one has with specimens, in turn decreasing the amount of deterioration to the specimen itself.

Plastination or polymer impregnation is often used to preserve the original form, color, and anatomy of a cadaveric specimen by dehydrating and degreasing the specimen. A plastic polymer or silicone is then injected into the specimen which binds to the tissue, replaces the water and fats, and preserves the morphology of the specimen (Weiglein 2005). Plastination provides a cost-effective alternative to purchasing plastic models, although an institution will require specialized equipment and training of personnel in plastination techniques. Although plastinated models do not preserve the texture and mobility of cadaveric tissue, it does maintain the volume and integrity of the specimen, which increases the longevity of the specimen without the worry of specialized storage containers filled with odorous chemical preservatives.

The evolution of medical illustration has surpassed the original paper-based medium and has transitioned toward digital creations using computer-based imaging software. The process of creating digital images is said to be faster and more efficient than physical, hardcopy illustrations, especially since digital drawing tools and technology have become more accessible and user friendly (Appukuttan 2021). Although, this is more accurate when the user is well versed with the software and technology needed to produce a digital image. Digital illustration is more beneficial when alterations or corrections to the image are needed. However, the additional steps involved during post-process editing and troubleshooting make this method more labor intensive and time consuming. Oftentimes, the traditional pen and ink medium of illustration is an efficacious option, while a digitized copy provides ease of transfer, eliminates the chance of damage, and allows one to create a digital or online catalog. However, a combination of digital and traditional media is also preferred in medical art, as traditional media often conveys a softer, less invasive appeal which is useful when demonstrating medical procedures to the public (Erolin 2020). This effect can also be translated into digital images using software tools and can be edited further to produce 3D rendered images. A common digital software that is utilized is Adobe Photoshop, as most certified medical illustrators are trained to use these programs and engage with digital content for online platforms. The progression of medical illustration toward digital media has allowed for the production of high resolution and quality images, which provides a "cleaner" and more enhanced visual. In addition, these digital images can be easily transcribed into 3D models for immersive and efficient learning. High quality and accurate illustrations can also be produced using traditional means, although this is dependent on the competency and anatomical knowledge of the illustrator.

The software needed to produce and edit digital images does incur additional costs due to the price of subscriptions and program updates, as well as the equipment involved which includes electronic drawing pads, printers, and scanners, as well as the computer or laptop. However, the cost of the illustration often depends on the level of detail and time spent on the illustration. Editing and adjusting images are also more convenient with digital images as various software programs allow the user to work in "layers" which permits changes to be added or deleted with ease. The implementation of biomedical animation and digital illustration has a different appeal compared with traditional medical illustration. This emerging field may require a different niche of skills and interests, which are centered around the knowledge of image editing software and technology, as well as advanced graphic skills that extend beyond artistic talent (Corl et al. 2000). This medium of illustration is highly beneficial as vector formats, which allows the creator to freely alter and customize images throughout the illustration process (Corl et al. 2000).

As we review the history of medical illustration, we notice the reliance on cadaveric dissection as a reference for illustrations during the genesis of medical art, with many artists relying on the recollection of the specimen features to complete their artwork. Nowadays, medical illustrators have multiple forms of cadaveric, patient and digital references such as photographs, endoscopic images, and computed tomography (CT) scans. Historically, anatomists and physicians had to rely on artists with no anatomical knowledge to recreate dissected specimens—however, contemporary trained medical illustrators must master both art and anatomy. By fusing both disciplines, accurate medical art is produced that effectively communicates vital anatomical findings without the distraction of elaborate embellishments.

4.3.1 Photographing and Digitization of Specimens

Clinical photography is an important field that provides imaging for the purpose of diagnosis, case reporting, and teaching. In the modern age of technology and imaging advances, photography allows the user to capture and catalog an event, procedure, or pathology instantly. This swift and convenient tool is useful for many physicians and medical educators, although photographs are often dismissed when compared with traditional illustrations. Medical photography is perceived as more clinical and disassociated, whereas medical illustration conveys critical interpretation and sustains the empathy of the viewer, especially when patients are depicted. Medical illustrations also allow artists to emphasize key structures in the illustration with clear annotations of landmarks that would otherwise not be able to be captured in a photograph. This lack of selection and prominence, especially in the early, unmastered days of photography led to its disconnection from art and cluttered aesthetic (Graver 1975). Medical photography focused on portraying flattering poses and clinical medicine until the mid-1800s, when medical photography evolved after the revision of photographic techniques and further development of the technology. This evoked further appreciation for the objectivity that medical photography offered compared with illustration. Photography may also be integrated with medical illustration, by photographing an event or patient case which provide source images that are later replicated by an artist. In this way, an accurate, real-time reference is provided to the illustrator without the need for reliance on memory. This method does not conform to the ethical constraints which accompany the photographing of patients, as the identity of the patient can be concealed by adjusting or otherwise obscuring their facial features in the final image.

Photography also plays a major role in the digitization of wet specimens and museum collections, allowing for a digital repository of cadaveric specimens that can be accessed at any point. Photography of human tissue, as with medical photography, is its own art form and requires specialized skill and knowledge of camera settings and lighting. Digitization of these collections encourages the utilization of these specimens and their application on online databases for effective and engaging learning. There are various examples of digitized repositories, such as the University of Cape Town's anatomical pathology collection which features restored pathology specimens with supplementary case studies and specimen details. The University of Pretoria's anatomy department is also currently undertaking the digitization of its anatomy and pathology specimen collections which equates to more than 1700 specimens. These projects enable anatomists to revive and rejuvenate these informative specimens, some of which are extremely rare and provide students with exemplary exposure to pathology cases. Refurbishing and digitizing presevered specimens encourage participation and engagement with these collections which are often underutilized and forgotten.

The photographing of anatomical specimens can be problematic, especially those that have been mounted and sealed in glass or Perspex display boxes, as is the common method of specimen preservation. Due to the glare which may arise from the glossy surface of the material of the display container, a specific studio and lighting setup may be required to produce the best quality image. Ideally, one would require a "dark room" devoid of external light, with carefully positioned lighting equipment in order to eliminate any reflections from the container surface. However, access or adaptation of such a room may be difficult or ergonomically inefficient due to limited availability and displacement of specimens from their normal housing. To overcome this, during the digitization of the anatomy collection held at the University of Pretoria, a specialized studio setup was established which allowed the photography station to be assembled within the facility which contains the collection. The technique was integrated and refined by Andre du Plessis of Creative Studios, University of Pretoria. The setup consisted of the specimen

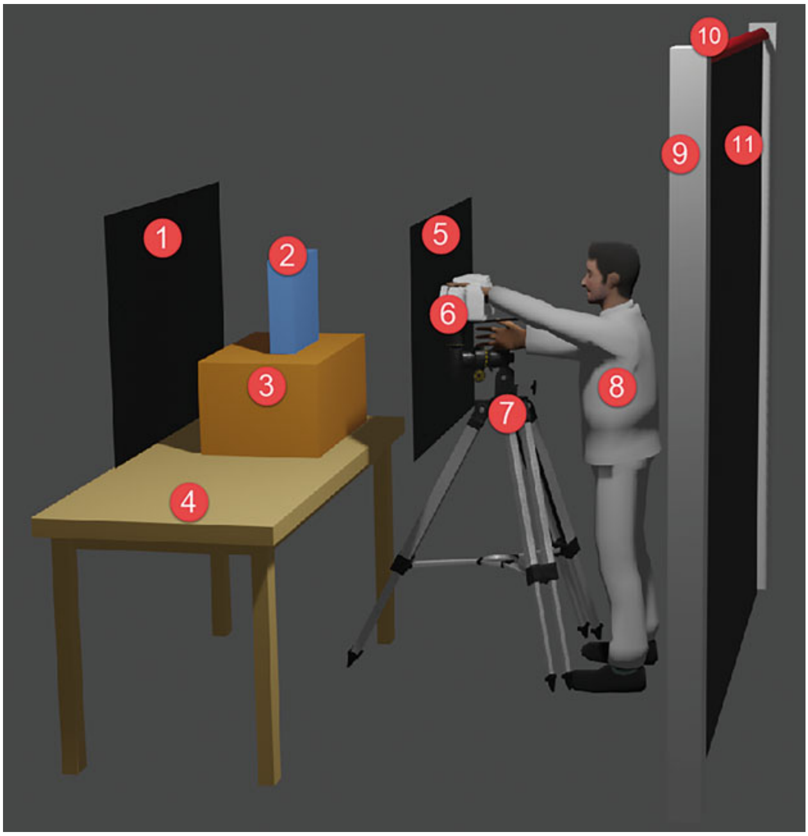

Fig. 4.5 Andre du Plessis (Medical Illustration in Anatomy, 2023). Photography station setup for the digitization of anatomy specimen. Key: (1) black velvet background, (2) specimen, (3) wooden stage, (4) table top, (5) black screen with cutout, (6) camera, (7) tripod, (8) photographer, (9) modified frame, (10) suspension of black velvet, (11) black velvet background

being placed on an elevated stage to ensure it was positioned in line with the camera lens and perpendicular to it. A dark background consisting of black triple-velvet was placed behind both the specimen and the photographer in order to eliminate any reflections of surrounding structures and to ensure that all reflected light was absorbed, in order to produce a refined quality image. The camera itself was positioned on a sturdy tripod with the lens of the camera being placed through a cutout located on a black screen which was positioned in front of the photographer. The black screen prevented any reflections of the photographer or the camera itself from presenting on the glossy surface of the display box. Lighting also influences the caliber of the image which is produced and must be situated in a way where minimal to no glare arises. During the digitization process, two color adjusted light-emitted diode lights were positioned at 45° from the front of the specimen on either side. This provides enough exposure to the specimen while ensuring no glare is produced when photographed (Fig. 4.5).

4.3.2 Contemporary Medical Imagery and Media in Education

Throughout the history of medical training and illustration, a pervasive methodology linked many anatomists and physicians. This was the use of various mediums of visualization and teaching to impart a concept in the most efficient manner. Even great teachers like William Hunter had supplemented his lessons with chalkboard drawings, wax models, and cadaver studies. It is evident that a presentation using a variety of visual media is beneficial in aiding the teaching of anatomical concepts to students and results in a deeper conceptualized understanding. Similarly, medical institutions strive for immersive and interactive platforms which recreate the same mixed media experience through virtual reality (VR) and augmented reality (AR). VR describes the experience whereby a user is immersed in an alternative reality via VR lenses and hand-held touch controllers, allowing the user to operate in a new environment. AR experience refers to the modification of the user's environment, allowing the user to interact with an overlapping 3D image in the surrounding settings which often allows for a more realistic encounter (Moro et al. 2017). AR experiences offer the closest interaction to that of a cadaver laboratory without using human remains, by allowing users to manipulate the 3D model as you would an actual specimen and have been shown to afford exceptional spatial understanding as compared with traditional methods of dissection (Yammine and Violato 2015). AR models also allow us to overcome the limitations of traditional study material and dissection, including the exploration of minute or deep structures which are otherwise difficult to observe due to the lack of visualization, such as the middle ear, ventricles of the brain, and embryological development (Hu et al. 2009).

Although the number of contact hours allocated to teaching and dissection varies between institutions, it is evident that not enough time is spent on anatomy, especially for medical students, with some tertiary institutions allocating only a few weeks to complete theoretical and practical sessions for all anatomical regions. This often leads to self-study and revision of concepts outside of teaching periods where students often rely on visual aids like the traditional atlases and schematic diagrams to study. However, these options do not deliver the realistic and spatial properties of a tangible specimen. This has led many anatomy students to explore 3D models and virtual experiences via their mobile device, tablet, or laptop computer. Interfaces that allow students to manipulate an image by changing the orientation and view of the specimen and removing "layers" from the image in order to view underlying structures not only closely replicates a cadaver interaction but also delivers effective self-study content. It is commonly known that anatomy is a content-heavy subject that can be initially difficult to comprehend for students, especially those who have not had exposure to introductory subjects such as biology, embryology, and histology. In this regard, additional learning resources are vital in supplementing the education of anatomy. An ideal platform for learning is anatomical exhibits and study resources where preserved and mounted dissected specimens are displayed and viewed by students at their own leisure and pace. Implementing AR repositories and tours of these collections maintains the excellent insight students receive from these perfectly dissected specimens, supplementing their learning and improving their academic performance, and providing an immersive platform for them to engage with. Medical museums have evolved after the 16th century from a repository of historical and notable specimens and pathological cases, to a hub for interactive and independent learning while combining traditional anatomy specimens with innovative technologies for contemporary students who regularly consume digitized media (Bates 2008). AR and image markers are often used to combine the real and virtual worlds in order to project an automated image or video in anatomy museums.

AR systems also allow users to experience virtual museums and tours on their devices, which proved to be useful during the COVID-19 pandemic restriction. Another AR tool that grants easily accessible information in museums is mobile vision-based AR technology, which superimposes supporting context and animations on the physical artwork or model (Tilon et al. 2011). A study by Sugiura et al. (2019) which compared the user experience of health care students in a medical museum using both traditional and AR based systems proved that AR technology is an effective study tool and provides further initiative for students to review anatomical concepts. Results also suggest that AR digitization may alleviate cognitive load, which is imperative when studying anatomy, due to the physically strenuous academic sessions and extensive content.

Some freely available 3D anatomy software that students can download onto their laptop computers or mobile devices is Complete

Anatomy, 3D Anatomy Learning, and AnatonicaPro. These programs provide 3D computer graphics of anatomical regions and systems in a readily obtainable manner. 3D rendering is not only useful when composing interactive learning tools and anatomy atlases, but also enables us to reimagine and re-encounter historically significant art by transforming them into 3D images, such as Andreas Vesalius's artwork. The Royal College of Physicians and Surgeons of Glasgow have created an interactive 3D digital model as a part of their "Visualizing Medical Heritage" exhibition which featured a number of Vesalius's most eminent creations published in his *De Humani Corporis Fabrica Libri Septem*. Some of his artworks are 3D rendered, allowing viewers a 360-degree perspective, including that of the woodcut images of the iconic articulated skeleton leaning on a worker's shovel, and one of his renowned "muscle men."

4.3.3 The Impact of Medical Imaging Techniques on Society and Culture

With the emergence of these innovative and trending imaging techniques, the inquiry of its impact and significance in art and culture is also explored. Medical art today is said to have allowed us to view the human body through the lens of a society striving for a lack of disease and defects, perceiving the body as a flawless and idealized image (Potier 2011). Imaging technology can remove a person's individuality and self-representation and instead offer us a standardized clinical image. As such, the existential impact of imaging techniques on the way we view patients and medical treatment as a whole needs to be confronted and analyzed further in order to preserve the sense of a patient's physically unique identity.

Although medical illustration itself has evolved even further from the clear and comprehensive traditional illustrations to encompassing mixed reality platforms, there is still further transformation which needs to be achieved with regards to the lack of diversity in medical illustration and its social impact. Medical illustration does not only provide a medium of learning, but it also influences the attitude and behavior of medical trainees, and in turn impacts the development of racial, sexual, and gender biases on a subconscious level. These biases and profiling are said to directly influence patient care and service delivery amongst medical professionals, leading to institutionalized prejudice. Diverse and inclusive representation in medical illustration is imperative as it affects the quality of health care professionals produced by our institutions and the caliber of health care provided to all demographics. Statistically, medical illustrations primarily depict images of lean, white males, with little to no inclusivity of diverse racial groups, body types, genders and diverse biological sex, with more focus on binary male and female categorization (Štrkalj and Pather 2021). The delivery and specialization of health care to intersex and transgender individuals is extremely inadequate, with much of the information not being taught or accessible to medical students (Chan et al. 2016). This has led to a remodeling of the medical curriculum to ensure medical students and health care professionals are more informed with regard to the health needs of the transgender community. Underrepresented individuals in medical and anatomical literature have also perpetuated the deficiency of knowledge in society and health care, especially the diagnosis and treatment of dermatological diseases. This generalized depiction of anatomy not only limits representation and diversity but also fails to account for human variation which is vital in customizing health care in these aspects of prevention and diagnosis.

4.3.4 Demographic Under-representation in Medical Illustration

Misdiagnosis of certain pathologies, especially dermatological cases, is one of the major concerns which arise from the lack of heterogeneity in medical illustrations and curricula. This may occur due to the limited exposure of students to diverse medical art. Most pathology cases used

Fig. 4.6 Oladokun et al. (2018) (Atlas of Pediatric HIV Infection, 2018). Figure 83: Ichthyosis on the shins. Image used under creative commons Attribution 4.0 International (CC BY 4.0). https://openbooks.uct.ac.za/uct/catalog/view/hivatlas/23/654-2. https://creativecommons.org/licenses/by-sa/4.0/

in teaching are presented using lighter skin tones, increasing the chance of misdiagnosis amongst patients with more melanin. This poses a serious health issue, especially due to the fact that these conditions express differently according to one's skin tone, and so detection and diagnosis will differ. This has led to higher mortality rates and delayed diagnosis periods in people of color with regard to conditions that have a lower prevalence in their demographic group (Gupta et al. 2016). Ilic et al. 2022, proved that dermatology students are able to perform better and conduct more accurate diagnoses when presented with more demographically diverse learning material. *Mind the Gap* (2020) by medical student Malone Mukwende is a pioneering medical handbook aimed at bridging the gap in knowledge with regard to presentation of dermatological pathologies in people of color. Mukwende's work not only imparts inclusivity and representation through the composition of clinical photography sourced from various resources, but also ensures accurate case reporting and diagnoses of people of color, in turn enhancing their health care experience. Figure 4.6 exhibits a case report of dermatological pathology included in the handbook which is freely accessible to the public, and especially targets young medical students.

Another illustrator and medical student who has been inspired to alter the normative trends and standards set in medical illustration is Nigerian born Chidiebere Ibe. Ibe has challenged the "default" image seen in medical textbooks by creating medical illustrations which depict people of color, with his most prevalent image being that of a black woman and fetus in utero. Students and young health care professionals like Ibe are conscious of the lack of diversity and inclusivity in medical illustration and strive toward the implementation of inclusive representation, not only to challenge generalized social constructs, but also to deter racial and cultural biases. Catherine MacRobbie is an adept medical illustrator who sought to amend the lack of diversity amongst gynecological images. Her illustration, which also accurately depicts a black mother and fetus in utero, among other inclusive illustrations of the female reproductive system, exhibits the progression in medical art by ensuring the representation of various demographics and in turn improving their quality of health care (Fig. 4.7). Implementing equality in visual learning allows for unprejudiced patient care and a truly human-centered health care system. An institution which has also initiated similar progress in their medical curriculum by including medical art with a

Fig. 4.7 Catherine MacRobbie (Biomedical Visualisation, volume 10, 2021). Pregnant woman. Digital illustration

conscious and intentional eye for representation and inclusion is the University of British Columbia's Hackspace for Innovation and Visualization in Education (HIVE) department. This department is spearheading inclusion in medical illustrations incorporated within their medical curriculum and aims to represent the spectrum of diversity seen in their staff and students with the digital images that they produce. The HIVE aims to impart a normative depiction of human and cultural variation by representing a range of body types, ethnicities and indigenous people, cultures, and sexual orientations.

4.4 Medical Illustration in Teaching

The use of medical illustration during the study of anatomy assists students by supplementing their theoretical knowledge. Health Sciences students may also benefit from medical art by actively drawing their own illustrations of anatomical concepts, especially during note-taking and the revision of theory text (Thapa et al. 2021). Although, this study tool is often undervalued, possibly due to the time and effort needed to compose illustrations—time which could have been used for studying text, as well as the misconception that one needs to be proficient in the discipline of art and drawing to be able to effectively benefit from medical art.

Spatial visualization is vital to comprehend and recall the relation of structures in the human body, which can be implemented through illustrations and is best conceptualized through cadaveric dissection. However, many students prefer online and mobile applications which provide accessible, modern, and hybrid learning (Ang et al. 2018). Students have a greater affinity for technology and fast, accessible information available on mobile applications, software, and eBooks. As a result, these platforms have become popular, especially as the more traditional mediums of teaching, such as cadaver dissections, begin to subside. There are already examples of tertiary anatomy departments which operate successfully without actual human dissection, and this may be a recurring trend for many of our

Fig. 4.8 Jade Naicker (medical illustration in anatomy, 2023). Septima reimagined

medical schools, especially when the supply of cadaveric material begins to deplete. Engagement with 3D models and animations are found to be more stimulating and interactive, especially when paired with a tactile interface, examination of knowledge, and gamification concepts (Ang et al. 2018).

In a time where medical imaging is evolving and becoming more accessible, we see a progression in the number of media used for the teaching of anatomy in medicine. Medical illustrations still perform an important function in retaining and revitalizing medical history and plays an essential role in anatomical study. Its history depicts the development of artistic talent and aesthetics as well as surgical techniques and imaging technologies which have been established over time. Subsequently, medical art transitioned from elaborate, detailed artwork to refined and clinical teaching tools, as the priority of medical illustrations shifted from beauty to informatics. There is no doubt that medical illustration will continue to evolve with the increasing inclusion of 3D rendered imaging, as well as imaging techniques such as CT, magnetic resonance imaging , and endoscopic scanning, propelling academic institutions and health care into an immersive interface which will hopefully improve teaching and patient care. However, one should remember the impact which early physicians and illustrators have had on the evolution and development of medical imaging and its significance in science. Illustrators are also able to be inspired by classical medical art and reimagine these images according to their personalized aesthetic and interpretation, as seen in Fig. 4.8. This further integrates an appreciation for early medical illustrations and validates their impact on emerging medical artists, despite the expansion of illustrating tools and techniques between the time periods.

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References

Andrews HR (1915) William Hunter and his work in midwifery. The Hunterian Society's Hunterian Oration. Barbers' Hall February 10, 1915. Br Med J 1: 277–282. https://doi.org/10.1136/bmj.1.2824.277

Ang ET, Chan JM, Gopal V, Li Shia N (2018) Gamifying anatomy education. Clin Anat 31(7):997–1005. https://doi.org/10.1002/ca.23249

Appukuttan A (2021) Digital art—a useful tool for medical professionals to create medical illustrations. JPRAS Open 28:97–102. https://doi.org/10.1016/j.jpra.2021.02.008

Bates AW (2008) "Indecent and demoralising representations": public anatomy museums in mid-Victorian England. Med Hist 52(1):1–22. https://doi.org/10.1017/s0025727300002039
Bay NS, Bay BH (2010) Greek anatomist herophilus: the father of anatomy. Anat Cell Biol 43(4):280–283. https://doi.org/10.5115/acb.2010.43.4.280
Bell J (1794) Engravings explaining the anatomy of the bones, muscles, & joints, 1st edn. John Patterson, Edinburgh, UK, p 191
Bell C (1801) Engravings of the arteries: illustrating the second volume of the anatomy of the human body, Bell J (ed). Longman and Rees, London. n28
Bell C (1870) Letters of Sir Charles Bell, K.H., F.R.S.C. àfE. Selected from his correspondence with his brother George Joseph Bell. John Murray, London, 410
Bell J, Bell C (1794–1804) The anatomy of the human body. 4 volumes, 1st edn. Cadell and Mudie, Edinburgh, UK, p 1798
Brödel M (1901) The intrinsic blood-vessels of the kidney and their significance in nephrotomy. Bull Johns Hopkins Hosp 12:118. Retrieved from http://resource.nlm.nih.gov/101648447
Brödel M (1915) The origin, growth and future of medical illustration at the Johns Hopkins Hospital and Medical School. Bull Johns Hopkins Hosp 26:185
Bulbulian AH (1961) Art in the service of anatomy. Bull Med Libr Assoc 49(2):178–186
Burch D (2008) Breathing life into Gray's anatomy. Lancet 371:1327–1328
Calkins CM, Franciosi JP, Kolesari GL (1999) Human anatomical science and illustration: the origin of two inseparable disciplines. Clin Anat 12(2):120–129. https://doi.org/10.1002/(SICI)1098-2353(1999)12:2<120::AID-CA7>3.0.CO;2-V
Cazort M, Kornell M, Roberts KB (1996) The ingenious machine of nature: Four centuries of art and anatomy. National Gallery of Canada, Ottawa
Chan B, Skocylas R, Safer JD (2016) Gaps in transgender medicine content identified among Canadian medical school curricula. Transgend Health 1(1):142–150. https://doi.org/10.1089/trgh.2016.0010
Clarke TH (1986) The rhinoceros from Dürer to Stubbs: 1515–1799. Sotheby's Publications, London
Corl FM, Garland MR, Fishman EK (2000) Role of computer technology in medical illustration. Am J Roentgenol 175(6):1519–1524. https://doi.org/10.2214/ajr.175.6.1751519
Crosby RW, Cody J (1991) Max Brödel: the man who put art into medicine. Springer, New York. ISBN: 0-387-97563-2
d'Errico F, Henshilwood CS (2007) Additional evidence for bone technology in the southern African Middle Stone Age. J Hum Evol 52(2):142–163. https://doi.org/10.1016/j.jhevol.2006.08.003
Di Ieva A, Tschabitscher M, Prada F, Gaetani P, Aimar E, Pisano P, Levi D, Nicassio N, Serra S, Tancioni F et al (2007) The neuroanatomical plates of Guido da Vigevano. Neurosurg Focus 23:E15. https://doi.org/10.3171/foc.2007.23.1.15
Elkins J (1986) Two conceptions of the human form: Bernard Siegfried Albinus and Andreas Vesalius. Artibus et Historiae 7(14):91–106
Erolin C (2020) Medical illustration in the 21st century and beyond. Med Writing 29(1):6–10
Ghosh SK (2015) Evolution of illustrations in anatomy: A study from the classical period in Europe to modern times. Anat Sci Educ 8(2):175–188. https://doi.org/10.1002/ase.1479
Graver N (1975) Photographie Médicale—Albert Londe's 1983 book, first in the field. J Biol Photogr Assoc 43(3):95–102. PMID: 1095587
Gupta AK, Bharadwaj M, Mehrotra R (2016) Skin cancer concerns in people of color: Risk factors and prevention. Asian Pac J Cancer Prev 17:5257–5264. https://doi.org/10.22034/APJCP.2016.17.12.5257
Hajar R (2011) Medical illustration: art in medical education. Heart Views 2:83–91. https://doi.org/10.4103/1995-705X.86023
Hiatt JR, Hiatt N (1995) The forgotten first career of Doctor Henry Van Dyke Carter. J Am Coll Surg 181:464–466. PMID: 7582216
Hodges ERS (2003) Pencil on coquille board. In: The guild handbook of scientific illustration. Wiley, Hoboken, NJ, pp 143–145. ISBN: 978-0-471-36011-7
Hu A, Wilson T, Ladak H, Haase P, Fung K (2009) Three-dimensional educational computer model of the larynx: Voicing a new direction. Arch Otolaryngol Head Neck Surg 135:677–681. https://doi.org/10.1001/archoto.2009.68
Ilic N, Prescott A, Erolin C, Peter M (2022) Representation in medical illustration: the impact of model bias in a dermatology pilot study. J Vis Commun Med 45(4):253–262. https://doi.org/10.1080/17453054.2022.2086455
Kaufman MH (2005) John Bell (1763–1820), the 'father' of surgical anatomy. J Med Biogr 13:73–81. https://doi.org/10.1177/096777200501300204
Keele KD (1979) Leonardo da Vinci's 'Anatomia Naturale'. The inaugural John F. Fulton lecture. Yale University School of Medicine November 3, 1978. Yale J Biol Med 52(4):369–409. PMID: 386621
Kemp M (1998) Vincian velcro. Nature 18:25. https://doi.org/10.1038/23832
Kemp M (2010) Style and non-style in anatomical illustration: from renaissance humanism to Henry Gray. J Anat 216:192–208. https://doi.org/10.1111/j.1469-7580.2009.01181.x
Marean CW, Bar-Matthews M, Bernatchez J, Fisher E, Goldberg P, Herries AI, Jacobs Z, Jerardino A, Karkanas P, Minichillo T et al (2007) Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. Nature 449(7164):905–908. https://doi.org/10.1038/nature06204
Marx FJ (2013) Galen of Pergamum (129–216/217 AD) and his contribution to urology: Part I: Life, work and

medical system. Urologe- Ausgabe A 52:570–575. https://doi.org/10.1007/s00120-012-3064-6
Massey L (2016) Against the 'statue anatomized': the 'art' of eighteenth-century anatomy on trial. Art Hist 40:8–103. Retrieved from https://doi.org/10.1111/1467-8365.12261
Moro C, Štromberga Z, Raikos A, Stirling A (2017) The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ 10(6): 549–559. https://doi.org/10.1002/ase.1696
Mount H (2006) Van Rymsdyk and the nature-menders: an early victim of the two cultures divide. Br J Eighteenth Century Stud 29:79–96. https://doi.org/10.1111/j.1754-0208.2006.tb00636.x
Mumford JG (1908) Surgical memoirs and other essays. Moffat, Yard, New York. 358 p
Netter F (1956) Medical illustration- Its history and present day practice. J Int Coll Surg 26:505–513. PMID: 13367497
Netter FM (2013) Medicine's Michelangelo: the life & art of Frank H. Netter, MD. Quinnipiac University Press, North Haven, CT
Oladokun RE, Lehloenya RJ, Hlela C, Ubesie AC, Katibi SO, Malande OO, Eley BS (2018) Atlas of Paediatric HIV Infection p:110. https://doi.org/10.15641/079922541-69
Olry R (1997) Medieval neuroanatomy: The text of Mondino de Liuzzi and the plates of Guido da Vigevano. J Hist Neurosci 6:113–123. https://doi.org/10.1080/09647049709525696
O'Malley CD, Saunders JB (1952) Leonardo da Vinci on the human body, 1st edn. Henry Schuman Press, New York. 506 p
Potier R (2011) Medical Imaging and Modern Art: Encounters over a Virtual Body. Recherches en psychanalyse 12:131–139. https://doi.org/10.3917/rep.012.0131
Rajkumari A (2015) Galen and his contribution to anatomy: a review. J Evol Med Dent Sci 4(26):4509–4516. https://doi.org/10.14260/jemds/2015/651
Reverón RR (2014) Frank Netter's legacy Anatomy 8:32–35. https://doi.org/10.2399/ana.13.027
Riva A (2004) Priorità anatomiche nelle Tabulae Pictae. In: Rippa Bonati M, Pardo-Tomàs J (eds) Il teatro dei corpi, le pitture colorate di anatomia di Fabrici d'Acquapendente. Milano, Mediamed Edizioni Scientifiche, pp 147–155
Riva A, Conti G, Solinas P, Loy F (2010) The evolution of anatomical illustration and wax modelling in Italy from the 16th to early 19th centuries. J Anat 216:209–222. https://doi.org/10.1111/j.1469-7580.2009.01157.x
Roberts KB, Tomlinson JDW (1992) The fabric of the body. Oxford University Press, Oxford
Shelton DC (2013) The emperor's new clothes. J R Soc Med 103(2):46–50. https://doi.org/10.1258/jrsm.2009.090295
Štrkalj G, Pather N (2021) Beyond the sex binary: toward the inclusive anatomical sciences education. Anat Sci Educ 14(4):513–518. https://doi.org/10.1002/ase.2002
Sugiura A, Kitama T, Toyoura M, Mao X (2019) The use of augmented reality technology in medical specimen museum tours. Anat Sci Educ 12(5):561–571. https://doi.org/10.1002/ase.1822
Thapa B, Nakarmi K, Karki S, Sen K, Pandy A, Gelal D, Pokhrel E, Ghimire S (2021) Perception of medical students on use of medical illustration in medical education. J KIST Med Coll 3(6):65–69. Retrieved from https://journal.kistmcth.edu.np/index.php/JKISTMC/article/view/108
Tilon AB, Marchal I, Houlier P (2011) Mobile augmented reality in the museum: Can a lace-like technology take you closer to works of art? In: Proceedings of 2011 IEEE international symposium on mixed and augmented reality—arts, media, and humanities (ISMAR-AMH), Basel, Switzerland, 26–29 Oct 2011. Institute of Electrical and Electronics Engineers (IEEE), Piscataway, NJ, pp 41–47
Tsafrir J, Ohry A (2008) Medical illustration: from caves to cyberspace. Health Info Libr J 18(2):99–109. https://doi.org/10.1046/j.1365-2532.2001.00315.x
Vesalius A (1543) De Humani Corporis Fabrica Libri Septem, 1st edn. Officina Ioannis Oporini, Basilea, Switzerland, p 663
Weiglein AH (2005) Overview & general principles of the plastination procedures. In: 8th interim conference on plastination. Archived from the original on 6 July 2011. Retrieved 27 Jan 2009
Wilson-Pauwels L (2009) Jan Wandelaar, Bernard Siegfried Albinus and an Indian Rhinoceros named Clara set high standards as the process of anatomical illustration entered a new phase of precision, artistic beauty, and marketing in the 18th century. J Biocommun 35(1):E10–E17
Yammine K, Violato C (2015) A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ 8:525–538. https://doi.org/10.1002/ase.1510

5 Valuing Creativity in Biomedical Science Education: A Reflective Narrative

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Abstract

Efforts in biomedical education to enable the translation of science into clinical applicability require an alignment of interdisciplinary collaboration that integrates working platforms to facilitate the sharing of knowledge, expertise, and tools. Within the context of this translatory process lies the phenomenon of creativity which is defined as a cluster of skills that is needed to produce ideas that are both original and valuable (Sternberg, Am Psychol 56:360, 2001). Creativity is generally acknowledged as a valued skill to refine; however, it is difficult to define and even more difficult to measure (Jenkins, Brilliantio, 2021). In recent years, there have been several reports of the interconnection between the study of the humanities and the biomedical sciences. Whilst incorporating humanities into biomedical courses may not always improve student knowledge, it enhances student's perception of critical observation and their empathetic nature (Collett and McLachlan, Med Educ 39:521–521, 2005). Moreover, it can offer benefits beyond didactics to both the students and educators and encourage learners to understand concepts outside the confines of the textbook (Platt et al., Human Anat Physiol Soc Educ 25:64–74, 2021). Students and educators need to understand the concept of creativity and be allowed opportunities that explicitly unlock and develop their creative capabilities. There is also evidence of the increased appreciation of the value of creativity as demonstrated by the revised cognitive category of Bloom's taxonomy in which "create" replaced "evaluate" as the pinnacle cognitive skill within the cognitive domain (Macaulay et al., J Feder Am Soc Exp Biol 32:535–524, 2018). Furthermore, there is a need to promote creative thinking in science education, and in particular methodologies that can achieve and measure creativity, is warranted (Macaulay et al., J Feder Am Soc Exp Biol 32:535–524, 2018). Thus, the intersection of humanities with biomedical sciences in the modern classroom of tertiary education has faced unique challenges, especially during the COVID-19

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pandemic (Oliveira-Silveira et al., Creat Educ 13:283–295, 2022). Under these circumstances, educators had to imagine new strategies to enhance teaching and learning as well as improve student engagement. Educators also had the responsibility of enhancing the pedagogical practices that prepare graduates for future employment. Due to the nature of creativity, reflective practice is important to promote self-awareness and creative thinking skills (Osterman, Educ Urban Soc 22:133–152, 1990).

This chapter incorporates a multidisciplinary approach that enhances student and educator perceptions of various creative modalities to improve current scientific teaching and learning methods. It explores the reflective practice of diverse creative tool practice to design an "inclusive curriculum" despite the digital divide, to further enhance teaching and learning in the biomedical sciences. The use of art, poetry, model building, and theme-park construction using game-based learning, digital storytelling/scrapbooking were implemented to develop multiple literacy skills (viz., graphical skills, technological skills, and mastering the content) to improve and enhance the proficiency of critical thinking in students. Additionally, this chapter includes educator reflection on the use of high-quality images to augment student learning. It illustrates the value of images in the demystification of science, to enable a deeper level of understanding and to improve one's perception of science. This challenging and valuable approach enriches learning whilst enhancing scientific interpretation, integrity, and the validation of scientific pedagogy.

Keywords

Art · Biomedical science · Creativity · Digital storytelling · Game-based learning · Poetry · Scrapbooking · Theme park construction

5.1 The Value of Creativity in Biomedical Science Education

Creativity is regarded as an essential component for building knowledge, skills, and attitudes necessary for future societal development (UNESCO 2013). By developing creativity in students, this skill enables novel perceptions, generates innovative and meaningful ideas, raises new questions, and assists in problem solving (Sternberg and Lubart 1999). Teachers perform a vital role in harnessing student creativity (Barbot et al. 2015) by providing creative learning opportunities in the classroom (Cole et al. 1999) and by acting as role models and mentors for their students (Kampylis et al. 2009). In addition, professionalism is a key feature in the discipline of biomedical teaching. The ability to reflect on one's own teaching skills is a requirement for proficiency in one's discipline. Teachers who reflect whilst teaching and about teaching are able to better understand and improve their teaching ability (Kaldi and Pyrgiotakis 2009). Moreover, the recent Covid-19 pandemic forced teachers into producing more creative and innovative ideas than previously in order to efficiently engage students during online teaching, especially in the delivery of complex scientific concepts. This consequently prompted an increase in teacher and student reflection in order to further improve the development of new creative teaching and learning techniques.

Students who appreciate the value of reflection and who practise reflexivity by using their creative skills are more successful in the workplace environment (Felix 2022). Reflection also improves critical thinking skills and empathy, which are two of several important components for producing innovative ideas to improve student growth and performance, as well as playing a crucial role in assisting teachers in their teaching abilities (Felix 2022). Health science professionals are required to fully comprehend demanding and complicated basic biomedical science subjects such as Anatomy and Physiology (Ruiz 2015). Improving their learning, understanding, and retention of discipline-specific content requires students to physically learn the language (Lemke 1990), which often entails verbalizing and transcribing concepts (Rivard and Straw 2000). It is important to note that the use of visual aids enhances learning. Collaborative learning is one route that can assist the student to fully comprehend and express their interpretation of the discipline-specific content associated with a basic science curriculum. This type of learning is best facilitated by active student conversations with peers and/or educators, which can be further enhanced with cooperative learning as it improves problem solving and conceptual rationalization (Michael 2006).

Creativity, when combined with inspiration and teamwork, also enhances thinking that is outside of regular forms of learning to ensure optimal success in education (Nayak et al. 2016). Moreover, incorporating creativity into basic science education improves critical thinking and problem-solving abilities and generates skilled and successful health professionals (Nayak et al. 2016). The use of medical illustrations is reported to enhance the study of the basic sciences exposing its complex content (Ruiz 2015). In addition, creativity greatly improves the development of observational skills not regularly taught in biomedical curricula and which form an essential part of in-patient examination and/or management (Bell and Evans 2014).

Several creative and innovative multimodal strategies exist in the teaching of biomedical sciences, viz., the building of anatomical models and the use of art, poetry, and theme-parks using the concept of game-based learning, digital storytelling/scrapbooking. These innovative teaching strategies are aimed at providing biomedical education with creativity and inspiration as well as promoting active student involvement in applying their personal imagination and intellect in classroom activities. The integration of innovative and creative strategies into existing biomedical education enhances knowledge comprehension and visualization of complex subject matter rather than the mere dissemination of factual knowledge. In addition, there is enhanced/improved student engagement in peer-learning and cognitive abilities and also a diminished possibility of loss of interest over time (Santos et al. 2019). This learning inclusivity has the potential to produce graduates with improved empathy, critical thinking, and problem-solving abilities (Wolters and Wijnen-Meijer 2012). The use of poetry in medical education has the advantage of generating memorable reflections since the common rhyming pattern contained in student excerpts enables a greater subject matter retention through the use of mnemonic creation (Stammers 2015). Poetry involves both active writing and passive interpretation of phrases and also has the potential to enable students to identify and acknowledge an extensive range of emotions in patients, patient relatives, as well as fellow healthcare professionals (Wolters and Wijnen-Meijer 2012).

In this digital age, the prolific generation of data is exacerbated by the complexities and intricacy of scientific data. Within this context, the student explores the use of multimodal modalities (visual, audio, read/write, and kinaesthetic) to improve cognitive perception. Science is often difficult and complicated and is best represented in simple, well-made graphs as well as tables and diagrams which enable the actual visualization of scientific phenomena *in situ*. Images in science is a powerful tool as it amplifies student understanding and retention of knowledge (Lee and Reeves 2007). For example, analytical data such as figures and tables summarize the representation of results, relationships, trends, patterns, and main research findings while at the same time reducing the manuscript length, as well as positively augmenting the text. Modern scientific microscopy, for instance, creates opportunities for the inclusion of images which provides a visual representation that supplement the analytical data, thereby enhancing student understanding (Huang et al. 2021).

In an attempt to enhance teaching and learning in biomedical education, various strategies such as art, poetry, model, and theme-park constructions, digital storytelling/scrapbooks, are employed as a means to increase learner engagement and understanding of the systems of the body. It is interesting to note that collaborative online learning through the use of digital storytelling has the potential to enhance student engagement and improve intercultural competencies and skills. Artwork and poetry, for example, may provide an opportunity for the perspectives of biomedical students to be relayed in a safe and student-centred teaching environment in order to better understand each other's life experiences. The use of creative tasks also prompts reflective practice, which is important in promoting self-awareness, enabling students to become innovative, resourceful, and adaptable thinkers (Osterman 1990). This chapter outlines the multi-disciplinary approaches that enhance student and educator perceptions of various creative modalities to improve current scientific teaching and learning methods.

5.1.1 Creative Approaches

5.1.1.1 Art or Reflective Drawings

The relationship between biomedical education and the study of the creative arts is widely described and has a long and storied past (Bell and Evans 2014; Platt et al. 2021), and especially so in the field of the anatomical sciences. Anatomy forms an important part in the foundation for the majority of clinical subject areas and is often labelled by students as burdensome, challenging and labour-intensive (Schabort 2013). In addition to the large workload, the Anatomy course encompasses an introduction and assimilation/mastering of terminology which is Greek or Latin based (Schabort 2013). Furthermore, Anatomy education requires the use of bodies donated for dissection and human remains which can have an emotional and psychological effect on students (Houwink et al. 2004; Leboulanger 2011). These factors may influence the ability of the student to express themselves holistically and the incorporation of creative outlets may therefore have both short- and long-term beneficial outcomes. Additionally, whilst the creation of artistic images may not always enhance student anatomical knowledge, it supplements their perception of critical observation and empathetic nature (Collett and McLachlan 2005). However, the combined use of art and Anatomy as an effective educational tool in the modern classroom of higher education however remains debatable. Despite the long association between the two fields of art and Anatomy, studies investigating the efficacy of art and drawing for educational purposes and other art-based practices with the teaching and learning of Anatomy are limited (Gull 2005; Clavert et al. 2012; Balemans et al. 2016; Backhouse et al. 2017).

The inclusion of humanities in the study of Anatomy has the potential to be advantageous beyond didactics to both students and educators, thereby encouraging students to learn concepts outside the confines of a textbook (Platt et al. 2021). For example, Shapiro et al. (2009) reported on student awareness of a greater sense of gratitude and a reduction in stress levels in the early years of medical training. Furthermore, Jones et al. (2017) reported similar observations of personal development, growth, and an increased sense of community in students where the making of art formed part of the curriculum. The use of drawing may also be an opportunity for students to express their attitudes and unmediated feelings as opposed to pre-emptive and restricted answers in quantitative and qualitative studies (Weber and Mitchell 1996). Foley and Mullis (2008) suggest that strong emotions may be expressed more easily in image form rather than words, thus enabling students to reflectively express feelings either to acknowledge them, work through them or attempt to communicate them to someone else.

The engagement by students with three-dimensional representations of anatomy, as is seen during dissection, compared with two-dimensional representations such as images in a textbook, results in a greater degree of depth in terms of their understanding and mastery of the subject (Reid et al. 2018).

It is well known that improved spatial awareness is essential in the teaching and learning of Anatomy and is pivotal for success in many areas of medical practice (Branson et al. 2021). These authors are of the view that many healthcare professionals struggle with the extrapolation of two-dimensional data to the three-dimensional world of Anatomy teaching and learning (Branson et al. 2021).

The use of touch as a general sensation to engage with the exploration and observation of three-dimensional forms, including anatomical structures, grounded on specific functions of the central nervous system, lends validity to these proposals (Branson et al. 2021).

Shapiro et al. (2019) state that multisensory observation and drawing can be highly effective for supporting and improving the learning of Anatomy and claim that this concept is supported by pedagogic research and theory, as well as theories of drawing. These authors report that a haptico-visual observation and drawing (HVOD) process has been developed by them as an aid to the understanding of the three-dimensional spatial form of anatomical structures. As explained by them, the HVOD process involves the exploration of three-dimensional Anatomy by combining the use of touch and sight and "the simultaneous act of making graphite marks on paper which correspond to the Anatomy under observation" (Shapiro et al. 2019).

Branson et al. (2021)) believe that improved spatial awareness is directly linked to improved spatial skill. They have developed exercises that result in the improvement in spatial awareness which can be of benefit to students in their study of Anatomy. These skills can be extrapolated by all healthcare professionals to many aspects of their medical practice (Branson et al. 2021). In their publication, the authors highlight how the underlying neuroscientific processes correlate to haptic and visual observation, memory, working memory, and cognitive load.

Additionally, the use of the multisensory visual and haptic observation and drawing (HVOD) process creates a supportive teaching and learning milieu which enhances three-dimensional (3D) visualization of anatomic structures. This improves student participation, memorization skills and contributes to deep learning (Reid et al. 2018; Shapiro et al. 2019).

To date, studies assessing the perceptions of student educational experiences through the use of drawings that provides the student with opportunities to illustrate their experience rather than verbalize their feelings are limited (McLean et al. 2003; Bessette 2008).

5.1.1.2 Poetry

Poetry is defined as "literature that evokes a concentrated imaginative awareness of experience or a specific emotional response through language chosen and arranged for its meaning, sound, and rhythm" (Nemerov 2022). An earlier report suggests that poetry is perceived as a "creative literary genre" that can be used for "imaginative-creative writing" (Pithouse-Morgan et al. 2017, pp. 127), indicative of its utility as an alternative mode for representation and analysis of ethnographic data. Despite the unlikely relationship between Anatomy and poetry (Stammers 2015), poetry has been widely used in a variety of clinical settings such as psychiatry, cancer and palliative care, midwifery, parent education, elderly home care, and patients with dementia and learning difficulties. Poetry can provide an awareness into the patient's and carer's journey in a synthesized format, thus bringing experiences to life and producing emotional responses in the listener or reader (Hopkinson 2013).

The incorporation of poetry, as a creative modality, has potential to improve the current teaching and learning of difficult and sensitive subject matter in biomedical sciences. An earlier study has reported that students are troubled and/or negatively affected by various aspects of their professional culture and often express major difficulties in adapting to biomedical ethos (Suchman et al. 2004). During traditional student training, they are taught to convey prescribed content in a uniform, impersonal, passive voice, which obscures the identity of the teller (Good and Good 2000; Poirier 2004). However, when students have the opportunity to personally reflect on their experiences from a human perspective, they struggle to connect their personal values with their clinical training (Branch 2000). Downie (1991, pp. 95) reported that: *"The humanities [. . .] are concerned with the* *particularity of situations and with their meaning, and that concern is the way to whole person understanding"* which translates to poetry having the ability to greatly refine intuitive understanding in biomedical students. Personal stories can thus represent a route in which students can re-examine their experiences and understand its possible meanings.

5.1.1.3 Model Construction, Theme-Parks, and Gamification

Visualization of 3-dimensional (3D) anatomical models in biomedical science education enhances student knowledge and interpretation of discipline-specific content. Of note, learning becomes more articulated when students personally engage in model constructions. An earlier study conducted amongst applied health sciences students confirmed that clay modelling significantly improves interim learning outcomes (Bareither et al. 2013). Theme-parks described in this chapter were conceptualized using game-based learning, requiring students to utilize simulated play instructions to create more engaging discipline-specific content. The development of theme-park formulation requires a replication of traditional theme-parks, i.e. illustrate rides, attractions, food stalls, etc., which improves student soft skills and their understanding of structural and physiological components of the human body. Gamification is defined as "the use of game elements and game-design techniques in non-game contexts, to engage people and solve problems" (De-Marcos et al. 2014), encourages peer interaction during learning, and is considered a valuable teaching tool (Squire 2011). The learning importance of the gaming configuration and description, visual appeal, subject matter, incentives, and musical score is widely documented (Plass and Homer 2012; Plass et al. 2015; Zamora-Polo et al. 2019). Zamora-Polo et al. (2019) suggest that combining teaching and learning with gamification augments student comprehension and motivation of basic science subject matter as well as exposing students to novel skills applicable in future educational ventures (Zamora-Polo et al. 2019).

Additionally, gaming configurations enhance student learning by nurturing students' intellectual, behavioural, emotive, and sociocultural interaction with the discipline-specific content, by enabling learners to remain engrossed with the content for extended periods during creation of the theme-parks and playing these games (Plass et al. 2015). When developing games, detailed attention must be given to the characteristics such as adaptability and customization, all of which enhance collaborative and emotional growth (Turkay et al. 2013). However, this may vary for learners since games have the potential to stimulate diverse levels of learner interaction based on the subject matter being studied. Noteworthy is the concept of genial failure associated with game-based learning which encourages exploration (Hoffman and Nadelson 2010) and self-regulated learning during play (Kim et al. 2009).

5.1.1.4 Digital Storytelling/Scrapbooking

Since information technology is rapidly revolutionizing our civilization and the way we think, digital storytelling/scrapbooking as innovative teaching and learning tools are increasingly being used in higher education (Porter 2005; Robin 2016; Benmayor 2008; Coventry 2008; Leon 2008; Wang and Zhan 2010). Digital storytelling is defined as "the combination of the ancient art of oral storytelling with a palette of technical tools to weave personal stories using digital images, graphics, music, and sound mixed together with the author's own story voice" (Porter 2005, pp. 12). Digital storytelling empowers learners to supplement pedagogically learnt theories and experiences into more technologically advanced constructs (Amory et al. 1999; Coventry 2008). Digital pieces of work are usually constructed with easily available software tools normally bundled with Windows-based computer hardware thus improving media, visual and information literacy, creative intellect, and collaborative learning (Brown et al. 2005; Ganley 2012). More recently, data from a systematic review confirm that educational digital storytelling has significant value singly or amalgamated with other pedagogies in the USA where it originated, as well as increasingly at a global level (Wu and Chen 2020). It was further reported that digital storytelling embodies a theoretical framework that has the potential to have a positive impact on our existing knowledge and promotes additional investigations and future scholarly activities. Of note, digital storytelling also influences soft skill development such as empathy, especially with the sharing of personal experiences (DePape and Doyle-Thomas 2022).

The inclusion of multimodal creative teaching strategies in biomedical curricula enables teacher reflections and allows for the subsequent encouragement of critical thinking in the learner. The approaches outlined may provide the student with the self-awareness and confidence to freely express themselves regardless of health, socio-economic, and culturally diverse beliefs. Data emanating from the disciplines of Anatomy and Physiology will be employed in this chapter to provide examples of drawings for conceptual interpretation as well as student reflections.

5.1.1.5 Descriptive Imagery

5.1.1.5.1 A Picture Is Worth a Thousand Words

In the visual learner, teaching and learning is best achieved via the use of videos and descriptive imagery (Mozaffari et al. 2020). In this digital, fourth Industrial Revolution, research has shown that the prolific generation of data is exacerbated by the complexities and intricacy of scientific data. Emanating from the early work of Michaelangelo and Versalius, the visualization of factual material improves cognitive perception of complex anatomical, histological, and physiological information. Formal scientific research as evidenced in peer-reviewed journals enables the actual visualization of a scientific structure *in situ* (Stanovich 2003) and supplements analytical data through various laboratory techniques including microscopy (Huang et al. 2021).

Notably, in teaching Anatomy, Histology, and Physiology as well as in scientific publication, figures facilitate a cognitive perception of a tissue and organ, whilst also summarizing the representation of results, relationships, trends/patterns, and main findings in experimental work. Moreover, the use of images serves to reduce manuscript length whilst also augmenting the text. The value of tables and graphs in representing large numerical data sets is that they eliminate the need to read expansive, lengthy descriptive texts within a short period of time. The human brain interprets a substantial amount of information received from an image and therefore images serve as a visual explanation aiding in the rapid perception and analysis of the results of a study. This approach is the best simplistic explanation of a medical concept or fact and is thus of immense value to medical education.

5.2 How We Stimulated Creative Reflection and Teaching

5.2.1 Student Reflection Data

5.2.1.1 Ethical Considerations and Participant Characteristics

Following ethical approval from the Institutional Research Ethics Committee (IREC 055/17), undergraduate students from two regional universities in the province of KwaZulu-Natal in South Africa were recruited. The study population included first, second, and third year Bachelor of Medical Science and third year Medicine undergraduates as well as first and second year undergraduate allied health science students registered for Medical Laboratory Sciences ($n = 35$), Environmental Health ($n = 30$), and Medical Orthotics and Prosthetic programmes ($n = 30$).

The biomedical science students who were registered for a Bachelor of Medical Science degree majored in various disciplines viz.,

(a) *Student submissions for Art or Reflective drawings*: first year majored in Anatomy ($n = 23$) or Occupational Therapy ($n = 39$); second year majored in Anatomy, Physiology ($n = 76$), or Physiotherapy ($n = 22$); and third year majored in Anatomy ($n = 43$) only; the third year Medicine students ($n = 77$) majored in various disciplines.

(b) *Student submissions for Poetry*: 1st ($n = 62$) and 2nd ($n = 42$) year students majoring in physiotherapy formed part of the sample.

5.2.2 Research Procedure

5.2.2.1 Art or Reflective Drawings and Poetry

Students were tasked with the formulation of art or reflective drawings (i.e. an illustration, drawing regarding their perceptions of Anatomy) or poems (i.e. *vis-à-vis* their initial cadaveric experience) using a free style format. This format allowed students the freedom to be as creative and expressive as they wanted in executing the task. For their reflective pieces, students were able to use black or white paint or other colours, depending on the colour of paper, otherwise pencil. However, each illustration and piece of poetry had to conform to the following criteria:

- All submitted drawings may consist of any type of drawing and/or illustration.
- Must include any type of annotation (words, phrases, sentences).
- All poetry submitted could follow an unrestricted style of writing.
- Express an open mind, be creative, and have fun in the use of both the written and spoken word.
- All submissions were expected to be submitted within ten days of the task being allocated.

5.2.2.2 Description of Instructions for Development of Creative Outputs (Model, Theme-Park, and Digital Storytelling) by Students

Various learning strategies, viz., development of 3D models, theme-parks, and digital storytelling/scrapbooking, were integrated into the Anatomy and Physiology 1 basic science course of all students registered for Medical Laboratory Sciences, Environmental Health and Medical Orthotics and Prosthetic programmes during 2019–2022. The course structure included two 2-hour theory sessions and one 3-hour practical session per week over a 16-week semester. The course encompasses various systems of the human body and is content overloaded, and therefore may well be overwhelming for the learner.

For each of the strategies implemented, students were required to identify a disease related to a system of the body that they would like to learn more about and subsequently create a product based on the learning activity chosen (i.e. model, theme-park, digital storytelling, scrapbook development). The rationale underpinning the implementation of various strategies was to give the student options in their preferences for learning as well as to create a more relaxed, interactive, and fun learning environment and improve the mastery of the subject content. Students were required to evaluate the target audience and create subject-specific content that demonstrated accuracy and an appropriate level of complexity. The learning outcome was to ensure that students expanded discipline-specific knowledge, professional, technological, and creative skills.

All students were directed to refer to the prescribed textbooks, reference books, and appropriate websites to ensure that they had prior understanding of the chosen body systems before commencing work on their creative outputs. Students were also requested to use eco-friendly material to create visually appealing hand-made submissions that accurately represent and replicate the organ system structures that the groups were researching. Additionally, online creative outputs were accepted as a submission option. The structures within the model or theme-parks were required to accurately reflect their original locations within the body. These activities were conducted in groups (a maximum 4 students per group), in which a group leader was chosen. The group leader was responsible for distributing and co-ordinating the activities, ensuring that the responsibilities of each group member are clearly defined, leading discussions on specific time-bound activities and outcomes negotiated with and agreed upon by the group. The creative outputs that were submitted were required to include an overview of the project overview, viz. the set-up, operation, a detailed description of the chosen features linked to Anatomy and Physiology, its reason for inclusion, and how it represented the selected body system.

Theme-park creations were required to include a thorough, all-inclusive summary of the important structures and functions of the system that was chosen and were required to replicate a traditional theme-park when being developed (i.e. illustrate rides, attractions, food stalls, etc.). Skills development was an important requirement, including discipline-specific skills (knowledge of the structural components of various organs within the body and an integration of the structure of an organ with the functions of the respective system), soft skills (working in groups or teams, collaboration, communication and writing expertise, leadership as well as conflict resolution and managing competencies), and information and communication technology skills (Microsoft proficiencies, viz., PowerPoint, Word or Paint; video development plus the ability to upload via the specified learning management systems, Google drive, emails, etc.).

5.2.3 Analyses

Thematic content analysis was employed where students' interpretations included either illustrations only or illustrations with concise written descriptions of the perceptions of the biomedical sciences (Charmaz 2005). Investigators independently reviewed students' illustrated perceptions of the respective reflective pieces and utilized an iterative coding system to identify specific concepts from each illustration. The various themes were reviewed and discussed until the authors identified an overarching theme that they felt represented the majority of the data reviewed. Theme connections were then determined by analysing the available data. The reliability of this study was aided by the different research levels of two investigators who are co-authors which resulted in different perspectives and understandings of the students' interpretations.

5.3 Results and Discussion

5.3.1 Art or Reflective Drawings

Students enter the anatomy laboratory eager to learn anatomy, but are often unsure of how to cope with the act of dissecting a human body. Many students experience a variety of emotional reactions and mixed feelings upon their initial encounter with the body of a human that is going to be dissected and studied. Hence, students are encouraged to engage in reflective practice as a means of handling these experiences, to achieve additional personal and clinical insight. A total of three themes indicative of various student sentiments emerged from the data, viz. positive responses, negative responses, and that of ambivalence.

5.3.1.1 Theme 1: Positive Responses

The donated body often evoked positive feelings of amazement, excitement, and interest in students (Fig. 5.1a). The feeling of "gratitude" is one of the common positive emotions expressed by students towards the increased knowledge gained from their study of and engagement with a donated body. There is an increased awe and wonder at the intricacies of the human body and an appreciation for the gift by the donor (Yeager 1996; Moore 1998). The flowers depicted in Fig. 5.1a represent a growth in knowledge in the discipline as well as first-time experiences with the bodies. It also symbolizes students' gratitude towards body donors as students are filled with appreciation and thankfulness for the opportunity of hands-on learning.

5.3.1.2 Theme 2: Negative Responses

Dissection also appeared to arouse negative feelings of fear and anxiety, sometimes even revulsion and disgust, in some students (Fig. 5.1b). Sadness was also one of the common negative emotions expressed by students towards the context of various anatomy topics and first-time exposure to the bodies. Uncertainty regarding job opportunities and the fact that Anatomy is an intensive content-loaded course may account

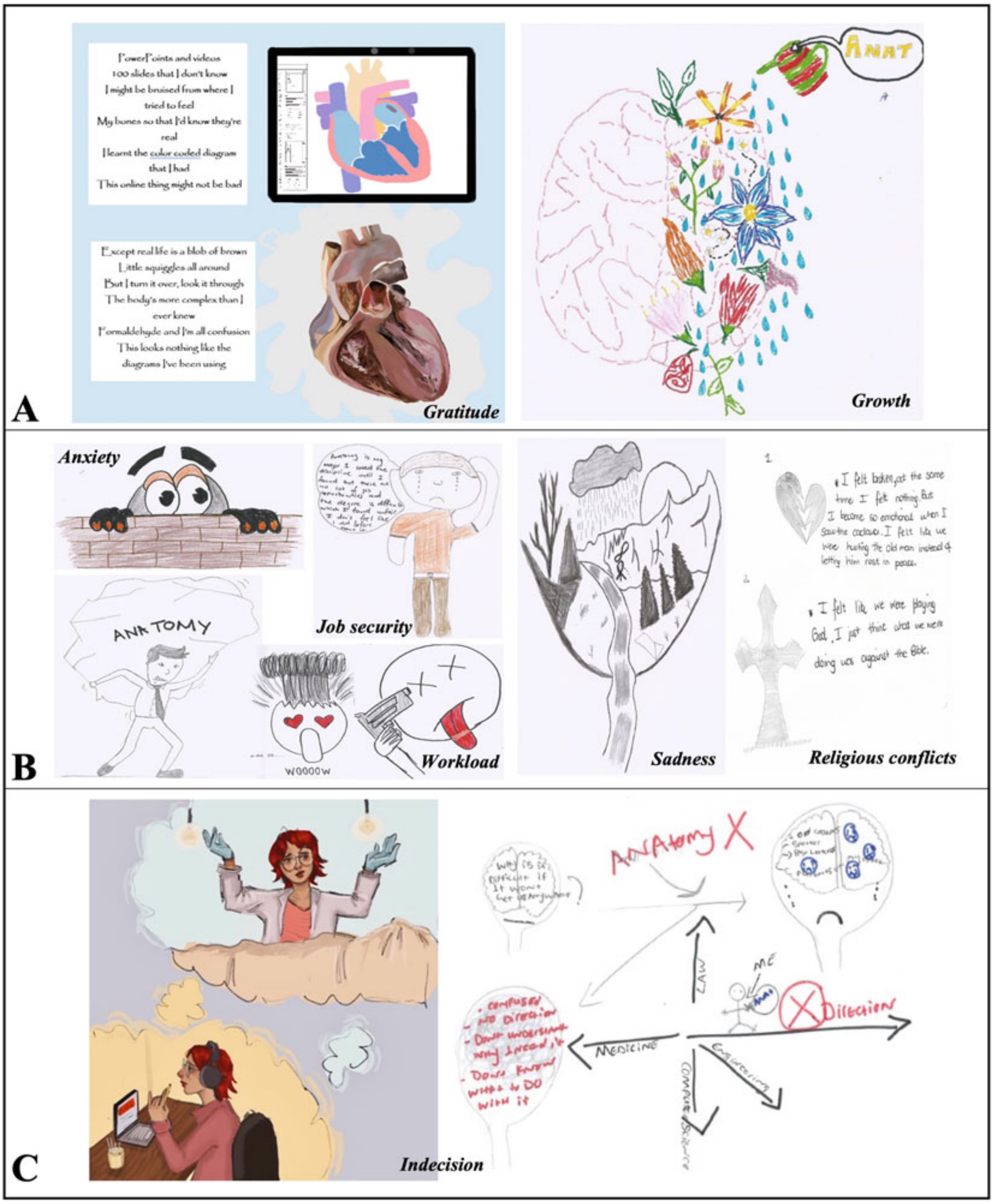

Fig. 5.1 Student perception of Anatomy: Use of Art to demonstrate (**a**) positive (**b**) negative and (**c**) ambivalent emotions

for the feelings of negativity expressed towards the discipline. Responses from a student body characterized by religious diversity revealed that some individuals referred to a conflict in their cultural beliefs while engaging with the bodies in the dissection hall (Fig. 5.1b).

5.3.1.3 Theme 3: Ambivalence

Cadaveric dissection evokes indecisive feelings regarding the study of Anatomy as a subject. As illustrated in Fig. 5.1c, confusion, uncertainty, sadness, and conflict are also evident. It is possible that the students' initial exposure to the process of dissection questions their career choices, albeit that this initial exposure is critical in developing and shaping the student for future vocational training.

Our findings indicate that the study of Anatomy evokes various positive and negative thoughts and emotions amongst students. Student participation in the reflective drawing process promoted self-reflection about anatomy and healthcare, examined the relationship between students and the body that they were studying, probed questions about religion and explored the emotional responses in the students towards dissection. The awe and wonder associated with the human body is well articulated by the students and is suggestive of their appreciation for the gift by the donor. Our findings corroborate several others who report the ability of students to appreciate the value of dissection (Yeager 1996; Jones 1997; Moore 1998; Johnson 2002; Cahill and Ettarh 2009). Furthermore, our results indicate that stressors such as the volume of content and difficulty in understanding the complex subject matter contribute negatively to the student perceptions of Anatomy (Orupabo et al. 2018).

5.3.2 Poetry

Students used poetry as an alternate craft to evoke a creative approach in their self-reflection based on their experiences in the dissecting hall. The use of poetry emanating from practices in the anatomy laboratory has produced an imaginative awareness of this experience as expressed through meaning and rhythmic language choices, evoking an embodied response. Four main themes were identified using thematic analysis, viz., the emotional response to dissection, the body in the dissection hall acting as a guide and teacher, body donation, and death and dying.

5.3.2.1 Theme 1: Emotional Response to Dissection

Students catalogue a wide range of emotions experienced during the anatomy course such as fear, sadness, shock, gratefulness, happiness, enjoyment, amazement, concern, curiosity, disgust, guilt, and shame. One of the poems submitted expresses fear, powerlessness, and a sense of feeling overwhelmed (Excerpt 1A). For others, the emotional journey is shown to commence with feelings of anxiety, trepidation, and dismay, but the student is later able to appreciate the complexity of the human body and strengthen their spiritual belief system (Excerpt 1B).

Excerpt 1: Emotional responses associated with dissection

Excerpt 1A: Dissection Hall *(Participant: EMM)*	Excerpt 1B: A Friday Afternoon *(Participant: NW)*
Roses are red *The cadaver is dead* *I knew its not going to harm me* *Its just the fear in my head* *As I walk into the dissecting hall* *Full of fright* *I fight the fear inside me* *With all my might* *They remove the covers for all to see* *I glanced at my friend beside me* *To my surprise* *She was more terrified than me* *Try to comfort her* *Gave comfort to me* *And that's when I thought* *How hard can it be?*	*I walked into the DH on a Friday afternoon* *Thinking what I would see and what I would smell* *Or how I'd react* *If it jumped up and yelled* *But I saw it there lying lifeless and flat* *And I thought to myself, "this can't be so bad"* *So I calmed myself down,* *Said "lets get this thing unwrapped"* *But the formaldehyde hit, "Man put this body back"* *But I said to myself "This is part of the job"* *Man up, "Cause it isn't so hard"* *And when I saw just how complex the whole body was* *I thought to myself,* *"There's definitely a God"*

Anecdotally, the cadaver is often objectified by students and is often referred to as "it". Our findings corroborate Chang et al. (2018), who stated that students expressed feelings of shock, apprehension, and anxiety during their initial exposure to bodies in the dissection hall. These negative emotions are instant and reactive, and spontaneously replaced by emotions such as gratitude and responsibility (Mulu and Tegabu 2012; Kotzé and Mole 2013). Similarly, other studies report diminished levels of anxiety with regular exposure to cadaveric dissection (Arráez-Aybar et al. 2004, 2008; Hancock et al. 2004).

5.3.2.2 Theme 2: The Cadaver as a Guide and Teacher

Human cadavers have many roles within the framework of biomedical teaching and learning. The practical knowledge gained via dissection by biomedical students through the study of Anatomy involves the essential touch and feel of human tissue and organs, as well as the relationship between structures within the body and the notion of human variation. No amount of information in textbooks can compare to the knowledge gained in the dissection hall. In this theme, the cadaver is portrayed as the teacher (Excerpt 2: "*for the purpose of education*").

Excerpt 2

Untitled *(Participant: ON)* *Once you were alive* *You chose to donate* *For the purpose of education* *Your family never got to bury you* *They still mourn your death* *But they have found peace* *And here I am today* *Learning from you* *Learning to save peoples' lives* *I thank you*

The excerpt indicates an attitude of student reverence for their highly esteemed teacher as they attribute a social role and position to him/her. Winkelmann and Güldner (2004) describe Thailand's approach towards body donors, where cadavers are honoured with the special status of "ajarn yai" ("a great teacher") and not merely treated as an object. Kundu et al. (2022) further reinforced the acceptance of the cadaver as the first medical teacher and definitely the first patient in the biomedical profession. Souza et al. (2020) articulated that the dead body assumes the form of a learning tool that offers a fascinating learning process in which the "dead" teach the "living".

5.3.2.3 Theme 3: Body Donation

This theme highlights body donation (Excerpt 3A) as an altruistic act where students identify with the donor by naming the cadaver (Excerpt 3B: "Just as Bob"). Students also recognize that donation is an anxiety-ridden subject, because students are not sure whether donors really understand what happens to their bodies during dissection (Excerpt 3A). The expressions outlined within these poems vacillate between confusion and reward.

Excerpt 3

Excerpt 3A: The Cadaver *(Participant: RJ)* *On the steel table you lie* *All covered up and mummified* *I see no emotions when I look into your eyes* *Running through your veins is formalin* *The smells bad makes me wanna cry* *Is this how you imagined it to be, for your body, after you die?* *They stand around you cutting up your biceps brachii* *With scalpels and forceps, I wanna close my eyes* *Would you cry if you could cry?* *Why did you do it?* *I don't know if you were noble or stupid* *Why would you donate your body, who just wanna abuse it*	Excerpt 3B: Just as Bob, I still *(Participant: KR)* *Dead, dead bodies in my mind rings* *Cold room with a smell that stinks* *Never seen a non-breathing human before* *DH, This place is haunted for sure* *He was lying there still* *I wonder what led to his kill* *Where and who is his kin* *Incisions were to be made on his skin* *I too, went cold and still* *I did not hear a word sad, I was still* *Focused on the empty soul in front of me lying still* *Narrating a story, Story of Bob the*	Excerpt 3C: Can I do this or will I run? *(Participant: BLR)* *With a mind full of questions and a nervous heart* *We approached the room where this journey would start* *I walked a bit closer to my friends* *As we entered the room where the corridor ends* *But it wasn't shock or horror we found* *No gaping black holes where runs the hell hound* *Instead more questions came into my head* *As we witnessed the quiet, the stillness of "Dead"* *Where did they come from?* *What was their story?* *Where had they gone? To*

(continued)

Was it for education? *Was it your last gift to our generation?* *Well, its pointless to ask you when you are living happily ever after* *Because you are just a cadaver*	*cadaver* *After that first visit I felt like* *I am the walking cadaver* *I am the shatter* *I am the gray matter* *That out of my head splattered*	*hell or to glory?* *Were they loved and did someone care?* *As death seemed so grey, so soulless and bare* *But curiosity and wonder soon gripped my sad heart* *Seeing each muscle, each tendon bone, each part* *Thanks to my Creator for the wonder I see* *Please use my hands in service to thee*

The data illustrate that some students tend to emotionally over-identify with the donors, whilst others were more likely to imagine them humanistically (Shapiro et al. 2009). Furthermore, body donation is highlighted again as an altruistic act which seems to be a key motivator for donation (Galic et al. 2016; Jiang et al. 2020). The data emanating in the poems are indicative of respect and honour to the individual for his/her donation made for the advancement of education. Our data endorse the outcomes of Chang et al. (2018) who highlighted the need for teachers to assist students in their initial reactions to the cadaver, foster and maintain respectful attitudes whilst upholding essential ethical practice in the gross anatomy laboratory. Souza et al. (2020) also reported that respect may be associated with the way one treats or handles the cadaver during dissection, which can later translate to how a healthcare professional will subsequently respect a patient in clinical practice. This concept is evident in Excerpt 3C: "*Can I do this or will I run*". Interestingly, Excerpt 3B denotes the human cadaver as "Bob", which is suggestive of a deeper learning as well as exposes a relationship with measures of humanism and compassion. Moreover, it indicates a sensitivity of the student towards the donor and their willingness to donate as well as time spent thinking about the living human that the body once was. There was also a sense of personal attachment to the assigned cadaver and personal duty to maximize the learning opportunity associated with this unique experience that enables students to become competent healthcare practitioners (Chang et al. 2018). In an earlier study, it was recommended that a pre-dissection orientation program be implemented to emotionally prepare students which may subsequently reduce anxieties associated with first-time cadaveric encounters (Bati et al. 2013). Of note, anxiety may also be curtailed by discussing death, dying and dissection with the students, providing detailed verbal information on the donor, arranging prior regular visits to the dissecting halls without cadavers and viewing videos of cadaver dissection before direct cadaveric exposure (Arráez-Aybar et al. 2004).

5.3.2.4 Theme 4: Death and Dying

This theme emphasizes students' attitudes towards the inevitable reality of death. Interaction with the cadaver assists students to put their own lives and priorities into better perspective (Excerpt 4A). Students experience feelings of vulnerability when it comes to the fear of death, the dying process, and the unknown. They also display an array of complex emotions such as attachment, empathy, guilt, blame, and fear (Excerpt 4B). The main image is one of darkness closing in—a darkened room, sight diminishing, and perpetual night imminent. The other image is fear—a recognition of overwhelming dread (Excerpt 4C).

Excerpt 4

Excerpt 4A: My first cadaver *(Participant: NM1)* *The blaze of the first sunshine* *Shines with the promise of a brighter tomorrow* *Yet bodies drop*	Excerpt 4B: A moment of silence *(Participant: NM2)* *A minute or two, that's all it took* *That brought up a pale grey look* *A glimpse of the steel plated room*	Excerpt 4C: The darkest day of life *(Participant: ST)* *My heart was full of fear,* *I was feeling guilty in such a way* *That I killed*

(continued)

like heavy rains of the first spring *Flooding every hope and dreams of a bright tomorrow* *As I stood there, looking at him, eye to eye,* *He lay there still, motionless, for a glimpse moment* *I thought his eyes were going to blink* *My heart skipped a few heartbeats and beat fast* *Sweat dropped down my face* *Never had I thought this day would come* *From dust you come, to dust you shall return* *It ran though my mind as I stood motionless* *Trying to put one and one together* *The thought of my journey to success flooded my mind* *That I owed this person who was once human but now a cadaver.* *Everything!*	*Where a dozen pure souls laid* *Still, lifeless and peaceful* *Nothing could be said* *A moment of silence* *A horror scene at first* *That had quenched my thirst* *Human remains were all a sight* *Subconsciously, one couldn't help but fright* *A moment of silence* *Up close, I smelt death* *Which had possessed me to hold my breath* *Eyes shut, mouth closed* *Sat there and froze* *A moment of silence*	*somebody* *I even thought that a dead person* *Is it possible for him or her to waken again?* *I tried to ignore what I was feeling* *But I failed the moment they opened the cadaver* *I nearly fainted because of the fear I had* *Death is a great disaster in the world* *I closed my eyes and touched myself* *Checking whether I'm still alive* *From the day I saw a cadaver* *I had those sleepless nights with scary dreams*

In undergraduate biomedical education, the introduction of the Anatomy course is perceived as the first human encounter with "dead human bodies" and thus provides an opportune prospect to open the doors for discussing the issues pertaining to "death and dying" (Alt-Epping et al. 2014). A previous study highlighted a mixture of primary emotional responses such as shock and apprehension from several students who experienced the fear of death during their first encounter with a dead body (Arráez-Aybar et al. 2004). Moreover, some students reported feeling an intense and sustained repulsion towards dissection because it revived their fundamental fear of death and required more individualized tactics and involvement to enable them to overcome such strong negative feelings (Snelling et al. 2003). Notably, religion is reported to be a significant coping mechanism to overcome such issues (Hancock et al. 2004). Noteworthy, the implementation of a reflective, interdisciplinary lecture slot at the beginning of the dissection course is warranted to prepare students mentally and emotionally before they enter the dissection hall. This may be a platform to empower students to understand and face challenges associated with death and dying, as well as exhibit an appreciation of human life, which is integral in managing the patient (Alt-Epping et al. 2014). This training phase of biomedical curricula is an important and particularly sensitive stage for students as they transition from layperson to medical practitioner and requires considerable input from all persons involved.

Our findings demonstrate a modest gaze into the changes and perceptions our students gain during their education journey of being enrolled in an anatomy course. Many of these lived experiences are recorded only in their memories and may have a profound meaning in later years. There are reflections which encompass the hitherto unknown fear of facing death, fantasies, and misconceptions about doctoring, and becoming comfortable with the uncomfortable. Recollections of achieving new knowledge, perspective, responsibility, and respect for the lives and circumstances of others who are not like themselves are also evident.

5.3.3 Student Reflections Based on Creative Output Development (Model, Theme-Park, and Digital Storytelling)

Four broad themes emerged based on the student group work experiences, viz. the development of thinking skills, the experience of personal strengths and challenges while working in a group, the creation of opportunities that aid in a better understanding of professionalism and lastly, the receipt of personal feedback to strengthen future online activities.

5.3.3.1 Theme 1: Development of Thinking Skills

This theme embraces the growth of students' thinking abilities (Fig. 5.2) during development of models (Fig. 5.2a–c) and theme-parks (Fig. 5.3) as well as digital storytelling (Fig. 5.4) conducted during group work activities. Student responses linked to thinking skills development are highlighted below:

> It allowed me to a better and broader understanding of anatomy & physiology due to increased visual representations

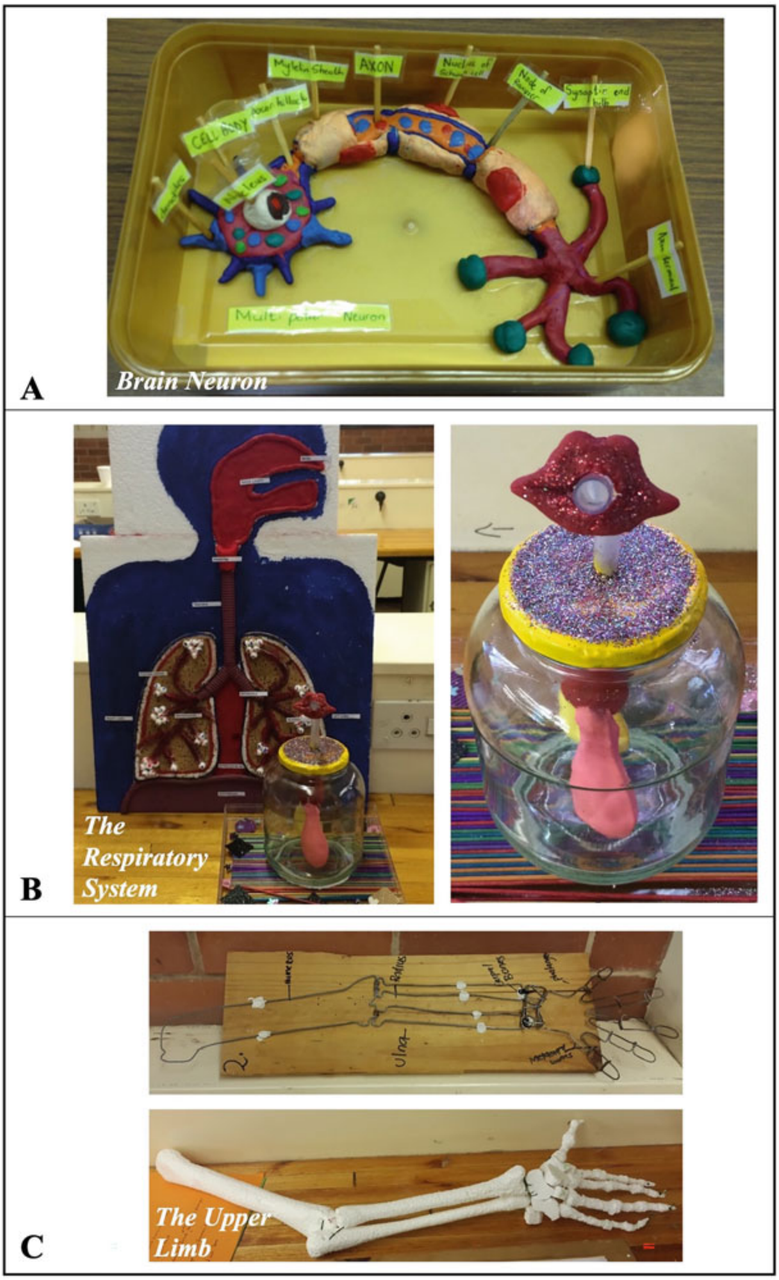

Fig. 5.2 (**a**–**c**) Model construction using various creative modalities to cultivate student engagement and understanding

Increased creative, innovative, critical thinking & analytical skills

Increased retention abilities due to new online learning techniques

Evidence was provided by the data that an improvement in the understanding of the basic science concepts was experienced by several students as they engaged with each other either physically or on the online platform. Anatomy and Physiology is a first-year course that requires the student to learn and understand factual material both in the classroom and during practicals in the laboratory. The discipline-specific content may be extremely challenging for the students especially since they represent a culturally diverse population with differing upbringings, levels of maturity, competencies, and demands. The majority of the participants reported achieving an improved and broader understanding of anatomical and physiological concepts because of an increased use of illustrations especially when developing the digital storytelling artefacts. Recently, Robin (2016) confirmed the effectiveness of digital storytelling as a learning tool, highlighting that participants involved in developing digital stories are more capable of consolidating and articulating opinions and composing storylines. Furthermore, many become proficient in evaluating personal efforts as well as the efforts of team members, thus suggesting that digital storytelling has the potential to enhance emotional intelligence, teamwork, and societal scholarship (Robin 2016).

Additionally, many students indicated an increase in knowledge regarding the use of their creativity, innovative ideas, critical thinking, and analytical skills as a result of the shift to new creative online learning techniques. This also enables students to achieve increased recollective and retention abilities. Earlier reports confirm that collaborative online teaching improves one's critical thinking proficiencies (Lee and Reeves 2007; Burgess 2009; Szabo and Schwartz 2011), improves self-confidence in technological ability (Osterman 2005), as well as enhances societal and scholarly presence (Peterson and Caverly 2005). More recently the effectiveness of digital teamwork in stimulating intellectual interaction and learning in an online space was confirmed by Darius et al. (2021).

5.3.3.2 Theme 2: Personal Strengths and Challenges While Working in a Group

The second theme highlighted the personal strengths and challenges (Fig. 5.3) students experienced whilst working as a group. Student reports suggesting an expansion of various personal strengths are highlighted below:

Enabled the development of creative skills

Enhanced comprehensive, time management, and communication skills

Empowered the deliberation of differing viewpoints

Facilitated respect amongst each other and increased self-discipline

Increased technological and leadership skills

Advanced good teamwork skills and problem-solving abilities

Fostered adaptability to new learning techniques and the use of innovative ideas

The data substantiate the tenacity of students to academic change, encompassing their ability to demonstrate creativity, effective communication and group work skills, respect, and increased self-discipline, all of which are essential in improving the efficiency of group work, especially when engaging on an online platform. Our findings corroborate Anderson et al. (2011) who indicated that collaborative online group work activities empowered student interaction and compel personal reflection regarding the processing of other's opinions. Moreover, students tend to be more drawn towards evaluating their personal comprehension and abilities in understanding various discipline-specific concepts. Furthermore, group work enhances student engagement and student-centred support by creating autonomous learning opportunities and improves oral presentation skills for effective peer interaction. Some students also reported that they were able to develop and improve their time management and problem-solving skills. Our findings substantiate reports from Smeda et al. (2014), who emphasized the potential of digital storytelling

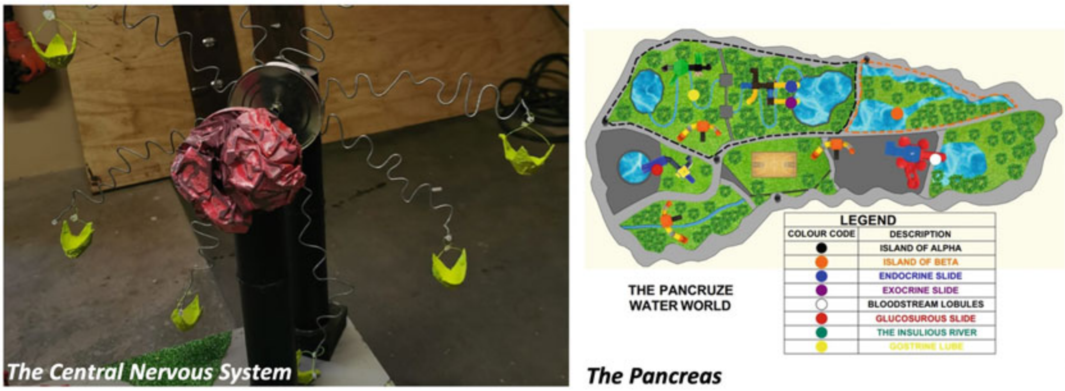

Fig. 5.3 Pictorial representation of theme-parks, illustrating personal strengths gained during group work (Theme 2: increased development of creative skills)

in individualizing the learning experience, improving societal and emotive skills as well as reinforcing intercultural diversity.

Additionally, several students reported experiencing many challenges, which are itemized below:

Miscommunication

Uncertainties regarding the project requirements

Conflict due to different viewpoints

Effective time management

Limited personal availability due to managing other module commitments

Imbalanced participation due to time constraints

Connectivity and data issues

Limited resources and technological support

Limited physical interaction due to lockdown restrictions imposed by the Covid-19 regulations

Lack of creativity skills

Unsuitable home environment and home distractions

Evidence provided by the data revealed that several students experienced similar challenges resulting from connectivity and data issues, followed by poor time management due to participant availability attributed to other module commitments, and the restricted physical

Fig. 5.4 Pictorial representation of digital storytelling/scrapbooks, demonstrating opportunities that contributed to improved understanding of professionalism (Theme 3: Adapting to different intercultural diversities)

interaction implemented by the Covid-19 regulations. Other challenges reported include miscommunication, an inadequate learning environment in the home and consequent distractions. In alignment with the outcomes of this study, Darius et al. (2021) highlight time management and interpersonal relationships as major challenges experienced during online learning whereas self-motivation and flexibility were reported as possible strengths.

5.3.3.3 Theme 3: Opportunities that Aided in a Better Understanding of Professionalism

This theme emphasizes the learning opportunities and cultural differences that students were exposed to, which subsequently improved their understanding of professionalism (Fig. 5.4). The responses reported by a number of students are presented below:

Respectful of different viewpoints
Responsibility, Dedication and excitement to the allocated project
Good time management skills
Showing initiative by taking minutes of progress report meetings
Good teamwork and communication skills
Equal participation
Being adaptable to online environment
Increased self-awareness
Good leadership abilities
Gaining opportunity to speak to clinician
Assembling final project whilst obeying Covid-19 protocols

The data extracted for this theme highlight several opportunities that students were subjected to both singly and whilst working as a team member within their respective groups. The data suggest that many felt these opportunities allowed them to gain a better understanding of what their specific professionalism requires. Recent data also indicate that an online learning space requires the student to assume full responsibility for attaining academic success, which is mostly driven by personal motivation (Kim et al. 2019). Interestingly, this self-regulated learning enhances the development of cognitive skills and peer engagement.

Additionally, several students confirmed that being respectful of each other's opinions and ideas as well as the ability to be shown dedication and commitment to the designated tasks enables one another to improve their understanding of professionalism in their future workplace. Teamwork, sharing of tasks equally amongst each other and being adaptable to skills also emerged as integral factors that enhanced students' understanding of the workplace professionalism that is expected.

The use of technology in higher education is reported to strengthen knowledge and skills progression (De Souza et al. 2021), thus accentuating theoretical comprehension (Ibañez and Pentang 2021; Domingo 2021) and critical thinking (Pentang 2021). Of note, the development of soft skills (teamwork, presentation, language, and intercultural competencies) is a possible authentication indicator of learning efficiency associated with group work activities and has the potential to improve graduate employability.

5.3.3.4 Theme 4: Personal Feedback to Strengthen Future Online Activities

Since some of the activities were conducted during remote teaching and learning as a result of the Covid-19 pandemic, this theme highlights feedback relating to personal activity which has potential to reinforce and encourage future online engagements. The key components pertaining to this theme as reported by students are detailed below:

Increase online learning support to guide student comprehension and adaptability
Development of time management and communication skills
Mental health support (how to deal with stress)
Strengthening team performance
Efficient online resources
Increase tutor support to improve interpretation of difficult concepts

As demonstrated in the emerging data, this theme provides student feedback that has the potential to strengthen and improve future online activities, as well as other group work activities when considered by academics for implementation. Most students suggested the possibility of providing increased guidance on transitioning from physical/onsite learning to online learning. Others suggested that an increase in online tutor support is essential to improve interpretation of difficult concepts and ensure a balanced participation. A few students also indicated the need for guidance on how to deal with stress, as well as to develop their time management skills. The suggestions provide a route to enhance the efficiency of online group work, and thus augment the overall student experience and group work performance under such circumstances.

5.3.4 Descriptive Imagery

5.3.4.1 Value of Schematic Diagrams to Illustrate Scientific Concepts

Schematic diagrams are useful in defining concepts as well as demonstrating relationships and inter-relationships between the variables that it affects and/or its origins (Umoquit et al. 2011). For example, the advanced immunostaining technique of immunohistochemistry has the potential to demonstrate the value of visualization techniques in biomedical education, medicine, and science. Immunohistochemistry is based on specific antigen–antibody reactions that permit the prompt detection of proteins. Antibodies distinguish proteins based on their structural content and configuration by binding to a specific epitope (a small part of an antigen) (Magaki et al. 2019). However, the commonest application of antigen–antibody is an enzyme-linked immunosorbent assay (ELISA) or several antibodies via a multiplex immunoassay.

Image visualization using microscopic immunolocalization techniques allied with morphometric image analysis improves cognitive interpretation compared to reading a block of text or series of numbers. Such pictures serve to demystify science; however, a poor schematic image may also confuse novices and misrepresent the facts. Nonetheless, figures give depth and perspective to students' scientific interpretation in biomedical education. A good image should clearly transfer the interpretation of a dataset at a glance in contrast to the representation of the data in a table. This simplistic approach of the provision of a figure enriches learning whilst maintaining scientific interpretation and integrity and also validating scientific pedagogy.

5.3.4.2 Representation of Morphometric Image Analysis

It is important to remember that medical science is aimed at being non-prejudiced and precise. Hence, microscopy interpretation should be non-biased and based on pixels or densitometric analysis using morphometric image analysis. For the purpose of quantification, every image should be geometrically calibrated according to the initial magnification prior to commencing the analysis. Morphometric Image analysis has clinical diagnostic potential in conditions such as pre-eclampsia which is characterized by the lack of partial physiological conversion within spiral arterioles (Fig. 5.5). The use of anti-cytokeratin labelling of trophoblast cells within spiral arteries clearly demonstrates the presence (Fig. 5.5a) or absence (Fig. 5.5b) of immune labelling, hence augmenting clinical findings.

5.4 Conclusion

We believe that novelty in education has the power to reinvent our teaching practices and encourages ongoing learning, professionalism, and future employment decisions. Our findings indicate that the use of various innovative teaching and learning strategies encourage active learning both in the physical and in the virtual classrooms. It is evident that the utilization of creative projects, viz. art and poetry, model building, theme-parks, schematic diagrams, and microscopy images positively enhance the visualization of complex concepts in biomedical education. It is therefore important that the incorporation of creativity into biomedical education be seriously considered by educators in order to complement teaching and learning in the disciplines of Anatomy and Physiology, as well as to reduce the perception of a very challenging

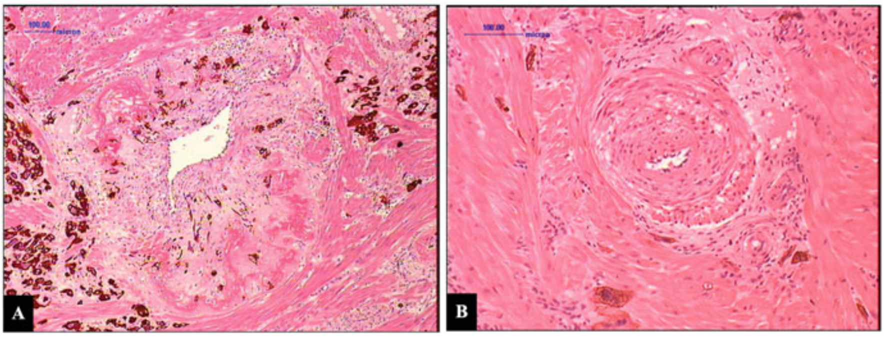

Fig. 5.5 The use of anti-cytokeratin staining illustrating (**a**) a spiral artery that is partially physiologically transformed in normal pregnancy; note the trophoblast cells stained brown in the arterial wall and in the juxtamyometrial regions; and (**b**) a non-converted spiral artery from a pre-eclamptic pregnancy. (Adapted from Naicker 2001)

workload, as expressed by the majority of students. Integrating the use of various creative and innovative pedagogical strategies in medical education supplements the learning and comprehension of subject content that is ordinarily difficult to master. Such strategies have been shown to support learning and instruction as these activities are more exciting and engaging for the learner. The implementation of the creative approaches described in this chapter will assist students in gaining a better understanding and knowledge of the concepts within Anatomy and Physiology, whilst producing students with improved empathy, critical thinking, problem-solving abilities, and professionalism. Creativity and different visualization techniques need to be incorporated into the teaching and learning of biomedical science subjects in order to improve the conceptual understanding of students and develop confident and positive attitudes towards learning. In a world of rapid technological advancement, educators should focus on empowering and creating holistically equipped alumni for future employment and individual activism in a variety of settings to fully embrace the challenges of technological evolution and globalization.

References

Alt-Epping B, Lohse C, Viebahn C, Steinbüchel NV, Benze G, Nauck F (2014) On death and dying—an exploratory and evaluative study of a reflective, interdisciplinary course element in undergraduate anatomy teaching. BMC Med Educ 14(1):1–7. https://doi.org/10.1186/1472-6920-14-15

Amory A, Naicker K, Vincent J, Adams C (1999) The use of computer games as an educational tool: identification of appropriate game types and game elements. Br J Educ Technol 30(4):311–321. https://doi.org/10.1111/1467-8535.00121

Anderson GL, Passmore JC, Wead WB, Falcone JC, Stremel RW, Schuschke DA (2011) Using "active learning" methods to teach physiology. Medical Science Educator 21(1):8–20. https://doi.org/10.1007/BF03341589

Arráez-Aybar LA, Casado-Morales MI, Castaño-Collado G (2004) Anxiety and dissection of the human cadaver: an unsolvable relationship? Anat Rec B New Anat 279(1):16–23. https://doi.org/10.1002/ar.b.20022

Arráez-Aybar LA, Castaño-Collado G, Casado-Morales MI (2008) Dissection as a modulator of emotional attitudes and reactions of future health professionals. Med Educ 42(6):563–571. https://doi.org/10.1111/j.1365-2923.2008.03079.x

Backhouse M, Fitzpatrick M, Hutchinson J, Thandi CS, Keenan ID (2017) Improvements in anatomy knowledge when utilizing a novel cyclical "observe-reflect-draw-edit-repeat" learning process. Anat Sci Educ 10(1):7–22. https://doi.org/10.1002/ase.1616

Balemans MC, Kooloos JG, Donders ART, Van der Zee CE (2016) Actual drawing of histological images improves knowledge retention. Anat Sci Educ 9(1):60–70. https://doi.org/10.1002/ase.1545

Barbot B, Besançon M, Lubart T (2015) Creative potential in educational settings: its nature, measure, and nurture. Education 3–13 43(4):371–381. https://doi.org/10.1080/03004279.2015.1020643

Bareither ML, Arbel V, Growe M, Muszczynski E, Rudd A, Marone JR (2013) Clay modelling versus written modules as effective interventions in understanding human anatomy. Anat Sci Educ 6(3): 170–176. https://doi.org/10.1002/ase.1321

Bati AH, Ozer MA, Govsa F, Pinar Y (2013) Anxiety of first cadaver demonstration in medical, dentistry and pharmacy faculty students. Surg Radiol Anat 35(5): 419–426. https://doi.org/10.1007/s00276-013-1075-7

Bell LT, Evans DJ (2014) Art, anatomy, and medicine: is there a place for art in medical education? Anat Sci Educ 7(5):370–378. https://doi.org/10.1002/ase.1435

Benmayor R (2008) Digital storytelling as a signature pedagogy for the new humanities. Arts Human Higher Educ 7(2):188–204. https://doi.org/10.1177/1474022208088648

Bessette HJ (2008) Using students' drawings to elicit general and special educators' perceptions of co-teaching. Teach Teach Educ 24(5):1376–1396. https://doi.org/10.1016/j.tate.2007.06.007

Branch WT (2000) Supporting the moral development of medical students. J Gen Intern Med 15(7):503–508. https://doi.org/10.1046/j.1525-1497.2000.06298.x

Branson TM, Shapiro L, Venter RG (2021) Observation of patients' 3D printed anatomical features and 3D visualisation technologies improve spatial awareness for surgical planning and in-theatre performance. In: Rea PM (ed) Biomedical visualisation. Advances in experimental medicine and biology, vol 1334, pp 23–37

Brown J, Bryan J, Brown T (2005) Twenty-first century literacy and technology in K-8 classrooms. Innovate J Online Educ 1(3)

Burgess ML (2009) Using WebCT as a supplemental tool to enhance critical thinking and engagement among developmental reading students. J College Read Learn 39(2):9–33. https://doi.org/10.1080/10790195.2009.10850316

Cahill KC, Ettarh RR (2009) Attitudes to anatomy dissection in an Irish medical school. Clin Anat 22(3): 386–391. https://doi.org/10.1002/ca.20777

Chang HJ, Kim HJ, Rhyu IJ, Lee YM, Uhm CS (2018) Emotional experiences of medical students during cadaver dissection and the role of memorial ceremonies: a qualitative study. BMC Med Educ 18(1):1–7. https://doi.org/10.1186/s12909-018-1358-0

Charmaz KC (2005) Grounded theory: methods for the twenty-first century. In: The SAGE handbook of qualitative research. Sage, Thousands Oaks, pp 507–536

Clavert P, Bouchaïb J, Duparc F, Kahn JL (2012) A plea for the use of drawing in human anatomy teaching. Surg Radiol Anat 34(8):787–789. https://doi.org/10.1007/s00276-012-0967-2

Cole DG, Sugioka HL, Yamagata-Lynch LC (1999) Supportive classroom environments for creativity in higher education. J Creative Behav 33(4):277–293. https://doi.org/10.1002/j.2162-6057.1999.tb01407.x

Collett TJ, McLachlan JC (2005) Does 'doing art' inform students' learning of anatomy? Med Educ 39(5): 521–521. https://doi.org/10.1111/j.1365-2929.2005.02165.x

Coventry M (2008) Cross-currents of pedagogy and technology: a forum on digital storytelling and cultural critique: introduction. Arts Human Higher Educ 7(2): 165–170. https://doi.org/10.1177/1474022208088646

Darius PSH, Gundabattini E, Solomon DG (2021) A survey on the effectiveness of online teaching–learning methods for university and college students. J Inst Eng (India) Ser B 102(6):1325–1334. https://doi.org/10.1007/s40031-021-00581-x

De Souza R, Parveen R, Chupradit S, Velasco LG, Arcinas M, Tabuena AC, Pentang J, Ventayen RJM (2021) Language teachers' pedagogical orientations in integrating technology in the online classroom: its effect on students motivation and engagement. Turkish J Comput Math Educ 12(10):5001–5014. https://doi.org/10.17762/turcomat.v12i10.5268

De-Marcos L, Domínguez A, Saenz-de-Navarrete J, Pagés C (2014) An empirical study comparing gamification and social networking on e-learning. Comput Educ 75: 82–91. https://doi.org/10.1016/j.compedu.2014.01.012

DePape AM, Doyle-Thomas K (2022) Students' perceptions of digital storytelling in higher education. Innovat Pract Higher Educ 4(3):383–417

Domingo JG (2021) Cognitive skills achievement in mathematics of the elementary pre-service teachers using Piaget's seven logical operations. Turkish J Comput Math Educ 12(4):435–440. https://doi.org/10.17762/turcomat.v12i4.524

Downie RS (1991) Literature and medicine. J Med Ethics 17(2), 93–96, 98

Felix J (2022) The importance of reflection for students – and teachers. University World News. Available at: https://www.universityworldnews.com/post.php?story=20221019114926402 (Accessed 12 December 2022)

Foley YC, Mullis F (2008) Interpreting children's human figure drawings: basic guidelines for school counsellors. Georgia School Counsellors Assoc J 1(1):28–37

Galic BS, Drvendzija Z, Strkalj G (2016) Attitudes of medical and allied medical students from Serbia toward whole body donation. J Biosci:1388–1402. https://doi.org/10.14393/BJ-v32n1a2016-34414

Ganley B (2012) Community, communication, and creativity: digital storytelling in the liberal arts classroom. Teach Multimedia:9–30

Good BJ, Good MJD (2000) Fiction and historicity. In: Doctors' stories: social and narrative dimensions of learning medicine. Narrative and the cultural construction of illness and healing. University of California Press, pp 50–69

Gull S (2005) Embedding the humanities into medical education. Educ Prim Care 16(3). https://doi.org/10.1111/j.1365-2929.2004.01974.x

Hancock D, Williams M, Taylor A, Dawson B (2004) Impact of cadaver dissection on medical students. N Z J Psychol 33(1):17–25

Hoffman B, Nadelson L (2010) Motivational engagement and video gaming: a mixed methods study. Educ Technol Res Dev 58(3):245–270. https://doi.org/10.1007/s11423-009-9134-9

Hopkinson C (2013) Teaching and using poetry in healthcare. In McIntosh P, Warren D (eds) Creativity in the classroom: case studies in using the arts in teaching and learning in higher education, pp. 101–114

Houwink AP, Kurup AN, Kollars JP, Kral Kollars CA, Carmichael SW, Pawlina W (2004) Help of third-year medical students decreases first-year medical students' negative psychological reactions on the first day of gross anatomy dissection. Clin Anat 17(4):328–333. https://doi.org/10.1002/ca.10218

Huang SH, Irawati N, Chien YF, Lin JY, Tsai YH, Wang PY, Chu LA, Li ML, Chiang AS, Tsia KK, Chu SW (2021) Optical volumetric brain imaging: speed, depth, and resolution enhancement. J Phys D Appl Phys 54(32):323002. https://doi.org/10.1088/1361-6463/abff7b

Ibañez ED, Pentang J (2021) Socio-constructivist learning and teacher education students' conceptual understanding and attitude toward fractions. Indonesian Res J Educ 5(1). https://doi.org/10.22437/irje.v5i1.12187

Jiang J, Zhang M, Meng H, Cui X, Yang Y, Yuan L, Su C, Wang J, Zhang L (2020) Demographic and motivational factors affecting the whole-body donation programme in Nanjing, China: a cross-sectional survey. Br Med J 10(9):e035539. https://doi.org/10.1136/bmjopen-2019-035539

Johnson JH (2002) Importance of dissection in learning anatomy: personal dissection versus peer teaching. Clin Anat 15(1):38–44. https://doi.org/10.1002/ca.1090

Jones DG (1997) Reassessing the importance of dissection: a critique and elaboration. Clin Anat 10(2):123–127. https://doi.org/10.1002/(SICI)1098-2353(1997)10:2<123::AID-CA9>3.0.CO;2-W

Jones EK, Kittendorf AL, Kumagai AK (2017) Creative art and medical student development: a qualitative study. Med Educ 51(2):174–183. https://doi.org/10.1111/medu.13140

Kaldi S, Pyrgiotakis G (2009) Student teachers' reflections of teaching during school teaching practice. Int J Learn 16(9):185–196. https://doi.org/10.18848/1447-9494/CGP/v16i09/46599

Kampylis P, Berki E, Saariluoma P (2009) In-service and prospective teachers' conceptions of creativity. Think Skills Creat 4(1):15–29. https://doi.org/10.1016/j.tsc.2008.10.001

Kim B, Park H, Baek Y (2009) Not just fun, but serious strategies: using meta-cognitive strategies in game-based learning. Comput Educ 52(4):800–810. https://doi.org/10.1016/j.compedu.2008.12.004

Kim HJ, Hong AJ, Song HD (2019) The roles of academic engagement and digital readiness in students' achievements in university e-learning environments. Int J Educ Technol High Educ 16(1):1–18. https://doi.org/10.1186/s41239-019-0152-3

Kotzé SH, Mole CG (2013) Talking about death: implementing peer discussion as a coping mechanism to overcome fears about dissection, death, and dying. Anat Sci Educ 6(3):191–198. https://doi.org/10.1002/ase.1332

Kundu S, Sherke AR, Gurudiwan R (2022) Cadaver as the first silent medical teacher: exploring bioethical perceptions of department of anatomy. Asian J Med Sci 13(5):75–84. https://doi.org/10.3126/ajms.v13i5.39305

Leboulanger N (2011) First cadaver dissection: stress, preparation, and emotional experience. Eur Ann Otorhinolaryngol Head Neck Dis 128(4):175–183. https://doi.org/10.1016/j.anorl.2011.01.007

Lee SJ, Reeves TC (2007) A significant contributor to the field of educational technology. Educ Technol 47(6):56–59

Lemke JL (1990) Talking science: language, learning, and values. Ablex Publishing Corporation, New Jersey

Leon SM (2008) Slowing down, talking back, and moving forward: some reflections on digital storytelling in the humanities curriculum. Arts Human Higher Educ 7(2):220–223. https://doi.org/10.1177/1474022208088650

Magaki S, Hojat SA, Wei B, So A, Yong WH (2019) An introduction to the performance of immunohistochemistry. Biopreserv Biobank 1897:289–298. https://doi.org/10.1007/978-1-4939-8935-5_25

McLean M, Henson Q, Hiles L (2003) The possible contribution of student drawings to evaluation in a new problem-based learning medical programme: a pilot study. Med Educ 37(10):895–906. https://doi.org/10.1046/j.1365-2923.2003.01629.x

Michael J (2006) Where's the evidence that active learning works? Adv Physiol Educ 30(4):159–167. https://doi.org/10.1152/advan.00053.2006

Moore NA (1998) To dissect or not to dissect? Anat Record 253(1):8–9. https://doi.org/10.1002/(SICI)1097-0185(199802)253:1<8::AID-AR6>3.0.CO;2-Z

Mozaffari HR, Janatolmakan M, Sharifi R, Ghandinejad F, Andayeshgar B, Khatony A (2020) The relationship between the VARK learning styles and academic achievement in dental students. Adv Med Educ Pract 11:15–19. https://doi.org/10.2147/AMEP.S235002

Mulu A, Tegabu D (2012) Medical students' attitudinal changes towards cadaver dissection: a longitudinal study. Ethiop J Health Sci 22(1):51–58

Naicker T (2001) Transforming growth factor isomers 1–3 in the placental bed of hypertensive complications of pregnancy. PhD Thesis. University of Natal, South Africa

Nayak SB, Mishra S, George BM, Kumar N (2016) Student project in anatomy (SPA)–making the first year medical students responsible and creative. J Clin Diagn Res 10(9):JC10. https://doi.org/10.7860/JCDR/2016/19327.8490

Nemerov H (2022) Britannica, the editors of encyclopedia: poetry. Encyclopedia Britannica. Available at: https://www.britannica.com/art/poetry (Accessed 21 August 2022)

Orupabo CD, Victor PD, Ordu KS, Gbaranor BK, Godam ET (2018) Factors affecting study of clinical anatomy among undergraduate medical laboratory students. Basic Sci Med 7(1):13–19. https://doi.org/10.5923/j.medicine.20180701.03

Osterman KF (1990) Reflective practice: a new agenda for education. Educ Urban Soc 22(2):133–152. https://doi.org/10.1177/0013124590022002002

Osterman PP (2005) A comparison of student performance in developmental reading using traditional versus a hybrid model of traditional and online instruction. Res Dev Educ 19(2):1–6

Pentang J (2021) Problem-solving performance and skills of prospective elementary teachers in Northern Philippines. Science Education Institute, Department of Science and Technology & Philippine Council of Mathematics Teacher Education, Inc. Mathematics framework for Philippine basic education 48(1), 122–132. https://doi.org/10.13140/RG.2.2.25873.76648

Peterson CL, Caverly DC (2005) Techtalk: building academic literacy through online discussion forums. J Dev Educ 29(2):38

Pithouse-Morgan K, Naicker I, Pillay D (2017) "Knowing what it is like": dialoguing with multiculturalism and equity through collective poetic autoethnographic inquiry. Int J Multic Educ 19(1):125–143. https://doi.org/10.18251/ijme.v19i1.1255

Plass JL, Homer BD (2012) Popular game mechanics as inspirations for learning mechanics and assessment mechanics. In Game Developers Conference, San Francisco

Plass JL, Homer BD, Kinzer CK (2015) Foundations of game-based learning. Educ Psychol 50(4):258–283. https://doi.org/10.1080/00461520.2015.1122533

Platt KM, Salmerón KE, Hatcher AR (2021) The art of anatomy: engaging student creativity in undergraduate anatomy courses. Human Anat Physiol Soc Educ 25(3):64–74. https://doi.org/10.21692/haps.2021.019

Poirier S (2004) Voice in the medical narrative. In: Stories matter. Routledge, pp 62–73

Porter B (2005) Digitales: the art of digital storytelling. The Creative Educator. Bernajean Porter Consulting. Discovery Education. Available at: www.unitedstreaming.com

Reid S, Shapiro L, Louw G (2018) How haptics and drawing enhance the learning of anatomy. Anatomical sciences education, 2018. Anat Sci Educ 00:1–9

Rivard LP, Straw SB (2000) The effect of talk and writing on learning science: an exploratory study. Sci Educ 84(5):566–593. https://doi.org/10.1002/1098-237X(200009)84:5<566::AID-SCE2>3.0.CO;2-U

Robin BR (2016) The power of digital storytelling to support teaching and learning. Digit Educ Rev 30:17–29

Ruiz V (2015) The spellbinding art of human anatomy. November. Available at: https://www.ted.com/talks/vanessa_ruiz_the_spellbinding_art_of_human_anatomy (Accessed: 13 August 2022)

Santos J, Figueiredo AS, Vieira M (2019) Innovative pedagogical practices in higher education: an integrative literature review. Nurse Educ Today 72:12–17. https://doi.org/10.1016/j.nedt.2018.10.003

Schabort D (2013) Students' perceptions of anatomy as expressed through drawings (Doctoral dissertation, Stellenbosch: Stellenbosch University)

Shapiro J, Nguyen VP, Mourra S, Boker JR, Ross M, Thai TM, Leonard RJ (2009) Relationship of creative projects in anatomy to medical student professionalism, test performance and stress: an exploratory study. BMC Med Educ 9(1):1–10. https://doi.org/10.1186/1472-6920-9-65

Shapiro L, Bell K, Dhas K, Branson T, Louw G, Keenan ID (2019) Focused multisensory anatomy observation and drawing for enhancing social learning and three-dimensional spatial understanding. Anatomical sciences education, 2019. Anat Sci Educ 0:1–16

Smeda N, Dakich E, Sharda N (2014) The effectiveness of digital storytelling in the classrooms: a comprehensive study. Smart Learn Env 1(1):1–21. https://doi.org/10.1186/s40561-014-0006-3

Snelling J, Sahai A, Ellis H (2003) Attitudes of medical and dental students to dissection. Clin Anat 16(2):165–172. https://doi.org/10.1002/ca.10113

Souza AD, Kotian SR, Pandey AK, Rao P, Kalthur SG (2020) Cadaver as a first teacher: a module to learn the ethics and values of cadaveric dissection. J Taibah Univ Med Sci 15(2):94–101. https://doi.org/10.1016/j.jtumed.2020.03.002

Squire K (2011) Video games and learning: teaching and participatory culture in the digital age. Technology, Education Connections (the TEC Series). Teachers College Press

Stammers T (2015) Healing allusions: the use of poetry in medical education. J Contemp Med Educ 3(3):127–133. https://doi.org/10.5455/jcme.20151030024353

Stanovich PJ (2003) Using research and reason in education: how teachers can use scientifically based research to make curricular & instructional decisions. Partnership for Reading (Project), National Institute for Literacy, US Department of Education

Sternberg RJ, Lubart TI (1999) The concept of creativity: prospects and paradigms. In: Handbook of creativity, vol 1. Cambridge University Press, pp 3–15

Suchman AL, Williamson PR, Litzelman DK, Frankel RM, Mossbarger DL, Inui TS (2004) Toward an informal curriculum that teaches professionalism. J Gen Intern Med 19(5):501–504. https://doi.org/10.1111/j.1525-1497.2004.30157.x

Szabo Z, Schwartz J (2011) Learning methods for teacher education: the use of online discussions to improve critical thinking. Technol Pedagog Educ 20(1):79–94. https://doi.org/10.1080/1475939X.2010.534866

Turkay S, Kinzer CK, Adinolf S (2013) The effects of customization on game experiences of a massively multiplayer online game's players. Proc GLS 9:330–337

Umoquit MJ, Tso P, Burchett HE, Dobrow MJ (2011) A multidisciplinary systematic review of the use of diagrams as a means of collecting data from research subjects: application, benefits and recommendations. BMC Med Res Methodol 11(1):1–10. https://doi.org/10.1186/1471-2288-11-11

UNESCO (2013) Twenty-first century skills. International Bureau of Education. Available at: http://www.ibe.unesco.org/en/glossary-curriculum-terminology/t/twenty-first-century-skills (Accessed 3 March 2022)

Wang S, Zhan H (2010) Enhancing teaching and learning with digital storytelling. Int J Inf Commun Technol Educ 6(2):76–87. https://doi.org/10.4018/jicte.2010040107

Weber S, Mitchell C (1996) Drawing ourselves into teaching: studying the images that shape and distort teacher education. Teach Teach Educ 12(3):303–313. https://doi.org/10.1016/0742-051X(95)00040-Q

Winkelmann A, Güldner FH (2004) Cadavers as teachers: the dissecting room experience in Thailand. Br Med J 329(7480):1455–1457. https://doi.org/10.1136/bmj.329.7480.1455

Wolters FJ, Wijnen-Meijer M (2012) The role of poetry and prose in medical education: the pen as mighty as the scalpel? Perspect Med Educ 1(1):43–50. https://doi.org/10.1007/s40037-012-0008-1

Wu J, Chen DTV (2020) A systematic review of educational digital storytelling. Comput Educ 147:103786. https://doi.org/10.1016/j.compedu.2019.103786

Yeager VL (1996) Learning gross anatomy: dissection and prosection. Clin Anat 9(1):57–59. https://doi.org/10.1002/(SICI)1098-2353(1996)9:1<57::AID-CA12>3.0.CO;2-9

Zamora-Polo F, Corrales-Serrano M, Sánchez-Martín J, Espejo-Antúnez L (2019) Nonscientific university students training in general science using an active-learning merged pedagogy: gamification in a flipped classroom. Educ Sci 9(4):297. https://doi.org/10.3390/educsci9040297

Biomedical Visualization in Embryology Education: A Scoping Review

6

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Abstract

This chapter presents a scoping review of the use of biomedical visualizations in embryology for the education of students in the health sciences professions. A preliminary search of MEDLINE and PROSPERO was conducted and no current or commencing systematic reviews or scoping reviews on the topic were identified. This review followed the reporting guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). The Population, Content, and Context (PCC) method was used to develop and refine a comprehensive literature search strategy for MEDLINE (Ovid). After being peer-reviewed, the search strategy was adapted for additional databases including EMBASE (Ovid), CINAHL (EBSCO), ERIC (EBSCO), and Web of Science. These databases were searched from the inception of their platforms until October 2022. Several gray literature sources were also searched. Gray literature represents "the diverse and heterogeneous body of material available outside, and not subject to, traditional academic peer-review processes". Identified citations were uploaded to Covidence, after which they were reviewed and screened by two independent reviewers, with an independent third-party adjudicator rating the citations on which the reviewers disagreed. Citations that were identified as potentially relevant were put forward for full-text screening, full-text review, and data extraction using a pilot-tested form. Our literature search yielded 12,062 records from published literature and 660 records from gray literature, out of which 168 met our inclusion criteria. Of these, 136 resulted from the published (peer-reviewed) literature search, 21 from search of the gray literature, and 11 from citation chain analysis. Pertinent features of identified studies included a skewed geographical predominance of studies originating from North America and Europe, a rapid increase in studies describing biomedical visualizations in embryology education from the turn of the millennium onward, and the majority of studies being concerned with basic science education of medical undergraduates as well as non-clinical

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embryology education of multiple health sciences professions. This study has the potential of being the stimulus for more comprehensive systematic reviews in this field, or hopefully as evidence to support action toward more equitable distribution of visualization resources in the global enterprise of embryology education of the health professions.

Keywords

Embryology · Biomedical visualization · Health professions education · Evidence synthesis

6.1 Introduction

A pillar of embryology education and research includes the development and deployment of a variety of tools including animations (Yamada et al. 2006), 3D printing (Plunkett et al. 2019), extended reality (XR) (Alfalah et al. 2019), and sonography (Fakoya et al. 2017). Reporting of the development, evaluation, and impact of these tools has occurred only intermittently in the literature and without systematic analysis. The teaching and learning of embryology has been documented as one of the most challenging components of health professions education (Evans 2011; Guo et al. 2022); however, the literature does not indicate a systematic, proven method of teaching this conceptually difficult content. The use of biomedical visualizations in embryology education has grown in complexity and application but the utility of such teaching methods is often under-documented or reported in silos. As such, the methods and their impact are not fully known by those engaged in teaching and learning. Being that embryology is taught in various contexts (clinical, laboratory, classroom, etc.) and using various visualization methods, it is crucial to identify the various uses of biomedical visualization in embryology education in order to understand best practices for teaching this content. Using a scoping review methodology, the objective of this review is to identify and summarize the existing literature on the types and applications of biomedical visualizations in health professions embryology education.

6.2 Rationale

A preliminary search of MEDLINE and PROSPERO was conducted and no current or early stage systematic reviews or scoping reviews on the topic were identified. The application of novel pedagogical approaches to embryology instruction is not entirely captured in the published literature. Many of the tools used to create and implement biomedical visualizations in embryology training, education, and scholarship exist as modules on websites, streaming video repositories and individual collections. Some other use cases have been captured in conference proceedings and poster presentations, blogs, and other unpublished literature. In order to map the landscape, the scoping review methodology allows for the fulsome review of all relevant literature sources.

While there are no existing systematic reviews on our topic, the 11th edition of *Biomedical Visualisation* (Abdel Meguid et al. 2022) includes a chapter that provides a historical perspective on embryology teaching resources and methodologies. The authors review evidence-based studies looking at the implementation of said resources and their impact on student learning. The chapter provides much more of a temporal overview and the included literature is analyzed in the framework of the impact on learning whereas our review focuses on the actual tools utilized. Our review has undertaken an exhaustive, replicable search with explicitly stated inclusion and exclusion criteria, and with a focus on biomedical visualization in embryology education, and thus differs in its scope from this previous work. The objective of this scoping review is thus to assess the extent of the literature that captures the vital role biomedical visualizations have in embryology education. In deciphering the state of the literature, the differentiation this review makes between visualization type, teaching environment, and other characteristics will provide novel insights into present applications and future directions of this teaching method in the context of embryology education globally.

6.3 Methods

Creating a search protocol as a critical first step and sharing that protocol with the research community, preferably as an open resource, is recommended best practice for studies such as the present one (Aromataris and Munn 2020). As such, an *a priori* protocol was developed and posted on the Open Science Framework platform (Elliot et al. 2021). This scoping review was conducted using the methodologically rigorous Joanna Briggs Institute (JBI) guideline for scoping reviews (Tricco et al. 2018) and the six-stage methodological framework outlined by Levac et al. (2010), and adheres to the reporting guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). (Tricco et al. 2018).

6.4 Review Question

To assess the current extent of the literature on the use of embryology visualizations in health sciences education, we developed specific inclusion and exclusion criteria. Studies were included in the review if they investigated, reported, or described the use of biomedical visualizations in the teaching of embryology to health professions students. For feasibility, only English-language publications were included. Additional details regarding study eligibility criteria are available in supplemental Appendix I.

6.5 Population, Concept, and Context

Using the Population, Concept, and Context (PCC) strategy for framing research questions (Palaskar 2017; Nishikawa-Pacher 2022), we proceeded as follows:

6.5.1 Population

The population consists of students, researchers, and faculty engaged in health professions education at all levels of study, including undergraduate, graduate, residency in postgraduate specialist training and post-doctoral fellows. Examples of the health professions covered in this review include medicine, nursing, dentistry, genetic counseling, physical therapy, and occupational therapy.

6.5.2 Concept

The concept being examined is biomedical visualizations.

6.5.3 Context

The context of this study is embryology education. This includes all teaching contexts (laboratory, clinical, classroom, etc.) and all geographic locations.

6.6 Operational Definitions & Key Terms

In order to provide an extensive and broad picture of the various biomedical visualizations used in the teaching of embryology, our search strategy and subsequent discussion categorized the multiple visualization methods that have been utilized in teaching. This required operationalizing key terms and defining concepts. The following are key terms and their operational definitions as discussed in this paper.

The phrase biomedical visualization is defined as a multidisciplinary field that draws upon and synthesizes subject matter from a variety of disciplines including the traditional sciences (e.g., anatomy, genetics, physiology), the arts (e.g., graphic design, animation), and computer science. In the context of this manuscript, biomedical visualization refers to the way that a resource—be it digital or non-digital, tangible or intangible, interactive or not, static or dynamic—represents visual information that is used to teach human embryology in an educational setting. Human embryology education is defined in the broadest sense and comprises all educational contexts (e.g., clinical, laboratory, and classroom). Undergraduate medical education (UME) is defined as the traditional four- to six-year professional medical degree; graduate medical education (GME) is defined as postgraduate training such as a residency program. Embryology is also defined in the broadest sense and includes all human development in the prenatal human development period, up to and including transition to newborn. Further to this, the concept of the placenta and the fetal membranes is sometimes considered as part of embryology education and sometimes as separate reproductive supporting tissues. For the purposes of this scoping review, the focus remained on the developing organism and not on the placenta and fetal membranes nor on the parturition process.

6.7 Types of Sources

The review considered all study types including descriptive observational study designs such as case series, individual case reports, and descriptive cross-sectional studies. Further study considerations included randomized controlled trials, non-randomized controlled trials, analytical observational studies including prospective and retrospective cohort studies, case–control studies, and analytical cross-sectional studies. Qualitative studies were also included in any theoretical framework and systematic reviews that met the inclusion criteria were also considered. Finally, text, opinion papers, and conference proceedings (presentations, papers, and posters) were also considered for inclusion in this scoping review.

6.8 Patient and Public Involvement

There was no patient or public involvement in this research.

6.8.1 Search Strategy & Selection Criteria

A health sciences research librarian (VK) with experience conducting systematic literature searches developed a comprehensive literature search strategy for MEDLINE (Ovid) in partnership with the principal investigators and subject experts (KC & OO). This search was peer-reviewed by an independent academic information specialist (JJ) using the Peer Review of Electronic Search Strategies (PRESS) checklist (McGowan et al. 2016) (Appendix II). Once finalized, the search was adapted (including all identified keywords and index terms) for use in the following additional databases: EMBASE (Ovid), CINAHL (EBSCO), ERIC (EBSCO), and Web of Science (University of British Columbia). All search strategies are available in Appendix III. The databases were searched from their inception to October 2022. A search of several gray literature sources (those literature not identified by commercial database searching, both unpublished and difficult to locate) was conducted to identify additional publications. The principal investigators and subject experts (KC & OO) identified relevant associations and the research librarian (VK) identified relevant repositories of educational content and non-commercially published content. Two authors (VK & AH) developed a gray literature search and a separate Google Scholar search in support of gray literature sourcing. Finally, reference lists of reviews on similar topics were searched by AH for additional relevant studies.

6.9 Study/Source of Evidence Selection

Following the search, all identified citations were collated and uploaded into Covidence™, a commercial, web-based software product that is used by researchers to streamline literature and systematic reviews (https://www.covidence.org/). Any duplicates of studies which were generated by the software were removed. Two reviewers (KC & OO) independently reviewed and screened the titles and abstracts of all citations identified by the search strategy using pilot-tested screening forms. Citations identified as potentially relevant or which the reviewers were unclear of its inclusion were eligible for full-text screening. Citations for which the reviewers disagreed received rating by an independent third-party adjudicator and subject expert (JP). Two reviewers (KC & OO) independently reviewed full texts of all included studies and discrepancies were resolved via consensus. The results of the search and the study inclusion process are reported in the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for scoping review (PRISMA-ScR) flow diagram (Fig. 6.1).

6.10 Data Extraction

A data extraction form was developed, and pilot tested independently by reviewers in the team. When required, the form was modified, using an iterative consensus-based process. Extracted data included: study identification, author(s), first author rank, publication year, publication type, study design, country of origin, type of health professions education, model of teaching (classroom, laboratory, clinical, etc.), type of visualization (imaging, videos & animations, XR, mobile apps, 3D-printed models, low-fidelity models, etc.), method of visualization (digital, non-digital, etc.), and whether the visualization was currently in use at the date of publication of the included study, or proposed for future use. Consistent with established scoping review methodology (Peters et al. 2020) we did not appraise the risk of bias of the included studies, nor did we summarize the data quantitatively (meta-analyses). Instead, we synthesized the findings using descriptive statistical analyses (e.g., frequencies and percentages) of the extracted variables and reported using graphs and tables.

6.11 Review Findings/Results

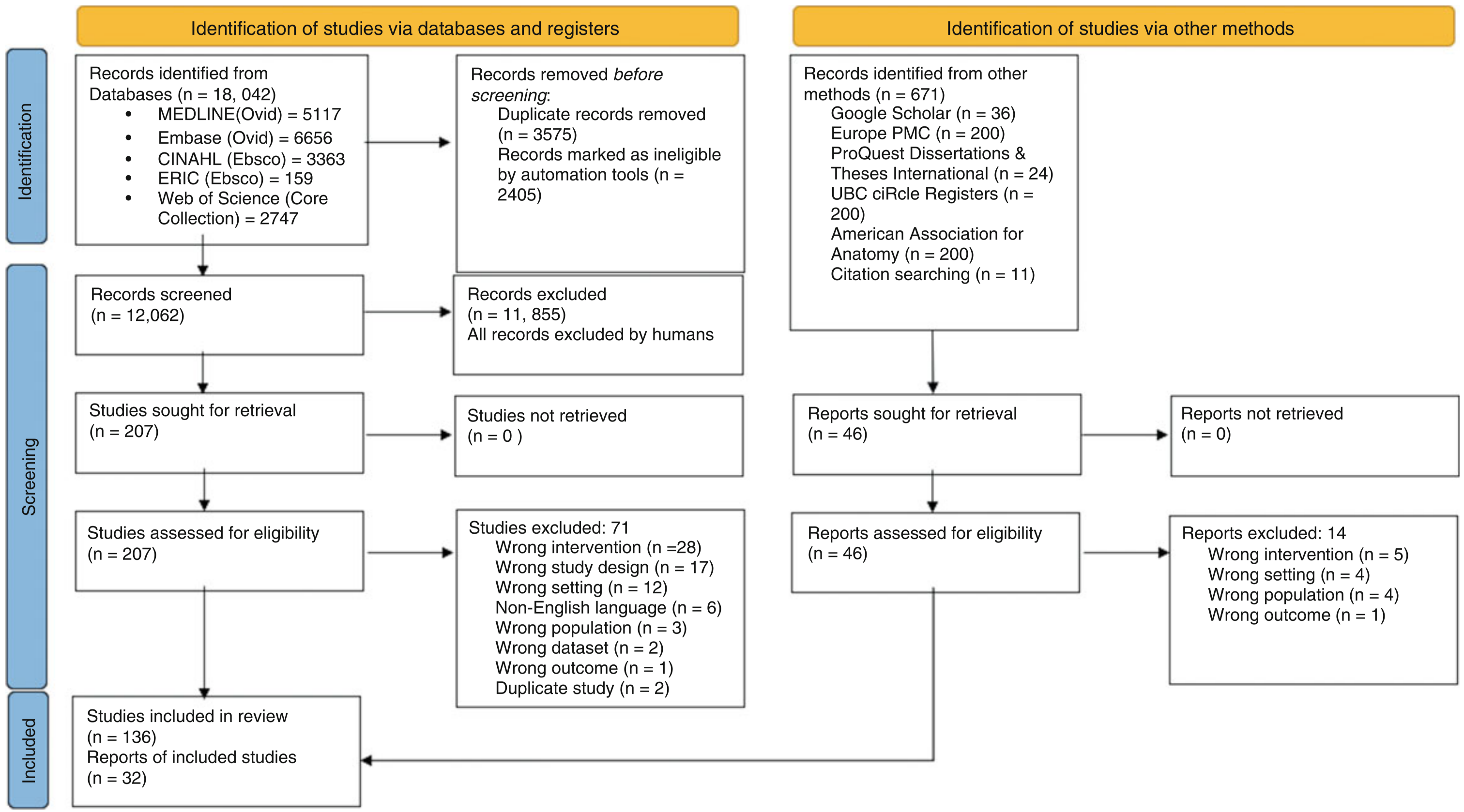
Our literature search identified 12,062 records from the initial database search, of which 136 studies met our inclusion criteria. A further investigation into the gray literature yielded a total of 660 records, of which 21 met our inclusion criteria. A thorough process of performing a citation chain on multiple resources yielded another 11 records, for a total of 168 eligible records for our analysis. A detailed description of the study selection process for this scoping review is depicted using the PRISMA study flow diagram for scoping reviews (Fig. 6.1).

6.12 Study Characteristics

The 168 studies analyzed through this scoping review may be subcategorized in many ways. One is whether they were found in the main literature (136), the gray literature (21), or via citation chaining (11). For the purposes of describing the review findings, all 168 studies will be discussed as a whole.

6.13 Location of Study

Of the 168 studies, there is representation from six of the seven continents and from 30 different countries (Fig. 6.2). Based on continental origin, 66 (39.2%) studies arose from Europe, 65 (38.7%) from North America, 23 (13.7%) from Asia, 8 (4.8%) from Australia, 5 (3%) from South America, and 1 (0.6%) from Africa. To further subdivide these into countries, in Europe the majority of the studies (19, or 11.3%



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;v372:n71. doi: 10.1136/bmj.n71

Fig. 6.1 PRISMA-ScR Flow chart of the literature search undertaken for this study. From an initial 18,042 peer-reviewed studies and 671 other publications from the gray literature, 168 records qualified for inclusion in this study (138 peer-reviewed and 32 other studies)

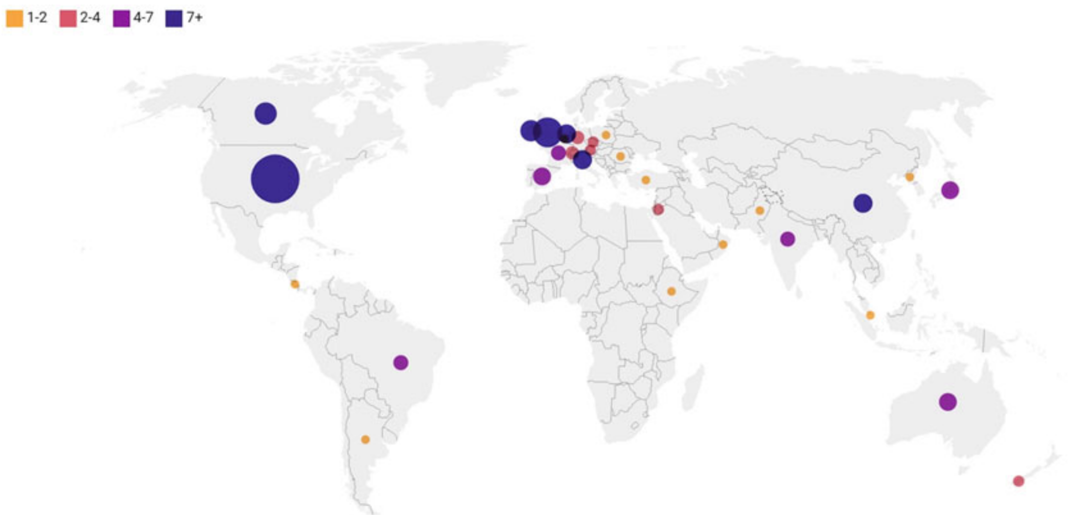


Fig. 6.2 Global distribution of retrieved studies on visualizations in embryology education. The size of each circle is proportional to the number of studies published for that location, also shown by the color of the circles (color legend)

of the total 168) originated in the United Kingdom, followed by Ireland (9, or 5.4% of the total 168)). Italy and the Netherlands both contributed 7 studies (4.2% each); Spain contributed 6 (3.6%); France contributed 4 (2.4%); Germany and Switzerland each provided 3 studies (1.8% each); Austria and the Czech Republic contributed 2 each (1.2% each); and Romania, Poland, Belgium, and Turkey each provided one study (0.6% each). In North America, the United States of America produced 54 (32%) of the included studies, Canada 10 (6%), and Costa Rica 1 (0.6%). In Asia, there were 7 (4.2%) studies originating from China, 6 (3.6%) from Japan, 4 (2.4%) from India, 2 (1.2%) from Jordan, and 1 (0.6% each) each from Singapore, Korea, Pakistan, and Oman. Australia contributed 6 (3.6%) studies while New Zealand provided 2 (1.2%). In South America, Brazil produced 4 (2.4%) studies and Argentina 1 (0.6%). Africa yielded 1 (0.6%) study from Ethiopia.

6.14 Year of Publication

Most of the work regarding biomedical visualization in embryology education has occurred in the twenty-first century, namely post 2010 which accounts for 129 of the 168 studies (Fig. 6.3). The twentieth century accounts for less than ten percent of publications (7.7%, 13 of the 168 studies), with all but 2 occurring in the last decade of that century. The twenty-first century therefore accounts for the vast majority of this work with 155 of the 168 (92.3%) records dealing with biomedical visualizations in embryology education produced during this time. The only years to produce relevant studies in the double-digits were 2018–2022, with 2019 alone yielding 23 studies.

There were single studies produced in 1956, 1977, 1978, 1987, and then 9 in total in the 1990s. The beginning of the new millennium illustrates a dramatic increase in relevant studies about visualizations in embryology education. From 2000–2004, 11 (6.5%) studies were produced, increasing to 28 (16.7%) from 2005–2011, 48 (28.6%) from 2012–2018, and 68 (40.5%) from 2019–2022, the latter number of publications occurring during a four-year, instead

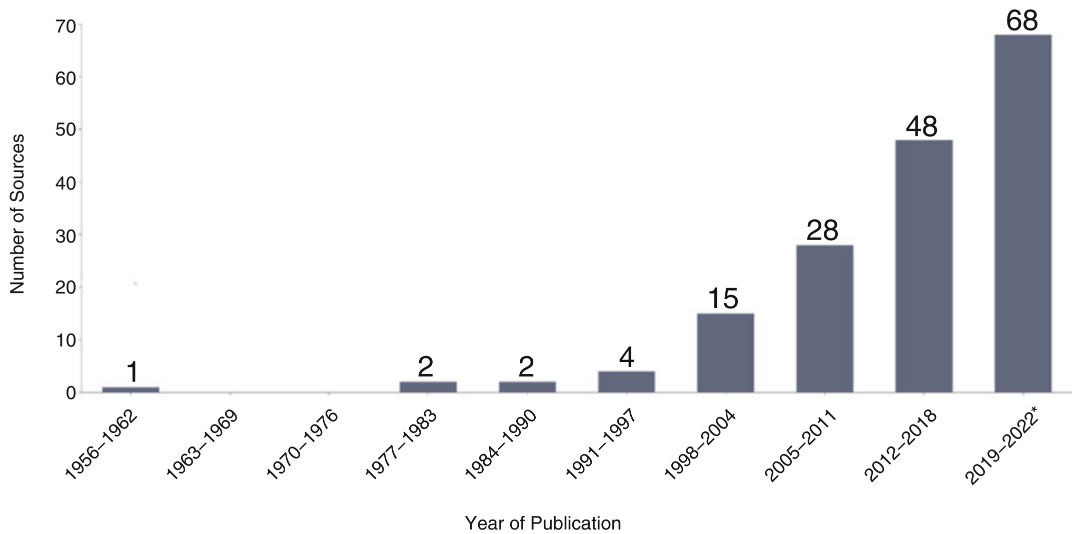


Fig. 6.3 Year of publication of studies included in this study. We found no records of studies investigating biomedical visualizations in embryology education for the years between 1963–1976

of a seven-year interval (Fig. 6.3). In spite of the shortened time frame of the last year interval described, there was still a significant increase in the number of studies published about visualization in embryology education.

6.15 Study Type and Usage

There was a clear trend in the types of studies undertaken regarding biomedical visualization in embryology education. The majority, 124 of 168 (73.8%), were descriptive or observational studies, in which the authors described a method or model of visualization and explained how and when it was used in certain areas of education. The remaining 44 studies (26.2%) were divided into 27 (16.1%) using mixed methods, 12 (7.1%) experimental studies, 3 (1.8%) scoping or systematic reviews, and 2 (1.2%) prospective studies which described visualizations that were still being developed or were soon to be available. At the time of publication of each of these studies, 116 of the described visualizations (69%) were currently being used in some type of educational setting while 52 (31%) were being proposed for educational use in the future.

6.16 Health Professions Educational Setting

The majority of studies focused on non-clinical health professions educational settings, specifically in undergraduate medical education. Of the 168 studies, 111 (66%) described the use of biomedical visualizations in non-clinical embryology education, 27 (16.1%) described usage in clinical education, 11 (6.5%) were used in both non-clinical and clinical educational settings, and 19 (11.3%) did not specify the educational setting in which the visualization was used (Fig. 6.4).

The majority of studies reported the use of biomedical visualizations in non-clinical health professions educational settings. Of the 168 studies, 111 (66%) described visualizations in embryology education in non-clinical settings, 26 (16%) in clinical settings, 12 (7%) in both clinical and non-clinical settings and 19 studies, in which the educational setting was not specified (11%) (Fig. 6.4). Within the prospective health sciences careers for which students were being educated, 72 studies (43%) described the use of embryology visualizations in undergraduate medical education, 13 (8%) in graduate medical education

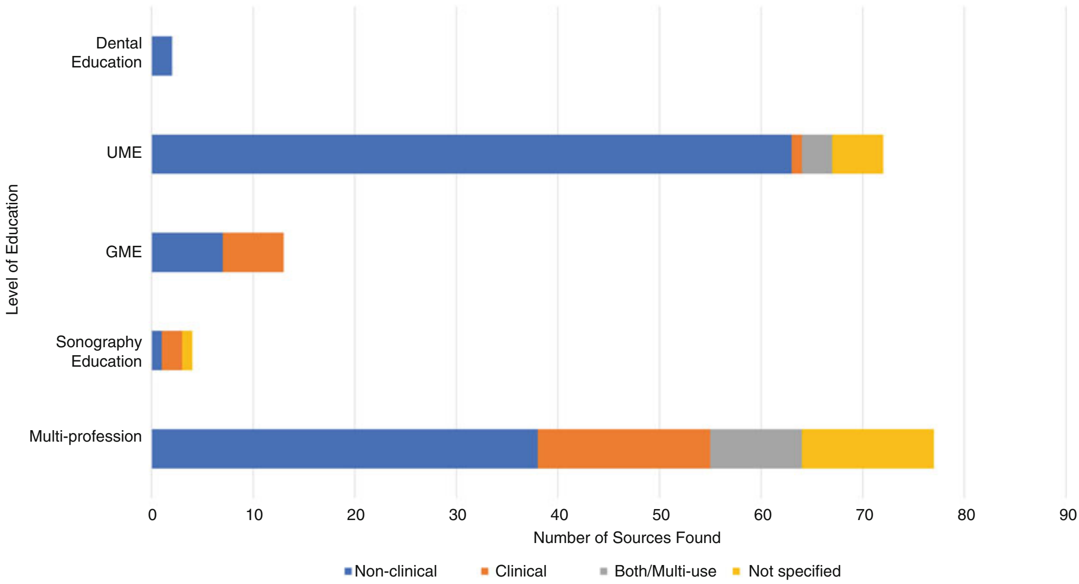


Fig. 6.4 Health professions educational setting in which included studies were performed. UME, Undergraduate Medical Education; GME, Graduate Medical Education. Health professions students were taught in clinical, non-clinical, both clinical and non-clinical as well as multiple (multi-use) contexts, and in contexts that were not specified in the retrieved studies

(e.g., obstetrics and gynecology residency, radiology residency), 4 (2%) in sonography education, 2 (1%) in dental education, and 77(46%) in multiple professional education areas that included at least two of the aforementioned categories (Fig. 6.4).

6.17 Method of Visualization

The biomedical visualizations of embryology in this scoping review included all prenatal stages of the developing human and related tissues: pre-embryonic, embryonic, and fetal. The visualizations are divided into three categories: digital, analog, and both digital and analog. For the purposes of this scoping review, digital visualizations pertain to any resource made with technological interventions such as magnetic resonance imaging (MRI), computed tomography scan (CT), sonographic imaging (US), or interactive online modules. Analog visualizations include resources produced with more historically traditional methods such as modeling clay, drawing, or three-dimensional (3D) printed specimens. The latter visualization is considered analog because our focus in this review is on how the visualization is utilized in teaching and learning embryology (i.e., whether the resource may be handled and manipulated in a tactile manner), rather than on how it was designed or produced (i.e., in the case of 3D-printed resources, with the assistance of computer software technology, among other components). Some of the studies included in this review describe the use of both digital and analog resources in the same educational context, either as a comparative experimental exercise to evaluate the relative impact on embryology learning or simply as a description of the educational resources available within the embryology curriculum. We thus kept the category of "both digital and analog" as a unique category in our review.

Of the 168 studies included in this scoping review, 123 (73%) described the use of digital embryology visualizations, 27 (16%) described analog visualizations, and 18 (11%) focused on both digital and analog embryology visualizations (Fig. 6.5). Studies recounting digital embryology visualization could be subcategorized as describing the use of: videos and animations (52 of 123, or 42%), medical imaging (38 of 123, or 31%), mobile applications (5 of 123, or 4%), multiple digital formats (16 of 123, or 13%), and extended reality platforms (12 of 123, or 10%) (Fig. 6.5). Within the category of studies dealing with the use of analog visualizations for teaching embryology were those describing low-fidelity models such as the use of clay or fabric (13 of 27, or 48%), 3D-printed models (10 of 27, or 37%), and those that used multiple analog formats (4 of 27, or 15%) (Fig. 6.5).

6.18 Discussion

6.18.1 History, Geography, and Economic Divides in the Use of Embryology Visualizations

Anatomical illustrations have a rich but convoluted history, where early attempts to depict human anatomy relied more on religious and philosophical beliefs than on scientific fact (Calkins et al. 1999). From the medically-related sixteenth century illustrations of the Egyptians, Chinese, Indians, and Babylonians to the illustrations of Frank Netter, the *Dean of Modern Medical illustrators*, successive generations of scientists refined anatomical illustrations to emphasize scientific accuracy of the human form (Calkins et al. 1999). The visualization of human embryology and fetal development has continued this tradition, including the famous publication by William Hunter in 1774, *The Anatomy of the Human Gravid Uterus Exhibited in Figures* McCulloch et al. 2002). One of the aims of the present authors was to describe the geographical distribution of the use of visualizations in teaching human fetal development. It is therefore pertinent to note that the historical endeavor to depict early human embryology was not confined to Europe or North America. *Mansur's Anatomy*, the color-illustrated text of Mansur ibn Muhammad of Persia (c.1380–1422) contains descriptions and illustrations of "the formation of the fetus," including that of a gravid uterus with a fetus lying in a breech position (Shoja and Tubbs 2007). In this study, we found that embryological drawings and other forms of visualizations have been used in Health Sciences education across 30 countries spanning almost every continent over the last 67 years. This widespread use of embryology visualization is unsurprising, given that the study of embryology presents a multi-level challenge to learners, educators, and curriculum planners (Abdel Meguid et al. 2022). Thus, the use of multiple modalities of visualizations could be reasonably expected to help, at least in part, ameliorate some of these challenges.

Not only did we find evidence of the widespread utilization of embryology visualization educational resources at the time of writing this review, the rate of increase in the number of studies describing these resources over time was remarkable. There were a total of 13 studies detailing the use of these resources in the approximately 40 years between 1956 and 1999, yet in less than one-quarter of that time in the succeeding years, almost the same number of similar studies had been added to the literature (11 more studies published by 2004) (Fig. 6.3). The number of studies about biomedical visualizations in embryology education more than doubled in the next seven years, growing by an additional 28 studies by 2011, and increasing this number by a further 20 studies, such that over the next seven years (by 2018), 48 additional studies were published (Fig. 6.3). If that rate of increase had remained steady, we would expect the addition of a further 20 studies on embryology visualizations in the next seven years, and the release of 68 more studies by 2025. From the data displayed in Fig. 6.3, it is clear that this number of studies was already attained by 2022—presumably three years ahead of schedule. It appears to be no coincidence that the exponential increase in the reported use of biomedical visualizations for embryology teaching began in the late 1990s around the turn of the millennium. This period marked the rapid development of

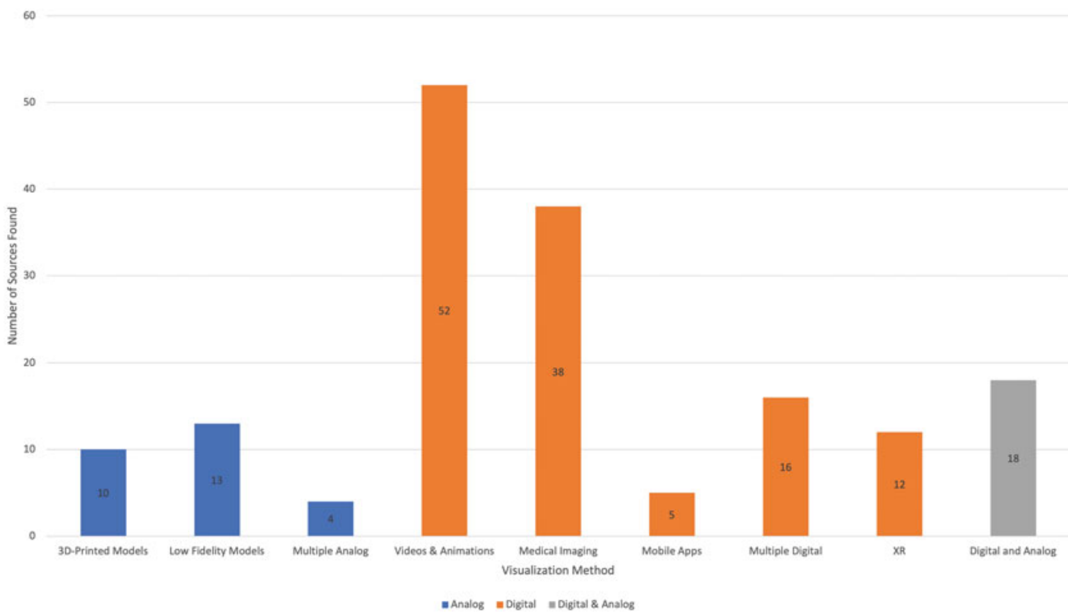


Fig. 6.5 Specific Visualization Types. Digital visualization methods (videos, animations, mobile applications, etc.) formed the predominant resources used for embryology education in this evidence synthesis. Other resources included a variety of physical (analog) resources and combined analog–digital education tools

communication technologies, such as the personal computer, CD-ROM, and digital media (Breivik 1992; Nesbit and Winne 2008).

Our observation of geographical diversity and the increased scholarly activity around the use of visualizations in embryology education from the late 1990s onward presented in this study reflects only part of the story. The counterbalance to these otherwise positive facts, for teachers and learners seeking to expand the use of these visualizations, is the disproportional numbers involved. The United States, Canada, and the countries of Europe together represent nearly 80% of publications described in this study (131 of 168), leaving only about 20% (37 of 168) for the rest of the world. This divide closely mirrors the economic disparity between the Global North and South (citation). Therefore, while the recent exponential increase in the use of biomedical visualizations in the teaching and learning of embryology for the health sciences professions is a potential cause for celebration for educators worldwide, more must be done to ensure that access to these learning resources becomes more equitable and that the situation existing at the time of this review does not continue in perpetuity.

6.18.2 Implications of the Distribution of Embryology Visualizations in Teaching

The evidence map for the use of embryology visualizations in educational settings (Fig. 6.4) underscores the predominant use of these resources in non-clinical settings, particularly for undergraduate medical education (UME). This is perhaps not surprising, given that many authors have stressed the continued relevance of embryology education to medical practice (Scott et al. 2013; Hamilton and Carachi 2014; Qazi et al. 2022), despite the dwindling hours devoted to embryology in medical curricula worldwide (McBride and Drake 2018; Robertson and Oyedele 2019). It is even more encouraging from the perspective of embryology educators that, according to our findings, the preponderance of the use of embryology visualizations among multiple health professions students (e.g., Nursing, Physiotherapy, Genetic Counseling, etc.) come second only to that described for UME. Therefore, it would appear that in the basic sciences education of various health professions students, the use of embryology visualizations continues to maintain a strong presence and is increasing (Fig. 6.4). By contrast, only 16% of the identified studies described the use of embryology visualizations in the clinical setting, including 8% using visualizations for graduate medical education (GME) (Fig. 6.4). An explanation for the relatively low use of these resources in graduate clinical programs may be that the specificity of skills needed in the diverse clinical disciplines largely excludes embryology knowledge. Even for sonography, where one may expect the need for practitioners to learn embryology (and thus heavily use visualizations during training), we found only 2% of identified studies describing visualizations being used in that context. A clue to understanding this apparent paucity of use of visualization resources in these clinical contexts may be garnered from some of the studies identified in our series, which described the development and/or evaluation of the curriculum for training specialist obstetricians/gynecologists (OBGYN). (Abuhamad et al. 2018; Kellerhals et al. 2021) It would appear that while human embryos and fetuses are visualized during the clinical sonographic examination, and while specialist OBGYN must be able to identify certain basic embryonic or fetal anatomical features, the emphasis of specialist OBGYN training in sonography is to be able to detect *sonographic* appearance of abnormalities. In fact, in pointing out the relative ineffectiveness of placing such undue emphasis on identifying fetal anomalies during the ultrasound examination, Benacerraf et al. said: ". . . . majority, if not all, of pregnant women today are offered standard obstetrical scans to rule out major anomalies, and the incidence of congenital anomalies is very low in the general population. With the risk of congenital anomalies at 3–4%, the ultrasound operator can be correct >95% of the time without even turning the ultrasound machine on!" (Benacerraf et al. 2018). The implication for our scoping review is that we may infer that the use of biomedical visualizations for embryology education in postgraduate medical and other clinical settings is mainly as an adjunct to training advanced students in other competencies, which are the real focus of such disciplines. In these situations, embryology education is peripheral or circumstantial, while in the basic science settings, embryology education is core to the curriculum, hence the relatively heavy use of visualization resources in those spheres of education (Fig. 6.4).

6.18.3 Types of Visualizations: Analog, Digital, or Both

In this review, the studies which described the use of digital embryology visualizations for the education of health professions students were approximately five times as many as those describing the use of analog resources. A further tenth of identified studies described the use of both analog and digital visualizations. Given the rapid emergence of digital media and technology described earlier in this chapter, this overwhelming presence of digital embryology education resources would seem to make sense. We were not concerned with the effectiveness of these resources in this study, so we make no assertions about whether digital resources are more effective in teaching embryology than analog resources; however, this should be the subject of future research. It would appear from a cursory examination of studies included in this review that the evidence is somewhat equivocal, even though students report improved interactivity and satisfaction with digital resources (Blezinski et al. 2017; Richardson and Lee 2016; Dueñas et al. 2018). More pertinent is the issue of access to digital embryology visualizations, which tend to require substantial resources (Brenton et al. 2007; Alfalah et al. 2019; Azkue 2021; Abas et al. 2022), and whether in pursuit of the aim of student-centered education, students of embryology at all institutions could be provided with both analog and digital embryology visualizations, allowing students the choice of the visualizations which best suit their preferred learning style (Romanelli et al. 2009; An and Carr 2017; Khamparia and Pandey 2020).

6.19 Limitations

Firstly, while our scoping review provides a comprehensive overview or evidence map of the use of embryology visualizations in training health sciences professionals, it does not provide a reason for, or impact of such utilization of these resources, a question for which a systematic review would be more suited to explore.

Secondly, our evidence map relates to the time that the studies describing the use of these embryology visualization methods were published. Given that significant time can often elapse between conducting research and publication of findings in peer-reviewed journal articles or conference proceedings, the pattern of the use of these resources may have changed between research and publication, or more plausibly, between publication of these reports and the present time. Still, a scoping review is one of the best methodologies available that is designed to "provide a comprehensive assessment of both what is known and where gaps in evidence exist... .. providing opportunities for new research" (Hetrick et al. 2010). As Pham et al. (2014) describe, a scoping review "provides a rigorous and transparent method for mapping areas of research." We believe that this review has provided such a map in the area of research on the use of biomedical visualizations in embryology education.

Thirdly, during the full-text review and data extraction phase, each author relied on their combined knowledge and expertise. Individual perceptions and opinions are based on varying experiences and education and even with double blind review and group consensus, biases occur.

Fourthly, we limited our studies to the English language only. This was based on resources the team had available. The databases searched were also limited to institutional access, and while we are very information privileged at our institutions, with access to the core biomedical and education databases, we did not have access to non-English language repositories and potentially others.

Finally, we may have missed some studies, which could have been included, or may have excluded studies which should have been included. We welcome correspondence from scholars in the field who notice such omissions and offer sincere apologies if any such omissions are discovered in future. We would be encouraged to see other researchers build on and extend this work for the purpose of answering related research questions.

6.20 Implications of the Findings for the Future

We have shown in this scoping review that undergraduate medical education and other health sciences professions historically and currently form the bulk of users of embryology visualizations as part of their basic medical sciences education. The majority of these visualizations are digital in nature, while a significant use is also being made of a combination of digital and non-digital biomedical visualizations. As mentioned earlier, further research would need to explore how effective these resources are in teaching and learning embryology, and what factors might be determining that effectiveness. This would be important to continued development of these resources for teaching human embryonic development, but also as evidence for those scholars who would like to maintain and expand the role of embryology in undergraduate and graduate health sciences curricula (Das et al. 2018; Cassidy 2015; Carlson 2002; Moxham et al. 2016). Another opportunity for further studies lies in exploring the specific content of embryology that is being taught in postgraduate residencies and other clinical contexts. This may help educators to better align undergraduate embryology curriculum as preparation to the clinical competencies that practitioners need to develop in order to provide more informed patient care. Such collaboration between undergraduate and postgraduate teachers is already bearing fruit in other contexts (Wiley et al. 2018; Dehnad et al. 2021; Sharma et al. 2017; Ginzburg et al. 2017) and may well be a much needed catalyst to raising the profile of embryology as an indispensable component of basic and clinical education of health sciences professionals. Finally, educators and researchers looking to investigate different aspects of embryology education or to expand the geographical, professional, or scientific scope of such education may look to this review as a useful and insightful starting point.

6.21 Conclusions

Our study maps historical and current research (in existence at the time of writing), which explore the use of biomedical visualizations for the teaching of embryology to health sciences students. We report in this volume that there was a spike in the number of studies dealing with this topic from 2019 onward; unsurprisingly, given the medical and technological advances of the last decade, a trend that is set to continue at a rapid and somewhat alarming rate (Wu and Ho 2023; Chadha et al. 2022; Chen et al. 2022). A key finding of this scoping review was the evidence map that revealed the geographical skew of the presumed development and use of embryology visualizations (most of which are digital) around the world. This geographical lopsidedness while not surprising, given the divide in economic power and digital resources between rich and poor countries, still comes across as stark and in need of remedy. It could be argued that our study shows that students of health sciences around the world still have access to both analog and digital embryology visualizations, but this argument simply makes the case that in the pursuit of equitable global health sciences education, we should insist on the availability of the same type of resources for embryology students everywhere. Having said this, low-fidelity or analog embryology resources need not be of low quality. In fact, most current teachers of embryology probably remember attending a lecture where a simple but creatively-crafted embryology model was used to bring a concept alive for them. Fieke Neuman and her colleagues at the University of Otago in New Zealand have an exquisite collection of hand-made embryology visualizations, which have been used to educate generations of health sciences professionals (personal communications). Their work is testimony to the adage that sometimes, simple is better—and probably more accessible. In summary, embryology educators should seek to employ whichever visualizations, based on rigorous evidence, prove to be most effective in the education of their students.

Some historical embryology visualizations which form part of the studies retrieved for this paper derive from actual display or drawings of normal and abnormal fetal and embryonic specimens (MacRobbie 2021; Ježová et al. 2008). In the light of the current focus and insistence on ethical acquisition of human specimen, we hope that this review constitutes another reminder that students and teachers of embryology must remain vigilant and give close scrutiny to the provenance of the fetal specimens which they allow to be displayed in their institutions, or which they draw, sketch, study, or reproduce in any way. The American Association for Anatomy has developed detailed positions, careful guidance, and helpful resources on this issue.

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Jessie Poskochil, MGC, CGC. Ms. Poskochil is a licensed and certified genetic counselor at the Munroe-Meyer Institute's Department of Genetic Medicine at the University of Nebraska Medical Center in Omaha, NE, USA. The authors thank her for the valuable assistance during the scoping review full-text analysis.

Prepublication History
Supplemental materials for this review are available online. To view these files, please visit https://osf.io/qw8m3/

Author Contributions
All authors (KC, AH, VK, OO) designed and refined the search strategies for all electronic databases. VK and AH translated searches, designed the gray literature search, managed the data, and created the data extraction form.

KC and OO designed the analysis, performed the title/abstract and full-text screen, performed the analysis, wrote the results, discussion, and composition of the final manuscript. All authors performed the final data extraction. VK documented and reported the methods section and provided methodological guidance. AH interpreted the data and created all data visualizations.

Data Availability Statement
All data relevant to the study are included in the article or uploaded as supplemental information. The following are available: template data collection form, data extracted from included studies; data used for all analyses; database search strategies; gray literature search strategies and results, Peer Review of Electronic Search Strategy (PRESS) form. To view these files, please visit https://osf.io/qw8m3/

Conflicts of interest None declared.

Appendix I

Inclusion Criteria

- English language
- All health professions education—medicine, nursing, dentistry, pharmacy, genetic counseling, occupational therapy, physical therapy, etc.
- Must involve human embryology education
- Any model of teaching (online, classroom, lab, etc.)
- All study types—mixed methods, case study, observational, etc.
- Any theoretical model
- Fellow and resident training
- Both undergraduate and postgraduateExclusion Criteria
- Non-English
- Purely for research; not teaching
- Solely for the treatment of patients; for example, the development of models for surgery where there is a clear lack omission of teaching/models targeted at healthcare (in utero-fetal surgery)

Appendix II

PRESS: Search Submission & Peer-Review Assessment

Search Submission: This Section to Be Filled in by the Searcher

Name of searcher: Olusegun Oyedele E-mail: vanessa.kitchin@ubc.ca

Date submitted: September 8, 2022 Date needed by: earliest convenience

Note to peer reviewers – please enter your information in the Peer-Review Assessment area

Review title:

Show Me: curating the evidence for how teachers visualize embryonic development for health professions students

This search strategy is . . .

x	My PRIMARY (core) database strategy—First time submitting a strategy for search question and database
	My PRIMARY (core) strategy—Follow-up Review NOT the first time submitting a strategy for search question and database. If this is a response to peer review, itemize the changes made to the review suggestions.
	SECONDARY search strategy—First time submitting a strategy for search question and database
	SECONDARY search strategy—NOT the first time submitting a strategy for search question and database. If this is a response to peer review, itemize the changes made to the review suggestions.

Database & Interface

Ovid MEDLINE

Research question

What is the evidence for the use and impact of biomedical visualizations in embryology for the education of health professions students?

PICOS format

PCC

Embryology

Biomedical visualization

Health professions education

Please 'copy and paste' your search strategy below

(exactly as run, including the number of hits per line) *[mandatory]*

Search Line #	Search Query	Results
1[JJ1]	exp embryology/[JJ2]	3577
2	developmental Biology/	2910
3	human development/	3373
4	exp embryonic development[JJ3] /	67026
5	exp fetal development/	100428
6	fetal.mp	381648
7	Fetus*.mp	139645
8	gestation*.mp.	276047
9	Embryolog*~~y~~.mp	204462
10	teratology.mp	1875
11	developmental biology.mp.	11126
12	embryonic development.mp.	52343
13	Gastrulation.mp.	7020
14	Neurulation.mp.	1838
15	Cell Lineage.mp.	35708
16	exp pregnancy/[JJ4]	978465
17	pregnan*.mp.	1098393
18	exp Germ Layers/	28158
19	Germ Layer*~~s~~.mp.	5311
20	or/1-19	1529966
21	data visualization/	553
22	Medical Illustration/[JJ5]	5642
23	exp video-audio media/	38074
24	Video Recording/[JJ6]	27431
25	Models, Anatomic/	20645
26	Models, Educational/[JJ7]	10495
27	Models, Biological/	355553
28	Imaging, Three-Dimensional/	79884
29	Radiography/	325369
30	Ultrasonography/ [JJ8] or Ultrasonography, Prenatal/	230921
31	Computer-Assisted Instruction/	12441
32	Software/[JJ9]	121465
33	computer simulation/[JJ10]	206362
34	augmented reality/	902
35	virtual reality/	4723
36	haptic technology/[JJ11]	96
37	Mobile Applications/	10492
38	Computer Graphics/	14632
39	visuali?ation.mp.	109031
40	Medical Illustration*1.mp.	5706
41	((anatom* or biological or education*) adj1[JJ12] model*).mp.	390903
42	((three-dimensional or 3D [JJ13] or two-dimensional or 2D) adj1 (imaging or print*).mp.	86457
43	animation*.mp.	2675
44	video*.mp.	169204
45	Radiograph*~~y~~.mp.	432600
46	ultrasonography.mp.	354718
47	Software*.mp.	297786
48	computer simulation*.mp.	213493
49	augmented reality.mp.	3695
50	virtual reality.mp.	15897
51	VR.tw.	10822
52	haptic technology.mp[JJ14] .	169
53	Mobile Application*.mp.	13423
54	app.mp.	35687
55	apps.mp.	10058
56	Computer Graphic*.mp.	16118
57	interactive module*.mp.	140
58	Anatomy, Artistic/	1201
59	or/21-58	1953882
60	Curriculum/[JJ15]	84186
61	Learning/	76645
62	Schools, Medical/	27487
63	curricul*.mp.	108179
64	learn*.mp.	627500
65	medical school*.mp.	38937
66	Education*.mp.	1017451
67	Education/[JJ16]	21503
68	Teaching/ or Teaching Materials/ [JJ17]	57020
69	teach*.mp.	262244
70	(classroom* or lecture* or coursework).mp.	60995
71	(course* adj3 (education* or embryology or developmental biology)).mp.	4694
72	Education, Nursing/[JJ18]	34269
73	Students, Health Occupations/	3290
74	((physical therap* or physiotherapy or occupational therap* or midwifery or physician* assistant or allied health) adj2 (education or student*)).mp.	15343
75	Genetic Counseling/	5989
76	or/60-75	1712825
77	20 and 59 and 76	4937

Peer-Review Assessment: This Section to Be Filled in by the Reviewer

Statement of Confidentiality

I agree to hold all the information contained in this worksheet and submission form as confidential and understand that materials may not be shared outside PRESSforum or used for any competing purpose without the written permission of the librarian who submitted the search for peer review.

Type "yes" to indicate agreement):__yes__

Peer Reviewer's name: Jane Jun

Email: jane.jun@ubc.ca

Date completed: 09.12.2022

Please select the one most appropriate answer for each element

	No revisions	Revision (s) suggested	Revision (s) required
1. Translation of research question	x		
2. Boolean & proximity operators		x	
3. Subject headings			x[JJ19]
4. Text word searching		x	
5. Spelling, syntax & line numbers	x		
6. Limits and filters		x	
Overall evaluation[a]		x	

[a]If one or more "revision(s) required" is noted above, overall evaluation must be "revision(s) required"

Additional comments:

Most comments are in-line!

Suggestion: instead of .mp., using .tw (MeSH is already comprehensive)

Suggested additional subject headings:

(a) Printing, Three-Dimensional/
(b) Animation/
(c) exp Regional Health Planning(?)

Alternatively: Regional Medical Programs/

Suggested additional text words:

(a) (moulage* OR manikin* OR mannequin*)
(b) haptic*
(c) (seminar* OR conference*)
(d) "smartphone app*"
(e) "prenatal genetic counseling"

Filter Human(?)

[JJ1]include embryology as a floating subheading on its own line (e.g., embryology.fs)

[JJ2]embryology/is already exploded under line 2 developmental biology

[JJ3]Lines 4 and 5 can be combined into exp "Embryonic and Fetal Development"/

[JJ4]Should you NOT "pregnancy, animal"/? or suggesting removal if this may be bringing in a lot of irrelevant results

[JJ5]Explode?

[JJ6]Explode?

[JJ7]Possibly irrelevant to goal of the study? Scope note: Theoretical models which propose methods of learning or teaching as a basis or adjunct to changes in attitude or behavior. These educational interventions are usually applied in the fields of health and patient education but are not restricted to patient care.

[JJ8]Since there is a more specific SH, could choose to omit unless using embryology.fs

[JJ9]Include hypermedia/ ?

[JJ10]Lines 34 and 35 can be combined by exploding line 33

[JJ11]Is the study only looking for visual? Or is there interest in haptics? Suggesting: is a more specific heading under haptic technology better?

[JJ12]Adj3 to include 'model of anatomy', 'model for higher education', 'biological effectiveness model', 'model for investigating biological _' etc.

[JJ13] [JJ13]Include 3-D and 2-D + use imag*3 instead of imaging

[JJ14]Refer to line 36 comment

[JJ15]Explode?

[JJ16]Could add another line for education.fs and/or explore under the education/ subheadings for more specific ones for relevance?

[JJ17]Is there a reason Teaching/ is not exploded under Education/ + could include Hospitals, Teaching/?

[JJ18]Explode?

[JJ19]Floating subheadings

Appendix III

Search Strategies

Database: Ovid MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed Citations,

Daily and Versions <1946 to October 20, 2022>

Search Strategy:

Search Line #	Search Query	Results
1	exp embryology/	3585
2	embryology.fs	197171
3	developmental biology/	2910
4	human development/	3373
5	exp "Embryonic and Fetal Development"/	398628
6	Fetal.tw, kf.	270954
7	Fetus*.tw, kf.	118994
8	gestation*.tw, kf.	242965
9	Embryolog*.tw, kf.	19942
10	teratology.tw, kf.	1875
11	developmental biology.tw, kf.	9767
12	embryonic development.tw, kf.	47466
13	Gastrulation.tw, kf.	6873
14	Neurulation.tw, kf.	1769
15	Cell Lineage.tw, kf.	12846
16	exp pregnancy/	978465
17	maternal-fetal exchange/	30087
18	placentation/	3097
19	placentation.tw,kf.	4769
20	pregnan*.tw,kf.	601616
21	exp Germ Layers/	28373
22	germ layer*.tw,kf.	5115
23	or/1-22	1628328
24	data visualization/	604
25	Exp Medical Illustration/	6272
26	Anatomy, Artistic/	1201
27	exp video-audio media/	38074
28	exp Video Recording/	44435
29	Models, Anatomic/	20645
30	Models, Educational/	10495
31	Models, Biological/	355553
32	Imaging, Three-Dimensional/	79884
33	Radiography/	325369
34	Ultrasonography/ or Ultrasonography, Prenatal/	230921
35	Computer-Assisted Instruction/	12441
36	Software/	121465
37	computer simulation/	206362
38	augmented reality/	902
39	virtual reality/	4723
40	haptic technology/	96
41	Mobile Applications/	10492
42	hypermedia/	405
43	Computer Graphics/	14632
44	visuali?ation.tw, kf.	109031
45	Medical Illustration*1.tw, kf.	5706
46	((anatom* or biological or education*) adj1[JJ12] model*).tw, kf.	390903
47	((three-dimensional or 3D or two-dimensional or 2D or 3-D or 2-D) adj2 (imag*3 or print*).tw, kf.	64451
48	animation*.tw, kf.	2675
49	video*.tw, kf.	164377
50	Radiograph*.tw, kf.	268004
51	ultrasonography.tw, kf.	108104
52	software*.tw, kf.	227278
53	computer simulation*.tw, kf.	26861
54	augmented reality.tw, kf.	3695
55	virtual reality.tw, kf.	15897
56	VR.tw, kf.	10822
57	haptic technology.tw, kf.	82
58	Mobile Application*.tw, kf.	5653
59	app.tw, kf.	35687
60	apps.tw, kf.	10058
61	Computer Graphic*.tw, kf.	2156
62	interactive module*.tw, kf.	140
63	Gamification.tw, kf.	1278
64	or/24-63	1953882
65	exp Curriculum/	97296
66	Learning/	76645
67	Schools, Medical/	27487
68	curricul*.tw, kf.	108179
69	Education, Medical/	60747
70	Students, Medical/	42622
71	Education, Pharmacy/	7270
72	Education, Dental/ or Education, Dental, Graduate/	17270
73	learn*.tw, kf.	583692
74	medical school*.tw, kf.	38937
75	Education*.tw, kf.	597156
76	Education/	21503
77	Teaching/ or Teaching Materials/	57020
78	teach*.tw, kf.	229488
79	(classroom* or lecture* or coursework or seminar or conference).tw, kf.	133600

(continued)

Search Line #	Search Query	Results
80	(course* adj3 (embryology or developmental biology)).tw, kf.	54
81	Education, Nursing/	34269
82	Students, Health Occupations/	3290
83	((physical therap* or physiotherapy or occupational therap* or midwifery or physician* assistant or allied health or genetic counseling) adj2 (education or student*)).tw, kf.	15343
84	Genetic Counseling/	5989
85	or/65-84	1712825
86	23 and 64 and 85	5117

Database: Embase <1974 to 2022 October 19>

Search Strategy:

Search Line #	Search Query	Results
1	exp developmental biology/	29057
2	human development/	5272
3	prenatal development/	39262
4	"embryonic and fetal functions"/	92
5	embryo development/	100428
6	fetus development/	20262
7	pregnancy/	657318
8	teratology/	4803
9	mother fetus relationship/	3725
10	placenta development/	6130
11	"embryo (anatomy)"/	1231
12	fetal.tw,kf.	340199
13	fetus*.tw,kf.	145882
14	gestation*.tw,kf	331429
15	teratology.tw,kf.	2788
16	development* biology.tw,kf.	9260
17	embryonic development.tw,kf.	39492
18	gastrulation.tw,kf.	7582
19	neurulation.tw,kf.	2037
20	cell lineage.tw,kf.	1529966
21	pregnan*.tw,kf	738127
22	placentation.tw,kf.	6685
23	germ layer*.tw,kf.	5944
24	or/1-23	1441378
25	medical illustration/	3781
26	videorecording/	108520
27	anatomic model/	3814
28	educational model/	8814
29	biological model/	195350
30	three-dimensional imaging/	109388
31	exp fetus echography/	30364
32	radiography/	200289
33	high frequency ultrasound/	903
34	interventional ultrasonography/	5178
35	software/	105491
36	biomedical software/	2864
37	hypermedia/	399
38	computer simulation/	133788
39	augmented reality/	902
40	virtual reality/	4723
41	haptic technology/	21
42	Mobile Application/	19157
43	gamification/	205
44	Computer Graphics/	10928
45	visuali?ation.tw, kf.	145238
46	Medical Illustrat*.tw, kf.	554
47	((anatom* or biological or education*) adj1 (render* OR model*).tw, kf.	29142
48	((three-dimensional or 3D or two-dimensional or 2D or 3-D or 2-D) adj1 (imag* or print*).tw, kf.	76003
49	animation*.tw, kf.	4910
50	video*.tw, kf.	225871
51	Radiograph*.tw, kf.	306520
52	ultrasonography.tw, kf.	156608
53	Software.tw, kf.	359481
54	computer simulation*.tw, kf.	27629
55	augmented reality.tw, kf.	4281
56	virtual reality.tw, kf.	19199
57	VR.tw.	16071
58	haptic technology.tw, kf	90
59	Mobile Application*.tw, kf.	6729
60	app.tw, kf.	48528
61	apps.tw, kf.	12002
62	computer graphic*.tw, kf.	2366
63	interactive module*.tw, kf.	268
64	gamification.tw,kf.	1192
65	or/25-64	1894699
66	education/	463455
67	curriculum development/	5341
6	Curriculum/[JJ15]	100063
61	Learning/	232925
62	medical school/	66996
63	medical education/	242480
64	dental education/	20115
65	pharmacy education/	724
66	teaching/	102486
67	nursing education/	87215
68	health student/	1759

(continued)

Search Line #	Search Query	Results
69	medical student/	83576
70	genetic counseling/	37229
71	curriculum.tw,kf.	70074
72	learn*.tw,kf.	705260
73	medical school*.tw,kf	45866
74	education.tw,kf.	746871
75	(classroom* or lecture* or coursework or seminar* or conference*).tw,kf.	186886
76	((embryology or developmental biology) adj3 course*).tw,kf.	94
77	teach*.tw,kf.	291224
78	((physical therap* or physiotherapy or pharmacy or dentistry or occupational therap* or midwifery or physician* assistant or health or medic* or nursing or genetic counsel?ing) adj2 (education or student*)).tw,kf.	245151
79	or/66-76	1712825
80	24 and 65 and 79	6656

Web of Science Core Collection

University of British Columbia Institutional Access

October 20, 2022

Search Strategy:

(TS)=((embryolog* or "Developmental Biol ogy" OR "Human Development" OR "Fetal Development" OR "embryonic development" or fetal Or fetus* or gestation* OR teratology OR gastrulation OR neurulation OR cell lineage OR pregnan* OR placentation OR germ layer* (Topic) and visuali?ation* OR "Medical Illustra tion*" OR animation* OR video* OR radio graph* OR ultrasonography OR software OR "computer simulation*" OR "augmented reality" OR "virtual reality" or VR or "haptic technology" OR "Mobile Application*" OR app OR apps OR "Computer Graphic*" OR "interactive module*" OR gamification or (anatom* or biolog* or education*) NEAR/3 (model* OR render*) OR (three-dimensional or 3D or two-dimensional or 2D or 3-D or 2-D) NEAR/2 (imag*3 or print*) (Topic) and Curriculum OR learn* OR education OR teach* or classroom* or lecture* or coursework or seminar or conference or (embryol ogy or "developmental biology") NEAR/ 2 (course*) or ("physical therap*" or physiother apy or "genetic counsel?ing" or dentistry or "occupational therap*" or midwifery or "physi cian* assistant" or medic* or nursing or health) NEAR/2 (education or student* or school*)) (Topic) = 2747

References

Abas R, Mohamad Asri SF, Saat A, Mohd Nor NH, Hod R, Mohd Nizam DN, Omar NS (2022) A review of multimedia usage in embryology education. Asia-Pacific J Inf Technol Multimed 11(1)

Abdel Meguid EM, Holland JC, Keenan ID, Mishall P (2022) Exploring visualisation for embryology education: a twenty-first-century perspective. In: Biomedical visualisation, vol 11. Springer International Publishing, Cham, pp 173–193

Abuhamad A, Minton KK, Benson CB, Chudleigh T, Crites L, Doubilet PM, Driggers R, Lee W, Mann KV, Perez JJ, Rose NC, Simpson LL, Tabor A, Benacerraf BR (2018) Obstetric and gynecologic ultrasound curriculum and competency assessment in residency training programs: consensus report. Am J Obstet Gynecol 218(1):29–67. https://doi.org/10.1016/j.ajog.2017.10.016

Alfalah SF, Falah JF, Alfalah T, Elfalah M, Muhaidat N, Falah O (2019) A comparative study between a virtual reality heart anatomy system and traditional medical teaching modalities. Virtual Reality 23:229–234

An D, Carr M (2017) Learning styles theory fails to explain learning and achievement: recommendations for alternative approaches. Personal Individ Differ 116(Journal Article):410–416. https://doi.org/10.1016/j.paid.2017.04.050

Aromataris E, Munn Z (eds) JBI manual for evidence synthesis. JBI, 2020. Available from https://synthesismanual.jbi.global. https://doi.org/10.46658/JBIMES-20-01

Azkue JJ (2021) External surface anatomy of the postfolding human embryo: computer-aided, three-dimensional reconstruction of printable digital specimens. J Anat 239(6):1438–1451

Benacerraf BR, Minton KK, Benson CB, Bromley BS, Coley BD, Doubilet PM, Lee W, Maslak SH, Pellerito JS, Perez JJ, Savitsky E, Scarborough NA, Wax J, Abuhamad AZ (2018) Proceedings: beyond ultrasound first forum on improving the quality of ultrasound imaging in obstetrics and gynecology. Am J Obstet Gynecol 218(1):19–28. https://doi.org/10.1016/j.ajog.2017.06.033

Blezinski B, Richardson A, Lee LM (2017) To model or not to model embryonic heart development, that is the educational question. FASEB J 31:736–731

Breivik PS (1992) Education for the information age. N Dir High Educ 1992:5–13. https://doi.org/10.1002/he.36919927803
Brenton H, Hernandez J, Bello F, Strutton P, Purkayastha S, Firth T, Darzi A (2007) Using multimedia and Web3D to enhance anatomy teaching. Comput Educ 49(1):32–53
Calkins CM, Franciosi JP, Kolesari GL (1999) Human anatomical science and illustration: the origin of two inseparable disciplines. Clin Anat 12(2):120–129
Carlson BM (2002) Embryology in the medical curriculum. Anat Record 269(2):89–98. https://doi.org/10.1002/ar.10075
Cassidy K (2015) Embryology in the medical curriculum: the perceptions and opinions of current anatomy faculty. FASEB J 29:695–691. https://doi.org/10.1096/fasebj.29.1_supplement.695.1
Chadha U, Abrol A, Vora NP, Tiwari A, Shanker SK, Selvaraj SK (2022) Performance evaluation of 3D printing technologies: a review, recent advances, current challenges, and future directions. Progr Addit Manufactur 7(5):853–886. https://doi.org/10.1007/s40964-021-00257-4
Chen X, Wang X, Zhang K, Fung K-M, Thai TC, Moore K, Mannel RS, Liu H, Zheng B, Qiu Y (2022) Recent advances and clinical applications of deep learning in medical image analysis. Med Image Anal 79(Journal Article):102444–102444. https://doi.org/10.1016/j.media.2022.102444
Das M, Claeson KM, Lowrie DJ, Bolender DL, Fredieu JR, Guttmann G, Conway ML, Ghosh T, Edmondson AC, Cork RJ, Rengasamy P (2018) A guide to competencies, educational goals, and learning objectives for teaching human embryology in an undergraduate medical education setting. Med Sci Educ 28:417–428. https://doi.org/10.1007/s40670-018-0542-5
Dehnad A, Jalali M, Shahabi S, Mojgani P, Bigdeli S (2021) Students' view on supportive co-teaching in medical sciences: a systematic review. BMC Med Educ 21:1–3. https://doi.org/10.1186/s12909-021-02958
Dueñas AN, Stratford J, Salcedo E, Blezinski B, Lee LM (2018) Can 3D printed and virtual whole embryo models save embryology education? FASEB J 32: 508.14-508.14. https://doi.org/10.1096/fasebj.2018.32.1_supplement.508.14
Elliott F, Errington TM, Bagby C, et al (2021) OSF. osf.io/4znzp
Evans DJR (2011) Using embryology screencasts: a useful addition to the student learning experience? Anat Sci Educ 4(2):57–63. https://doi.org/10.1002/ase.209
Fakoya FA, Emmanouil-Nikoloussi E, Sharma D, Moxham BJ (2017). A core syllabus for the teaching of embryology and teratology to medical students: embryology core syllabus. Clin Anat (New York, NY.), 30(2), 159–167. doi:https://doi.org/10.1002/ca.22802
Ginzburg SB, Brenner J, Cassara M, Kwiatkowski T, Willey JM (2017) Contextualizing the relevance of basic sciences: small-group simulation with debrief for first-and second-year medical students in an integrated curriculum. Adv Med Educ Pract 8:79–84
Guo Y, Liu H, Hao A, Liu S, Zhang X, Liu H (2022) Blended learning model via small private online course improves active learning and academic performance of embryology. Clin Anat (New York, NY) 35(2): 211–221. https://doi.org/10.1002/ca.23818
Hamilton J, Carachi R (2014) Clinical embryology: is there still a place in medical schools today? Scott Med J 59(4):188–192. https://doi.org/10.1177/0036933014550953
Hetrick SE, Parker AG, Callahan P, Purcell R (2010) Evidence mapping: illustrating an emerging methodology to improve evidence-based practice in youth mental health. J Eval Clin Pract 16(6):1025–1030. https://doi.org/10.1111/j.1365-2753.2008.01112.x
Ježová M, Múčková K, Souček O et al (2008) Hypertext atlas of fetal and neonatal pathology. Diagn Pathol 3 (Suppl 1):S9. https://doi.org/10.1186/1746-1596-3-S1-S9
Kellerhals S, Badell M, Arluck J (2021) 549 Evaluating use of ultrasound simulation to meet recommended obstetric ultrasound goals in residency. Am J Obstet Gynecol 224(2):S347–S347. https://doi.org/10.1016/j.ajog.2020.12.570
Khamparia A, Pandey B (2020) Association of learning styles with different e-learning problems: a systematic review and classification. Educ Inf Technol 25(2): 1303–1331. https://doi.org/10.1007/s10639-019-10028-y
Levac D, Colquhoun H, O'Brien KK (2010) Scoping studies: advancing the methodology. Implement Sci IS 5(1):69–69. https://doi.org/10.1186/1748-5908-5-69
MacRobbie C (2021) The embryonic re-development of an anatomy museum: visualising anatomical collections: human female reproductive anatomy and biology and foetal development. In: Advances in experimental medicine and biology, vol 1334. Springer, pp 81–111. https://doi.org/10.1007/978-3-030-76951-2_5
McBride JM, Drake RL (2018) National survey on anatomical sciences in medical education. Anat Sci Educ 11(1):7–14
McCulloch NA, Russell D, McDonald SW (2002) William Hunter's Gravid Uterus: the specimens and plates. Clin Anat: Off J Am Assoc Clin Anatomists Br Assoc Clin Anatomists 15(4):253–262
McGowan J, Sampson M, Salzwedel DM et al (2016) PRESS peer review of electronic search strategies: 2015 guideline statement. J Clin Epidemiol 75: S0895-4356(16)00058-5:40-6
Moxham BJ, Emmanouil-Nikoloussi E, Standley H, Brenner E, Plaisant O, Brichova H, Pais D, Stabile I, Borg J, Chirculescu A (2016) The attitudes of medical students in Europe toward the clinical importance of

embryology. Clin Anat 29(2):144–150. https://doi.org/10.1002/ca.22667

Nesbit JC, Winne PH (2008) Tools for learning in an information society. In: Willoughby T, Wood E (eds) Children's learning in a digital world, vol 1–Book, Section. Blackwell Publishing, pp 173–195. https://doi.org/10.1002/9780470696682.ch7

Nishikawa-Pacher A (2022) Research questions with PICO: a universal mnemonic. Publications (Basel) 10(3):21. https://doi.org/10.3390/publications10030021

Palaskar J (2017) Framing the research question using PICO strategy. J Dental Allied Sci 6(2):55–55. https://doi.org/10.4103/jdas.jdas_46_17

Peters MD, Marnie C, Tricco AC, Pollock D, Munn Z, Alexander L et al (2020) Updated methodological guidance for the conduct of scoping reviews. JBI Evid Synth 18(10):2119–2126

Pham MT, Rajić A, Greig JD, Sargeant JM, Papadopoulos A, McEwen SA (2014) A scoping review of scoping reviews: advancing the approach and enhancing the consistency. Res Synth Methods 5(4):371–385. https://doi.org/10.1002/jrsm.1123

Plunkett C, Dueñas A, Stratford J, Leppek N, Lee LM (2019) Embryos in gross anatomy laboratory? The educational impact of 3D printed embryo model integration in medical basic sciences education. FASEB J 33(S1):17.1. https://doi.org/10.1096/fasebj.2019.33.1_supplement.17.1

Qazi E, Wilting J, Patel NR, Alenezi AO, Kennedy SA, Tan KT, Jaberi A, Mafeld S (2022) Arteries of the lower limb—embryology, variations, and clinical significance. Can Assoc Radiol J 73(1):259–270. https://doi.org/10.1177/08465371211003860

Richardson A, Lee LM (2016) Utility of virtual 3D animations and 3D printed models of heart development in graduate embryology education. FASEB J 30:568.20. https://doi.org/10.1096/fasebj.30.1_supplement.568.20

Robertson AB, Oyedele O (2019) The decline of embryology instruction within medical schools worldwide: options for adapting. UBC Med J 10:39–40

Romanelli F, Bird E, Ryan M (2009) Learning styles: a review of theory, application, and best practices. Am J Pharm Educ 73(1):9–9. https://doi.org/10.5688/aj730109

Scott KM, Charles AR, Holland AJA (2013) Clinical embryology teaching: is it relevant anymore?: Clinical embryology. ANZ J Surg, Journal Article, n/a–n/a https://doi.org/10.1111/ans.12213

Sharma S, Ali A, Takhelmayum R, Mahto M, Nair R (2017) Co-teaching: exploring an alternative for integrated curriculum. J Natl Med Assoc 109(2):93–97. https://doi.org/10.1016/j.jnma.2017.02.002

Shoja MM, Tubbs RS (2007) The history of anatomy in Persia. J Anat 210(4):359–378

Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, Hempel S, Akl EA, Chang C, McGowan J, Stewart L, Hartling L, Aldcroft A, Wilson MG, Garritty C et al (2018) PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 169(7):467–473. https://doi.org/10.7326/M18-0850

Willey JM, Lim YS, Kwiatkowski T (2018) Modeling integration: co-teaching basic and clinical sciences medicine in the classroom. Adv Med Educ Pract 9:739–751. https://doi.org/10.2147/AMEP.S169740

Wu T-C, Ho C-TB (2023) A scoping review of metaverse in emergency medicine. Austr Emerg Care 26(1):75–83. https://doi.org/10.1016/j.auec.2022.08.002

Yamada S, Uwabe C, Nakatsu-Komatsu T, Minekura Y, Iwakura M, Motoki T, Nishimiya K, Iiyama M, Kakusho K, Minoh M, Mizuta S, Matsuda T, Matsuda Y, Haishi T, Kose K, Fujii S, Shiota K (2006) Graphic and movie illustrations of human prenatal development and their application to embryological education based on the human embryo specimens in the Kyoto collection. Dev Dyn 235(2):468–477. https://doi.org/10.1002/dvdy.20647

A Framework for the Design, Production, and Evaluation of Scientific Visualizations

7

Ke Er Zhang, Shehryar Saharan, Gaël McGill, and Jodie Jenkinson

Abstract

Visualizations play a critical role in discovering, understanding, interpreting, synthesizing, and communicating scientific knowledge. Effective scientific visualization requires careful attention to a number of factors, in particular, a faithful translation of scientific evidence, understanding of the communication needs of the target audience, and skillful application of visualization design principles. As a result, science visualization projects require a team of contributors with specialized knowledge and technical expertise. Regardless of team size and structure, a clear definition and appreciation of the design process as well as an understanding of the responsibilities of each contributor are imperative to the success of a project. Gaps in understanding often result in conflict between visualizers and stakeholders, compromising the quality of the scientific visualization.

Although many companies have developed their own process through trial and error over years of experience, to date, there is no formalized framework for scientific visualization that details the steps of the process and the contributions of each individual. Informed by our examination of case studies, frameworks, and our collective experience as practitioners, we propose a framework tailored to the design, production, and evaluation of scientific visualization that aims to support practitioners in

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meeting their objectives and facilitating conversations that allow others to better understand the impact of the design process on the final product. We explore underlying drivers of decision-making within the visualization design space, describe the activities and outputs that impact decisions made about the final visualization, and discuss potential applications and limitations of this framework in practice.

Keywords

Scientific visualization · Multimedia production · Framework · Design process · Design decisions

7.1 Introduction

Visualizations (illustrations, three-dimensional models, animations, simulations, multimedia, etc.) play a critical role in discovering, understanding, interpreting, synthesizing, and communicating scientific knowledge (Evagorou et al. 2015; Goodsell and Jenkinson 2018; Lynch 2006; McGill 2022; Reilly and Ingber 2017). An integral part of the scientific process, visualizations contribute to conceptual understanding, scientific reasoning, and knowledge discovery. In addition, visualization plays an essential role in science education (Schönborn and Anderson 2006) both formally and informally, and in public outreach (Trumbo 1999).

Whatever the goal or intended target audience, communication is critical to the research enterprise and a central component in fostering trust within the scientific community (Evagarou et al. 2015). In the age of digital communication, scientific visualization has played an increasingly large role in translating scientific findings for the general public and building trust between science and society (Roche et al. 2021). From beautiful imagery of never-before-seen phenomena to detailed representations and animated narratives, visualization has become commonplace in popular culture and has a pervasive influence on the public's awareness of science (Bucchi and Saracino 2016; Landau et al. 2008).

When we consider the components of a successful visualization, at its core is clear and faithful translation of scientific evidence accompanied by an understanding of the communication needs of the intended target audience (Torsani et al. 2020). These components are intrinsically linked, with the success of one wholly dependent upon the other. Effective visualization is also contingent upon shared understanding of communication goals as well as the process underlying the development of visualizations. A gap in understanding can result in conflict, miscommunication, and/or lack of trust between visualizers, stakeholders, and other project partners (McGill 2017). This can compromise the quality of the scientific visualization and ability of the final product to serve the needs of the target audience.

The design of visualizations may involve a team of one or it may require a large, interdisciplinary team of researchers, visualizers, developers, user experience (UX) and user interface (UI) designers, evaluators, subject matter experts, and managers facilitating interactions between all parties. Regardless of team structure, a clear definition and appreciation of the design process as well as an understanding of the responsibilities of each contributor is imperative to the success of the project. Although many groups and companies have developed their own process through trial and error over years of experience with scientific visualization, to date, there is no formalized framework for scientific visualization that establishes the steps of the visualization process and the contributions of each individual.

In this chapter, we review scientific visualization case studies that span a number of modalities and contexts-of-use, and examine a number of frameworks related to the design of visualizations. We explore the many underlying drivers of decision-making within the visualization design space, and how activities and outputs created throughout the design process impact decisions made about the final visualization. Informed by our examination of case studies, frameworks, and our collective experience as practitioners, we propose a framework tailored to the design, production, and evaluation of scientific visualizations and detail the benefits and challenges experienced at each step of the visualization process. Finally, we discuss the potential applications and limitations of this framework in practice.

7.2 Analysis of Existing Visualization Processes

7.2.1 Case Studies

We present a selection of case studies that provide an overview of the scientific visualization landscape and reveal a variety of factors that drive decisions behind the design of visualizations. These case studies cover a wide range of contexts and come from our own experiences working in these spaces, featuring projects with different visualization goals, subject matter, clients, target audiences, design styles, media types, and venues. While many of these cases have successful outcomes, they also highlight the challenges faced by visualizers and their collaborators when one or more steps of the design process do not go as planned. By examining these case studies, readers can gain a better understanding of the intricacies involved in creating scientific visualizations.

7.2.1.1 Visualization for Academic Research Communications

The production of didactic illustrations for academic publication or presentation is a frequently assigned task for scientific visualizers. This case study examines an illustration project for an academic research group working on cutting-edge research, developing biodegradable and biocompatible polymers for biomedical applications. The research group (client) contracted a scientific visualizer who was tasked with creating a visualization that highlighted the use of injectable biodegradable polymers for treating critical limb ischemia through local pro-angiogenic peptide delivery. The main goal of this visualization was to communicate the research of the academic lab in a more accessible and efficient way to scientists within this field and adjacent fields. Although its primary context-of-use was in an academic research publication, it was also meant to be used in formal audio-visual presentations.

From the outset of the project, there was clear and open communication with the client regarding their specific expectations. The client appointed a researcher to liaise with the scientific visualizer and represent the interests of the research group. The first step of the project included the creation of a collaborative and living document outlining the research content and scope of the project. This document allowed the visualizer and client to collaborate on content, initial treatment possibilities (including fidelity of the end product), and collect existing visual media to build a landscape of the field and identify standards for visually encoding information early in the project. This initial step clarified the project expectations, scope, and goals for all stakeholders, laying a solid foundation for the remainder of the project.

After the visualizer created several thumbnails, the most successful concepts were selected and presented to the client. The client was highly responsive and engaged, providing suggestions for the concept and feedback regarding scientific accuracy. Once a concept was selected, the visualizer created a comprehensive draft, which was refined over several rounds of iterative feedback. The client was again highly involved and looped in team members to review the visualization for its accuracy as well as its effectiveness in communicating the content. Once both parties were confident in moving forward, the design was "locked in," and the production of the final visualization began. Thanks to the collaborative and iterative refinement that took place at the beginning of the project, the production phase proceeded exceptionally smoothly. The only revisions made during this step were edits to the copy. The project was deemed successfully completed once the visualization was approved and the final files were delivered to the client (see Fig. 7.1). This success was largely due to the strong partnership and trust between the

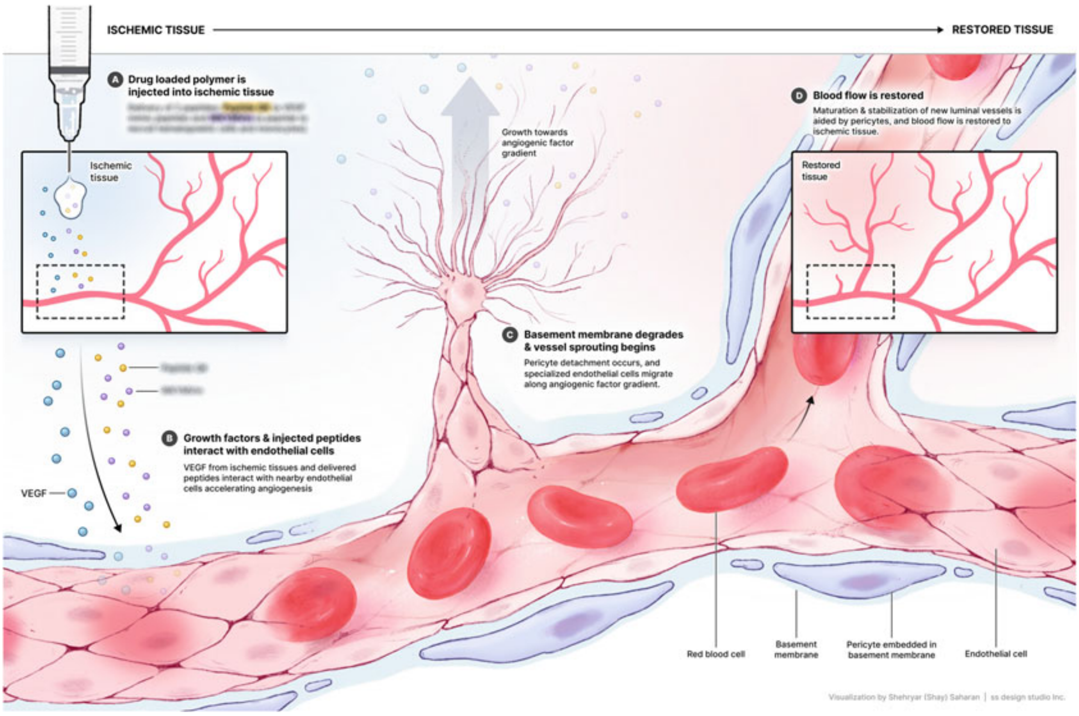

Fig. 7.1 Final illustration for an academic research group developing biodegradable and biocompatible polymers for biomedical applications. Copyright 2023 by ss design studio Inc. Reprinted with permission

visualizer and the client, fostered through consistent collaboration, communication, and engagement. By investing time and effort to achieve alignment at the outset of the project, both the client and visualizer set the stage for a smooth execution of the project. However, due to resource-related constraints, the final visualization was not tested with the target audience to assess if it met its communication goals.

7.2.1.2 Visualization for Biotechnology and Pharmaceutical Marketing and Communications

One of the primary markets for the creation of commission scientific animations is the biotechnology, pharmaceutical, and medical device industry. Projects in this space often fall into a few common categories: mechanism of action animations, product launch animations, and animations for internal training, education, and onboarding. Depending on the size of the biotechnology or pharmaceutical company, scientific designers/animators may either interact with the marketing and communications team (for larger, more mature companies) or with C-level executives (and even CEOs, in the case of earlier-stage companies). It is also common for scientists from the research and development department to be brought into the process for early-stage conceptualization and review. The following case study represents a rather typical and successful path through the process of scientific animation development by a team of scientific visualizers, where, despite the client having a clear idea of the key messages and visuals needed to communicate to their target audience, the visualization design team still navigated the full pre-production and production phases to arrive at a finished animation.

Fenix Health Sciences is a nutritional supplement company that develops a lipid formulation to address nutritional deficiencies associated with inattention and emotional dysregulation. The visualization team worked directly with the

CEO, who gave the team a series of preliminary storyboard outlines at the start of the project. This was seen as unusual because many clients do not necessarily take steps in advance to "think visually" and develop a progression of events they want to see onscreen, even if it is only captured as a text document. Although the storyboards and eventually the final animation were substantially different from these initial drafts, creating preliminary outlines placed the client in a frame of mind suited to visual thinking and raised their awareness of the design and visual storytelling process.

As part of this project, the visualization team created "story beats" before launching into the storyboarding process; these story beats are representative sketches associated with a particular segment of an animation. While storyboard frames follow the pace of the narration script and offer detailed representations of individual shots (a "shot" is a continuous sequence of images that shows a specific action or scene in an animation or film), story beats have a different purpose. Rather than being directly linked to the script, story beats serve as early visual explorations of the kinds of environments that could be useful in conveying the client's story before one has reached the storyboarding stage. After collaborating on the narration script, which was initially drafted by the client and further refined by the visualization team, the team created storyboards that could visually capture the overall story. At this stage, color was incorporated into the storyboards since it played an important role in communicating specific aspects of the science, such as the variety of structural components in various families of membrane lipids in cells; typically, color is explored at later phases of the visualization process, such as in the "mood board" development phase. Once the storyboards were finalized, the visualization team explored a suitable representation style for the molecules featured throughout the animation before launching into the 3D production phase of the project. At this stage, they created complex molecular models and simulations of dynamic cellular membranes, the accuracy of which was guaranteed by scientists on the visualization design team with the corresponding expertise (i.e., PhD-scientists who had worked on such modeling and simulation tasks as part of their research theses).

Overall, this exemplified a *"successful"* development process, where navigating the pre-production and production phases proceeded smoothly with the client. By leveraging the different outputs created throughout the pre-production phase (see Fig. 7.2 for script, story beats, storyboards, preliminary 3D models), the visualization team avoided unforeseen changes in story direction and shifts in stylistic approach.

7.2.1.3 Visualization for Formal Education

Unlike visualizations for corporate marketing and communication clients, projects in the formal education space are driven by a different set of design priorities. In the former, decisions often center around the client's desire to tell a compelling story and engage the audience—in this context, it is not uncommon for issues of scientific accuracy to clash with the narrative goals. Although these issues can be reconciled with careful scientific and design discussions, storytelling lies at the heart of the project's design mandate and becomes the driving force for many subsequent decisions. In contrast, formal education projects prioritize *learning objectives* as the principal driver of all decisions throughout the project. These pedagogical goals become the central organizational pillars around which media types (e.g., static figures, animations, interactive tools) and design styles (e.g., simple, diagrammatic 2D artwork versus immersive 3D content) are chosen, especially in the development of highly structured curricular products by the publishing industry (e.g., textbooks and their supplemental digital materials). Although many of the stakeholders—including authors, editors, curriculum designers, assessment specialists, and platform programmers—share an overarching goal of increasing learning gains for students, there is often confusion and poor management in the process necessary to achieve these goals.

Historically, in the textbook publishing industry, authors drive the creation of text content early

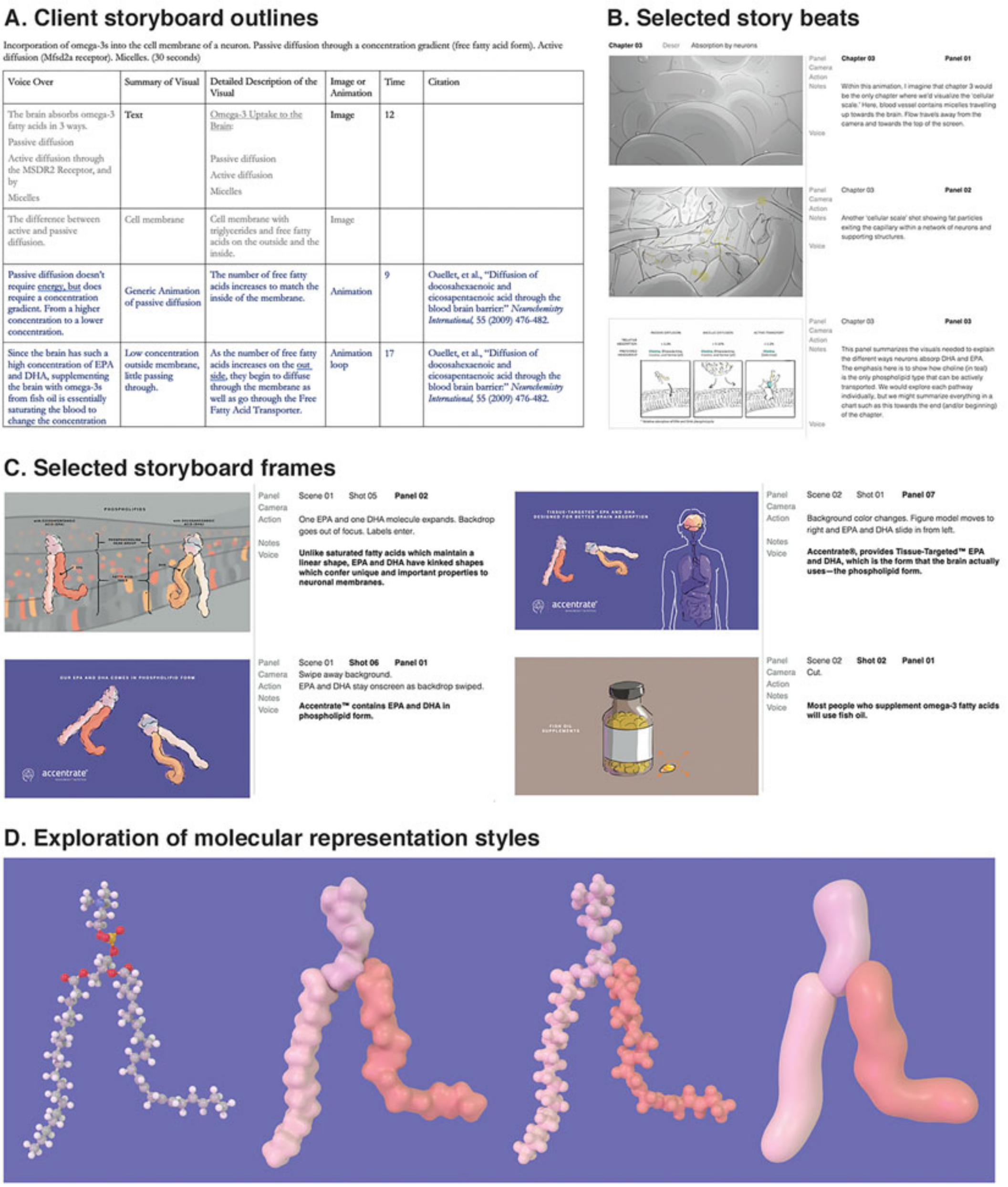

Fig. 7.2 Pre-production materials (outlines (**a**), story beats (**b**), storyboard frames (**c**), style exploration (**d**)) for a 3D animation for Fenix Health Sciences. Copyright 2022 by Digizyme Inc. Reprinted with permission

on in the process and treat visual media as an afterthought secondary to the text. In the best of cases, editors recruit artists with scientific training to produce static imagery and to provide guidance on the strategic use of visuals, though this depends on their level of collaboration with the authors. However, the advent of digital platforms (e.g., eBooks, online learning systems to host textbook supplements) has expanded the range of educational multimedia beyond static images and figures. These new types of multimedia, such as animations and interactive tools, require a more complex process to develop than the traditional, diagrammatic art found in print textbooks; unfortunately, this is where the publishing industry has lagged in its understanding and ability to innovate. For example, it is not uncommon for educators to be recruited on a contractual basis to ideate storyboards for educational animations, despite the fact that they are not trained in the design of animated media and may not possess the graphical skills to capture their ideas effectively. These storyboards are reviewed by a different set of educators who, again, provide feedback without context or experience in the process of multimedia production. Authors can sometimes remain divorced from early ideation phases, and they are only brought in to review design concepts when it is too late to adjust course.

Conversely, working with scientifically trained visualizers provides a competitive advantage in the development of successful pedagogical media for textbooks and classrooms. These practitioners are able to engage authors at the earliest stages of the ideation process and leverage their skills to design clear storyboards that fulfill pedagogical goals, as seen in Fig. 7.3. This approach avoids the loss of important pedagogical and engagement opportunities that can result from following an ill-informed design process. Overall, a well-organized pipeline is one of the key foundational elements that designers can introduce at the start of a project to establish a productive working relationship with publishers and their authors.

7.2.1.4 Visualization for Health Policy and Communications

Thus far, our case studies illustrated the role that narratives and pedagogical goals play in influencing a scientific visualizer's design decisions. In this case study, we highlight the influence clients and audiences can have on the visualization process. One such area is in health policy and communications. Public health agencies, focused on maintaining and improving the physical and mental health of its citizens, employ graphic designers to create visualizations that facilitate communication between policy workers (clients) and senior policy decision-makers (audience), for instance, in the pitching for or proposing of public health initiatives. This requires designers to communicate a mix of conceptual ideas (e.g., the vision of a future healthcare system) and concrete evidence (e.g., current data on a public health topic) while also leaving a strong impression on their audience in a limited amount of time. Scientific visualizers excel at creating visual syntheses that tie various

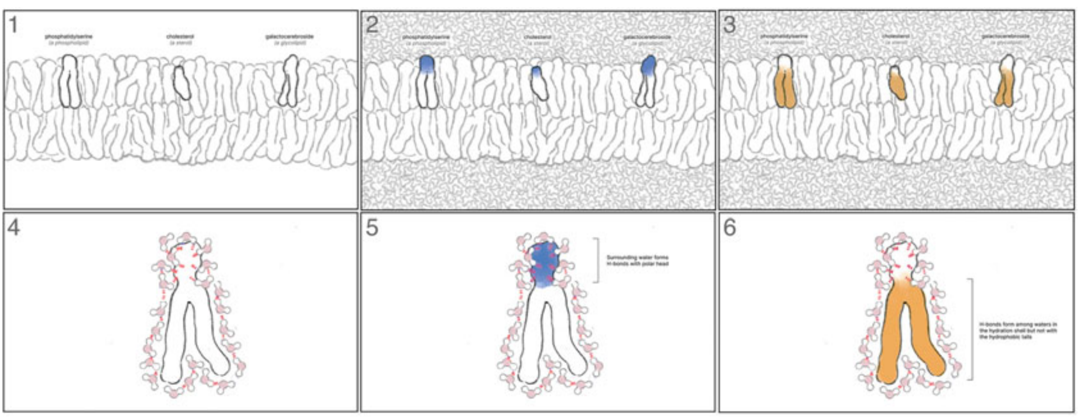

Fig. 7.3 Selected storyboard frames crafted by a scientifically trained artist who collaborated closely with a textbook author team to develop a visual sequence that caters to chosen learning objectives. Copyright 2023 by Digizyme Inc. Reprinted with permission

streams of information together, showing what these ideas could look like as tangible products—for example, creating static mock-ups of an interactive tool that visualizes environmental health indicators.

An in-house designer within the government agency is usually brought onto a project that already has a reasonably well-developed narrative crafted by a client team consisting of content writers and/or subject matter experts (e.g., epidemiologists, policy analysts). In the initial consultation, the designer assesses the needs of their client and translates their request into a set of design requirements. Since it is important for clients to actively engage their audience (e.g., senior decision-makers), the designer and client will often make design decisions together. For example, the designer may capture their design recommendations (e.g., design decisions, content structure, design approach, style inspiration) in a design brief and hand this over to their client—this gives the client the ability to contribute to the overall structure and esthetic of the final product so that it can better engage their audience. These briefs also help designers familiarize clients new to the design process and clarify expectations.

Projects progress more smoothly when designers and clients communicate effectively during the initial consultation and collaborate on pre-visualization materials. These are all opportunities to make sense of the project, with designers and clients sharing a common understanding at the end of these activities. Challenges, on the other hand, arise due to different decision-making approaches, time pressures, and varying levels of awareness of the visualization process. Top-down decision-making is not uncommon in governmental bodies; but when it occurs at the eleventh hour, it leads to changes in content and design during late stages where projects tend to be less editable. These changes in direction occur especially when the client and the visualization team are misaligned throughout the project and have different interpretations of the project requirements. Although review sessions are scheduled into the project plan to prevent these complications, these sessions may be overlooked due to time constraints. In situations where there is bottom-up rather than top-down decision-making, "design by committee" can occur; this translates to rounds of review sessions where most of the feedback is integrated equally into the final product. Oftentimes, this feedback can come from individuals without a background in design or visualization. This can lead the process down a path of well-intentioned but ill-informed decisions, creating a "Frankenstein-esque" product that is unable to serve its specific visualization goals.

7.2.1.5 Visualizations for Public Education

Science museums are wonderful venues for informal science education and often require the expertise of scientific visualization designers and animators to support their exhibit development goals. There is a great variety of work that results from these projects since museums innovate new forms of engagement for the public and often integrate both physical and digital exhibit components. In the following case studies, we detail the typical design process for museums that work with in-house exhibition designers (e.g., content writers, visualization designers, fabricators) as well as third-party collaborators.

7.2.1.5.1 Ontario Science Center: Vaccine Awareness Exhibit

The Ontario Science Center (OSC) is a science and technology museum located in Toronto, Canada, catering primarily to families with children, as well as educators and their students. The OSC employs a collaborative and non-linear, iterative design methodology in the production of a wide range of media (including static, animated, and interactive media), primarily designed for in-person exhibitions. The OSC often creates exhibits that are highly visual and interactive, with the goal of "showing before telling" to engage the audience.

The process begins with a team of designers, science writers, educators, and science researchers working together to identify the content objectives and target audiences of their visual media. A wide environmental scan is conducted to gain a better understanding of the subject area and scope of the project. Test groups (focus groups) are sometimes used to narrow potential topic areas. Once key points and messages are identified, the team begins to think about the different types of experiences they can potentially craft. This includes deciding on the best approach based on the type of information being communicated and how it will be presented. Once a design direction is set, the team begins to think more specifically about the details—for example, determining a balance between written and visual content such that it is suitable and interesting for a wide range of visitors that may enter the exhibit. This also includes building a detailed content inventory to identify and document assets needed for production. The final product is then built and tested with museum visitors in order to identify and iterate on areas of improvement.

An example of a current and ongoing OSC project is a new *Vaccine Awareness* exhibit about the science of vaccines and immunity. The project includes a physical exhibit and accompanying digital content, available on the exhibition floor and to other educational institutions online. The project team is large in size, with multidisciplinary members that draw expertise from a variety of domains such as science research, scientific writing, 2D and 3D media design, electronics, software development, project management, sponsorship, marketing, education, and evaluation. Clear communication is key to a positive working experience, especially in a project of this scale and complexity. OSC has achieved this through clearly outlining project objectives, documenting and constantly reflecting on a predetermined design methodology, delineating the roles and responsibilities of each contributor, and identifying liaisons from each domain. Some recurring problems in past projects resulted in steps taking longer than expected (e.g., contributors may be resistant to handing off materials before they are perfected), and the project team not communicating expectations and timelines with peripheral stakeholders (e.g., marketing) at an earlier stage of the project. These issues, if not addressed immediately, may lead to the addition of unexpected tasks, revisions of completed work, and ultimately delays throughout the project timeline. Project managers may schedule regular check-ins and weekly team meetings to avoid potentially costly revisions and additional work in a new project.

7.2.1.5.2 Nobel Prize Museum: *Life Eternal* Interactive Exhibit

As part of an exhibit at the Nobel Prize Museum (Stockholm, Sweden) on longevity that features Nobel Prize winning discoveries, the museum team collaborated with a scientific visualization company and an outside exhibit design team to create a kiosk experience. The project leveraged the Unity game engine software platform to build the user interface and let visitors select from four Nobel discoveries—Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), Telomeres, Pluripotent Stem Cells, and Autophagy—and learn how each relates to the exhibit title, *Life Eternal* (see Fig. 7.4).

This project exemplified a situation where project review and collaboration can occur not only with a client, but also with a third-party collaborating design firm. While it is generally beneficial to involve another team of visual professionals for their expertise and creativity, it may also impact the pre-production and production processes by introducing additional viewpoints that must be thoughtfully incorporated. The scientific visualization team was given the responsibility to select scientific narratives as well as determine the appropriate level of detail and accuracy with which to depict them, and thus they developed storyboards that they believed included adequate scientific context to orient a general audience visiting the exhibit. However, the initial response to these storyboards was to increase the level of interactivity for the visitor and reduce the expository scientific content. This advice was based on the collaborating design firm's overall experience with museum exhibit design, but it was one devoid of experience with the communication of challenging scientific topics. Although the storyboards were modified to immerse visitors into interactive activities as suggested (and this direction was

Fig. 7.4 *Life Eternal* Nobel Museum exhibit in Stockholm (top panel) for which a series of science education exploratory modules related to Nobel-winning discoveries were created in the Unity game engine (bottom four panels). Copyright 2022 by The Nobel Prize Museum. Reprinted with permission

followed for the rest of the project's pre-production and production phases), it was acknowledged in hindsight that the scientific visualization team's original suggestion to provide a stronger scientific background was a better one!

It is challenging to know when and how to relinquish important design decisions, especially if one perceives that the client or third-party design group has more experience in a certain design space. The realm of scientific visualization is rather unique in that our training prepares us to be attuned to the right balance of esthetic and veridical experiences for viewers. While another collaborating group may specialize in a particular design space or mode of delivery, the challenge of conveying complex scientific concepts to an audience oftentimes takes precedence over other areas of expertise, and prioritizing the audience's needs becomes the first and foremost consideration from which all other design decisions should flow.

7.2.1.5.3 Science Documentary Films

Science documentary films are a less common type of project that nonetheless leverages the skills of the scientific visualization community. These projects often involve working with a film director and sometimes a funding entity that commissions the film. This case study details the challenges inherent with this medium and the difficulties of integrating into the typical workflow of documentary filmmakers. The film in question focused on the human microbiome and aimed to help general audiences appreciate the ubiquitous role that bacteria play in human development. It contrasted these themes with the common assumption that these microorganisms are mostly detrimental to human health and at the root of many illnesses. Although the project was funded by a probiotics company, the CEO and executives communicated clearly from the outset that they did not want this film to feel like a corporate advertisement; instead, it should be a public education effort that broadly raises awareness about the human microbiome. The film director, an experienced artist who was sensitive to the nuances of the science throughout, was not a scientist by training and relied heavily on the client and the scientific visualization team's expertise—in fact, a central thread of the film became the "behind-the-scenes" creation process of the very visualizations produced. Despite this interesting and flattering turn of events, the visualization team experienced serious misalignment issues while collaborating on this project—issues that they soon realized were inherent to the creative journey by which documentary films are produced.

Many documentary filmmakers have a fluid process that begins with an idea or a set of questions that propels their research and determines the initial footage they plan to shoot and include in the film. They begin the project exploratively with the understanding that the shape and even overarching theme of their film can shift significantly as they learn about their topic and discover unexpected human stories during filming. As such, much of the key creative decisions that result in the "final cut" can take place at the eleventh hour in the editing room rather than at the start of a project. Although this approach gives filmmakers maximum flexibility to discover the most compelling version of the story, it sharply contrasts the level of planning and certainty required in scientific visualization projects; in the latter case, a significant amount of time is often invested during pre-production to increase clarity and a smooth production process in later stages of the project. In this case study, the visualization team came to realize their storyboards served more as a tool to educate the filmmaker about interesting aspects of the scientific story rather than as final visual sequences to create. Instead of developing storyboard ideas that matched an existing script, the team wrote a script that accompanied and explained the storyboard to the film director and client. As the director continued to refine successive "rough cuts" of the documentary, the storyboard sequence was similarly trimmed and rearranged as modular pieces of the scientific story. After much flexibility in unfolding of the creative process (i.e., the concomitant flexibility in deadlines), the final shot list was "locked" from further tweaks so that the visualization team could focus on production.

Ultimately, this project demonstrated a seamless integration of scientific knowledge and artistic expression, made possible by a high degree of openness and trust between the visualization team and the film director. The director relied on the scientific expertise and feedback provided by the visualization team to shape the final story arc (i.e., story sequence), and the visualization team relied on the director's creative vision to craft an engaging film that remained faithful to the science.

7.2.1.6 Visualization for Knowledge Discovery

Unlike projects where the story and/or learning objectives are the primary factors influencing visualization decisions, knowledge discovery projects are driven by the need to enable scientists and collaborators to make sense of data—the data themselves *are* the story. The priority becomes the development of visual methods and representational styles that support a more open-ended exploration and experimentation with the visualized data. Since it is not yet clear what findings and epiphanies will emerge from inspecting the visualized data—whether they are more abstract, quantitative data sets or ones based on three-dimensional structural features at molecular, cellular, anatomical, or other scales—it is critical for the visualizer to work closely with scientists to gauge the usability of the visualization and how users' interaction with it may evolve over time. Unlike story-driven projects where it is important to "lock down" the visual treatment (cinematic and stylistic aspects of the project) early on to protect it from changes that may appear during production, knowledge discovery projects begin with the assumption that the approach to visualizing the data must remain flexible enough as users continue to experiment with the visualized dataset and, hopefully, learn to inspect and derive new insights from these data.

Another key feature of specific knowledge discovery projects is that they encourage the integration of multiple types of data within a common visual environment. A visualization in this case may be the first time that disparate datasets (i.e., ones coming from different kinds of instruments or addressing different characteristics of a biological structure or process) are brought together and merged in order to derive novel observations. This approach is exemplified in a recent project that aimed to create a continuous visual model of the SARS CoV-2 spike-induced membrane fusion process. Visualizing this process required that numerous datasets (structural and dynamic) from multiple fields (X-ray crystallography, nuclear magnetic resonance, cryo-electron microscopy and tomography, circular dichroism, and microscopy) be combined into a cohesive, dynamic model. This visual model was then used for both conceptual and communication purposes—(a) it helped collaborating researchers form an improved mental model of this 3D process and a better understanding of the mechanism of action of their spike-targeted peptide inhibitors, (b) helped reviewers understand the research during the peer-review process and, ultimately, (c) allowed readers to understand the context of the therapeutic intervention (de Vries et al. 2021; see Fig. 7.5).

It was particularly rewarding when the hypothesized intermediates of the viral spike—i.e., the protein conformations that resulted from the careful modeling, rigging, and simulation stages of the visualization process—were later found to be in agreement with a follow-up cryo-electron tomography study (Marcink et al. 2022). Other scientist-practitioners have described similar uses of visualization (Iwasa 2010; McGill 2022), which emphasizes the value and importance of building scientifically accurate models that allow users to freely explore the data and create alternate versions of the model. Visualizations in this case serve as the basis for *in silico* experimentation and exploration, as opposed to only tools for communication and engagement.

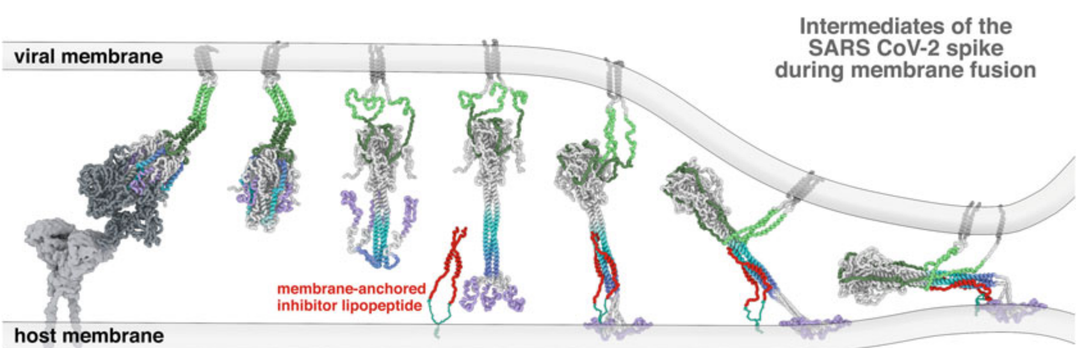

Fig. 7.5 Example of a figure derived from a knowledge discovery project modeling and simulating the intermediate conformations of the SARS CoV-2 spike during membrane fusion. Copyright 2022 by Digizyme Inc. Reprinted with permission

7.2.2 Analyzing Visualization Workflows in Practice

7.2.2.1 Decision-Making Between Visualizers, Clients, and Their Collaborators

All of the case studies described above reinforce our understanding of the key components that contribute to a successful visualization—in particular, an accurate representation of scientific evidence and a shared understanding of visualization goals between visualizers, clients, and their collaborators. These case studies give further insight into the dynamics of the interactions between these groups, especially how they interact with one another and influence design decisions. It is clear that clients and peripheral collaborators wield considerable influence over decisions about the final product as well as the design process. A few of our cases show how changes in direction from clients and collaborators, especially at the eleventh hour, can drastically change the outcome of the final product at the cost of additional stress to scientific visualizers, delays to the project timeline, and revisions to already completed work. In situations where decision-makers are not experienced in scientific visualization nor its process, these case studies demonstrate a need for clients and collaborators to trust visualizers to make informed decisions as trained experts in scientific storytelling and provide timely input on outputs (e.g., comprehensive drafts, storyboards, design briefs) throughout the design process that are meant to maintain common ground between visualizers, clients, and collaborators. Conversely, visualizers should also take the initiative to familiarize clients with respect to the collaborative design process.

7.2.2.2 Design Process Dictated by Project Requirements

Additionally, these case studies illustrate how the design process is a flexible one that is shaped and molded by project requirements such as visualization goals, media type, and context-of-use. These factors affect the steps to be included or excluded in a workflow, time and importance allocated to each step, and overall flexibility in the workflow. In situations where the visualization goal is open-ended (e.g., knowledge discovery), visualizers develop highly flexible techniques and workflows that allow data exploration and serendipitous discoveries. Conversely, in situations where the goal is more defined (e.g., marketing communications), projects are scoped early on in the design process, and the degree of editability diminishes throughout the process so as to push the project to its finish line. Therefore, it is important for visualizers, clients, and collaborators to clarify and mutually agree upon project requirements near the start of the project, to ensure the development of a workflow that can effectively fulfill those requirements.

7.2.3 Analyzing Conceptual Frameworks for Visualization Design Processes

To further contextualize our work, we examined conceptual frameworks related to the design, production, or evaluation of visualizations. The author team drew from their personal knowledge and experience in various fields to identify existing frameworks that are commonly used and cited in scientific visualization and visualization-adjacent fields—this was a selection of seven frameworks in product design, instructional design, multimedia production, knowledge translation, and science communication (see Table 7.1 below). We compared these frameworks and highlighted a few traits that are common among the different perspectives and approaches to visualization projects.

7.2.3.1 Phased Approach

Many of these frameworks view the overall design process as a phased approach that involves defining a problem at the start of the process and delivering a tailored solution at the end. Each phase consists of steps with actions or activities, where users of the framework must actively perform these steps and activities to progress toward

Table 7.1 Frameworks, models, and workflows analyzed in the development of our scientific visualization framework

Framework	Author	Description	Details
ADDIE	Branch (2010)	ADDIE (Analyze, Design, Develop, Implement, and Evaluate) is a phased approach to building effective learning solutions. It is meant for use in intentional learning environments that are student-centered, innovative, authentic, and inspirational.	Five phases: 1. Analyze: Identify causes for performance gaps in the learner. Determine instructional goals, target audience, and required resources to deliver the learning solution. 2. Design: Design a learning solution that aligns learning objectives and instructional strategies with instructional goals. 3. Develop: Generate, validate, and conduct a pilot test for learning resources in development. 4. Implement: Implement the learning solution by preparing the learning environment and engaging participants who will interact with learning resources. 5. Evaluate: Assess the quality of the learning solution formatively. Assess how successfully the solution meets instructional goals summatively through participant perception, learning, and performance.
Systems approach model	Dick and Carey (1978)	This component-based model focuses on the interrelationship between context, content, learning, and instruction in the design process. The instructor, learners, materials, instructional activities, delivery system, and learning work together to produce the desired outcomes. Components of this model are executed iteratively and in parallel with each other.	Ten Components 1. Identify instructional goals. 2. Conduct instructional analysis. 3. Analyze learners and contexts (entry behaviors, learner characteristics). 4. Write performance objectives. 5. Develop assessment tools (criterion-referenced test items). 6. Develop instructional strategies. 7. Develop and select instructional materials. 8. Develop and conduct formative evaluation. 9. Revise instruction. 10. Develop and conduct summative evaluation.
Design thinking	Stanford d. School (2010)	Design thinking is a methodology (set of cognitive, strategic, and practical procedures) for creative problem-solving. It presents a non-linear, iterative process for designing user-centered solutions. It puts people at the center of the development process and encourages the creation of products that resonate more deeply with an audience.	Five modes: 1. Empathize: Understand the needs, actions, beliefs, and values of people within the context of the design challenge. 2. Define: Craft a meaningful and actionable problem statement that focuses on the insights and needs of a particular user or composite character. 3. Ideate: Generate ideas and defer judgment. 4. Prototype: Iterative generation of artifacts that can elicit useful feedback from users and colleagues. 5. Test: Solicit feedback about the prototypes from users and gain empathy for them.

(continued)

Table 7.1 (continued)

Framework	Author	Description	Details
Double Diamond	Design Council (2019)	Double Diamond is a design methodology within the British Design Council's framework of innovation that presents a non-linear, iterative process of divergent and convergent thinking.	Four phases: 1. Discover: Understand rather than assume what the problem is. 2. Define: Use the insights gathered to clearly define the challenge in a new light. 3. Develop: Develop different solutions to the defined problem by seeking inspiration and co-designing with diverse perspectives. 4. Deliver: Test the different solutions at a small scale, rejecting those that will not work and improving the ones that will.
Knowledge-to-action framework	Graham et al. (2006)	A conceptual framework for facilitating the use of research knowledge by various stakeholders. The framework emphasizes collaboration between knowledge producers and knowledge users throughout the process.	Two multiphase components: 1. Knowledge creation: Distill knowledge into a tool or product tailored to knowledge users. a. Knowledge Inquiry. b. Knowledge Synthesis. c. Knowledge Tools/Products. d. Tailoring knowledge throughout. 2. Action: Bring knowledge into practice or awareness. a. Identify the problem. b. Identify, review, and select knowledge. c. Adapt knowledge to local context. d. Assess barriers to knowledge use. e. Select, tailor, and implement interventions. f. Monitor knowledge use. g. Evaluate outcomes. h. Sustain knowledge use.
Animation design workflow	Jantzen et al. (2015)	A typical workflow for the design of 3D computer animations. This three-phase workflow is an iterative process of generation and refinement that balances storytelling with the communication needs of the intended target audience.	Three phases: 1. Pre-production: Identify communication objectives, audience, and scope and collect reference material that inform the development of a script. This script is broken down visually into storyboards and paced using an animatic. 2. Production: Produce visual assets through activities such as 3D modeling, rigging, animation, dynamics, texturing, lighting, and rendering. 3. Post-production: Tie together the different assets generated during production through compositing. The final product is then exported to meet dissemination requirements as specified by the client.
Building Science Graphics	Christiansen (2023)	A practical, step-by-step workflow for communicating science through illustrated explanatory diagrams and data visualizations for a variety of venues (e.g., articles, poster presentations, press releases, social media posts).	28 steps: 1. Confirm the need for a graphic. 2. Describe the context (outlet, audience, tone). 3. Initiate a team list and schedule (active content collaborators, reviewers). 4. Shift focus to content. 5. State the specific goal of your graphic.

(continued)

Table 7.1 (continued)

Framework	Author	Description	Details
			6. Check-in with collaborators about the goal statement. 7. Gather reference material related to the goal statement. 8. Read and take notes on the reference materials. 9. Revisit your goal in light of reference material. 10. Translate writing into sketches. 11. Create frames/miniatures of the final graphic. 12. Organize information within the miniature frames in an abstract and gestural manner. 13. Draw out your favorite miniatures in more detail. Write preliminary captions and annotations. 14. Check if the emerging plan aligns with the context and content. 15. Create a full-sized concept sketch including preliminary captions and labels. 16. Critique the communication value of your own sketch. 17. Seek concept sketch feedback from collaborators. 18. Digest concept sketch feedback. 19. Develop a tight sketch. 20. Seek tight sketch feedback from collaborators. 21. Digest tight sketch feedback. 22. Execute the final graphic. 23. Seek a final round of feedback from collaborators. 24. Address final notes. 25. Write image alternative (alt) text. 26. Write an image credit. 27. Confirm that your files are ready to print or post. 28. Create variations of the same content for different audiences and outlets.

an end goal. Each phase of the process builds upon the next to improve and refine the solution, and completing these steps in succession ensures a solid foundation for a visualization project.

These frameworks emphasize a shared understanding of project requirements among collaborators and stakeholders at the start of the design process, such as defining realistic visualization goals, target audience(s), medium(s), and venue(s) after a review of the problem space (a "problem space" refers to the entire range of components that define and solve a problem, e.g., history of the problem, stakeholders involved) and available resources. The next phase involves designing and drafting a potential solution, with some frameworks encouraging the development of innovative and creative ideas by deferring judgment (Stanford d.School 2010; Design Council 2019). The visualizer then refines the draft into a final product, and the design process ends when this product is delivered and assessed for its efficacy in meeting the initial visualization goals.

7.2.3.2 Iterative and Non-linear Steps

Most frameworks also describe the design process as one that is iterative and non-linear. This means that visualizers may revisit steps based on feedback from collaborators and other reviewers. For instance, frameworks in product design, instructional design, and knowledge translation (e.g., Stanford d.School 2010; Branch 2010; Graham et al. 2006) ask practitioners to solicit feedback in phases, formatively assessing the quality of their product with experts and users during development (e.g., pilot-testing) and summatively evaluating the effectiveness of the final product. These activities aim to provide creators with a perspective different to their own and to flag errors in the design in order to continuously improve the product as it moves through the design process (Design Council 2019).

7.2.3.3 Context-of-Use

Lastly, the steps in the design process depend on the context in which the product is used. Some frameworks, such as in instructional design, aim to create products that change aspects of the problem space and the target audience (e.g., change student behavior). In such instances, the product serves as a "means to an end" and is most valuable when it helps users achieve specific goals in specific contexts. To ensure this, these frameworks often involve steps that assess the needs of the target audience and evaluate the effectiveness and impact of the product in a given setting.

On the other hand, frameworks, such as in multimedia production and science communication, may see the product as intrinsically valuable. In these cases, the product is valued for both its artistic qualities and in its ability to communicate information across a range of contexts (e.g., an infographic read widely by different audiences). These frameworks emphasize the production process, technical prowess, and iterative feedback between visualizers, clients, and collaborators required to create a product that communicates its intended message.

7.3 Development of a Visualization-Specific Framework

Our analysis of both conceptual frameworks and case studies has provided us with a set of features that form the foundation of the scientific visualization framework presented in this chapter. This is a phased approach that is able to account for iterative, non-linear revisions during the design, production, and evaluation of a visual product; an interdependent system of steps, activities, and people, or rather the skills of people, that ensure the selection of and agreement upon design decisions best suited to the project; and lastly, a process that can be adjusted to fit different project requirements with different visualization goals, media types, and contexts-of-use. Below, we propose a tailored, formalized framework that will support scientific visualizers to meet their objectives and facilitate necessary conversations with stakeholders that allow them to better understand the impact of the design process on the final product.

7.3.1 An Overview of the Scientific Visualization Framework

The process of creating a successful visualization project involves several phases and steps that should be carefully followed to achieve the desired outcome. The proposed framework follows a non-linear, iterative process and is described in 11 steps that fall under three main phases. The first phase, pre-production, involves gaining a shared understanding of the project requirements by engaging with stakeholders and collaborators, defining project requirements, ideating, creating drafts, and conducting several rounds of review. The second phase, production, involves building data-driven and scientifically accurate assets and compiling them into a preview of the final visualization for feedback and approval. The final phase, post-production,

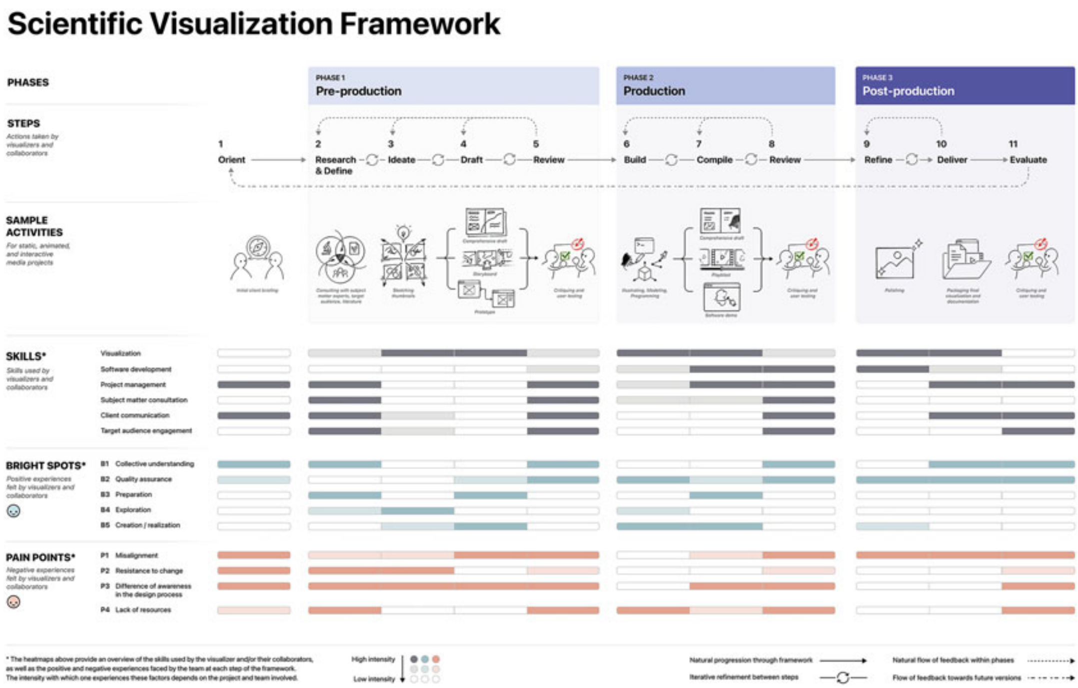

Fig. 7.6 An overview of our proposed Scientific Visualization Framework. View a detailed version of this graphic and companion resources at sciencecomm.ca

involves refining the final product, delivering it to the client, and evaluating whether the final product has met project requirements. In the following section, we will explore each of these phases in-depth and the steps involved in achieving a successful visualization project. Figure 7.6 provides an overview of the framework's phases and specific steps. It is important to note that the number of steps within each phase is not indicative of the complexity or time invested in each phase.

A key characteristic of the framework is its highly iterative nature, allowing for repetition of the entire process or specific parts of it. This allows for continuous improvement and refinement of the product as feedback from each cycle can be used to make changes and refinements in subsequent versions of the design. The framework, from left to right, can be thought of as a cycle of continuous refinement (through a funnel) with each iteration building upon the previous one until the desired outcome is achieved. The extent to which the framework is repeated depends on budgetary constraints, the specific goals, and scope of the project. A comprehensive account of each step and phase of the framework is provided in the following.

7.3.1.1 Phases and Steps

7.3.1.1.1 Outset of the project

Step 1: Orient Gaining a shared understanding of the project requirements at the outset is critical for the success of the project. This involves engaging with all stakeholders and collaborators to ensure that everyone has a clear understanding of the project's objectives, scope, and timeline. This will serve to establish a shared vision for the project and also minimize the risk of misunderstanding and conflict later in the project.

7.3.1.1.2 Phase 1: Pre-production

The pre-production phase (see Fig. 7.7) is arguably the most critical phase in the development of a visualization project, where the groundwork for the project is laid out. It involves conducting

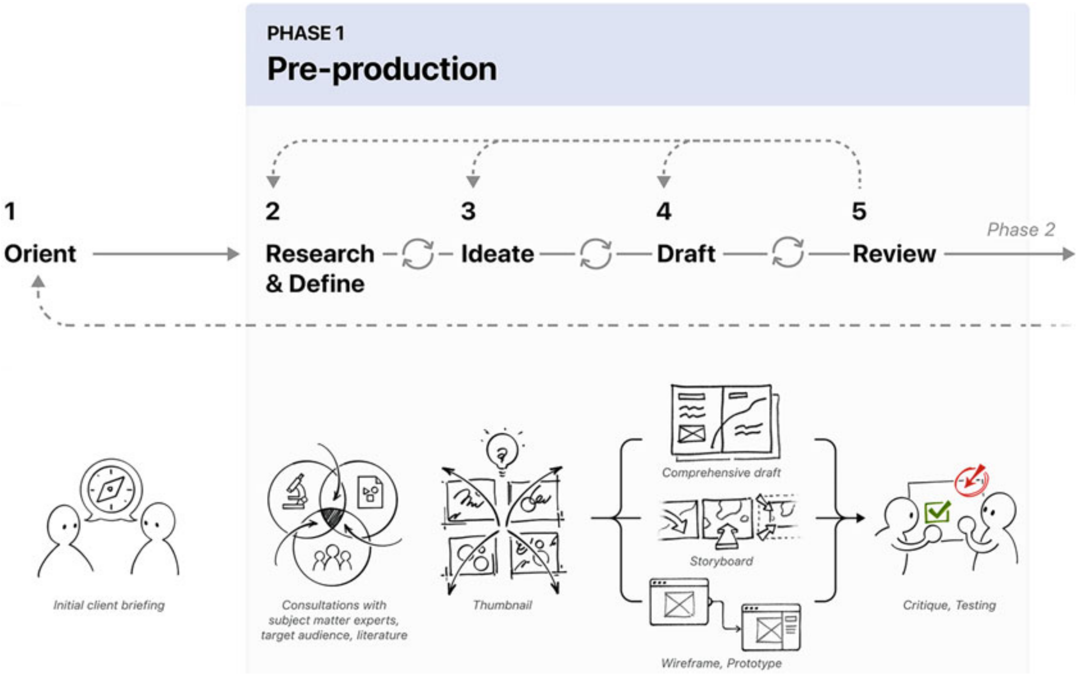

Fig. 7.7 A close-up view of the orient step and the pre-production phase (encompassing the research and define, ideate, draft, and review steps) of the scientific visualization framework

research to gain an understanding of the content and context-of-use, defining project requirements, ideating to generate a broad range of ideas and solutions, creating drafts to elicit feedback, and conducting several rounds of review to solicit feedback from stakeholders (e.g., clients, collaborators, target audience). The ultimate goal of pre-production is to establish a clear vision for the project and ensure that the final product meets the needs of the stakeholders, especially those of the target audience.

Step 2: Research & Define In this step, it is important to gain a deep understanding of the project's content and context-of-use, rather than making assumptions. This involves collecting insights about the subject matter, knowledge gaps and barriers, as well as building a comprehensive understanding of the needs of the target audience within the problem space. This may include defining or redefining the project requirements based on insights gleaned from research, and crafting objectives that guide collaborators during the development of the visualization.

Step 3: Ideate During the ideation phase, it is important to generate as many different ideas and solutions as possible based on the problem statement formulated in either the first or second step. Keeping an open mind throughout the process and drawing inspiration from a range of sources can help generate a broad range of ideas and moderate productive discussions between visualizers, clients, and collaborators. It is also essential to involve a diverse group of collaborators in the design process to bring fresh perspectives and insights to the table.

Step 4: Draft In the draft step, it is important to iterate artifacts that can elicit useful feedback from collaborators and users. By doing so, one continuously improves the design concept and ensures that it meets the needs of all stakeholders.

In this step, one should carefully consider the feedback received and integrate it into future versions of the visualization.

Step 5: Review In the review step, it is essential to assess whether the prototype is fulfilling project requirements (defined earlier in the project) by soliciting meaningful feedback from collaborators, reviewers, and users. This step allows for the opportunity to iteratively refine the design concept based on feedback, and verify that the visualization effectively communicates the intended message, fulfills the needs of stakeholders, and meets design standards (e.g., accessibility, branding, etc.).

7.3.1.1.3 Phase 2: Production

The production phase (see Fig. 7.8) is where the "actual work" is done to create the final visualization. In this phase, the team uses a variety of software and draws from reliable data sources to build individual assets and components that make up the final visualization. They may also take this time to refine approaches to the visual treatment of subject matter. The assets are then combined and integrated into a preview of the final product,

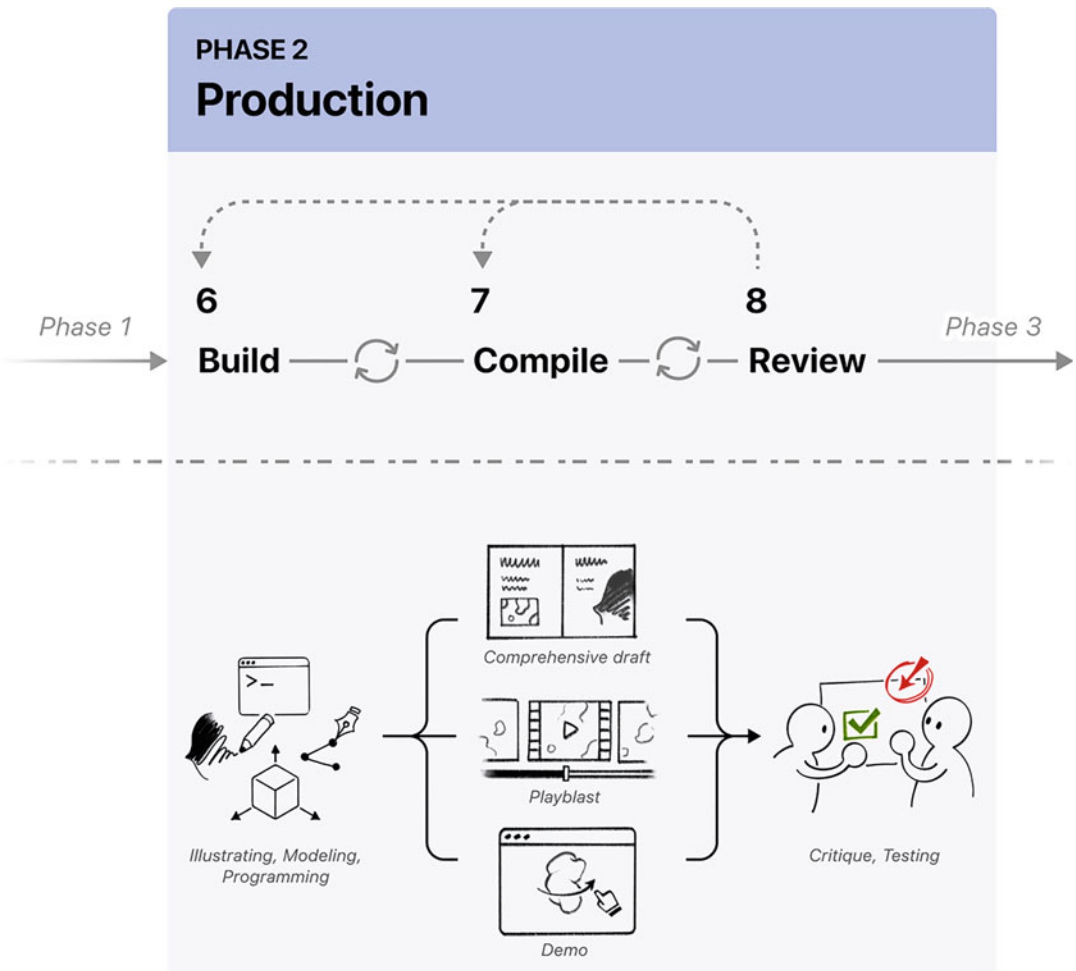

Fig. 7.8 A close-up view of the production phase (encompassing the build, compile, and review steps) of the scientific visualization framework

which is used to solicit feedback and approval from stakeholders.

Step 6: Build After pre-production, the team moves on to building individual assets of the visualization. The team focuses on creating data-driven and scientifically-informed assets that will be integrated into the final visualization (in many cases, where scientific data is lacking, a discussion about the visual treatment of more speculative features would occur in pre-production). We should note the specific activities in this step vary depending on media type.

Step 7: Compile During this step, the team assembles assets created in the previous phase to produce a preview—a work-in-progress—of the final visualization.

Step 8: Review In the final step of production, the team assesses whether their work-in-progress is fulfilling project requirements (established earlier in the project) by soliciting meaningful feedback from stakeholders. This is an opportunity to use the feedback to iteratively refine the visualization; at this point, the visualization should be close to completion. It is worth noting that although it is optional to involve the target audience in this step, doing so allows practitioners to assess whether their work fulfills the communication goals identified during earlier stages of the project.

7.3.1.1.4 Phase 3: Post-production

Post-production is the final phase of the visualization process (see Fig. 7.9). It involves refining the final product, delivering it to the client, and evaluating whether it has successfully met its project requirements.

Step 9: Refine During the refine step, the team adds the finishing touches to the final visualization that tie together all assets generated during production. The team will undergo a final round

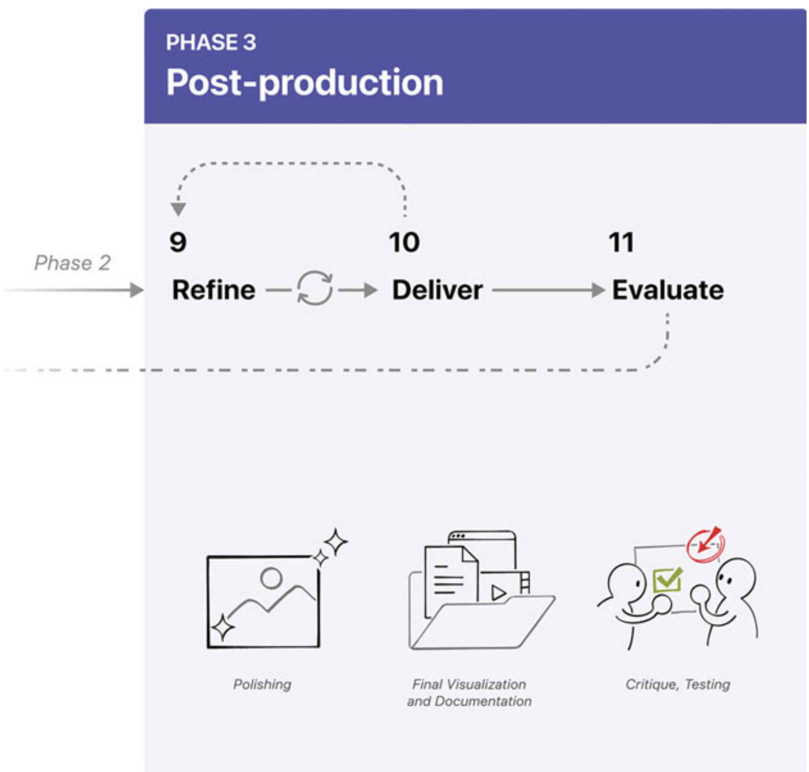

Fig. 7.9 A close-up view of the post-production phase (encompassing the refine, deliver, and evaluate steps) of the scientific visualization framework

of review to verify all aspects of the visualization (e.g., ensure the science has been accurately conveyed; ensure the visualization meets existing design standards in the problem space; etc.).

Step 10: Deliver Once the final product has been thoroughly polished, reviewed, and approved, it can be delivered to the client. In this step, the team packages the final visualization files and project documentation, adhering to the client's specified dissemination requirements.

Step 11: Evaluate In this final step, it is important to assess (informally or formally)—with the intended audience of the visualization—whether the final product has actually fulfilled the project requirements defined at the start of the project. This is an opportunity to reflect on the project as a whole and identify areas for improvement in future projects.

7.3.1.2 Skills

Drawing on the case studies above and our collective experiences, we distilled a set of skills that are often required for crafting scientific visualizations of varying media types. These capabilities are illustrated in the heatmap diagram presented in Fig. 7.6. These key skills can be grouped into six categories: visualization (e.g., ability to create visual sketches, drafts, final assets, etc.), software development, project management, subject matter consultation (e.g., ability to provide scientific expertise), client communication, and target audience engagement (e.g., ability to conduct focus groups, usability tests with users, etc.). It is important to note this heatmap provides a generalized view of the skills used by the visualizer and their collaborators, and the intensity with which one experiences these factors depends entirely on the project and team involved.

7.3.1.3 Activities & Outputs

To effectively execute the framework, the practitioner actively performs activities and creates outputs that contribute to the design of the final visualization. Table 7.2 shows a breakdown of the types of activities and outputs that occur at each step of our proposed framework.

7.3.1.4 Bright Spots & Pain Points

The framework includes a detailed breakdown of "bright spots" and "pain points" that reflect—in the authors' collective experiences—the benefits, challenges, and limitations of employing this framework. In this section, we use bright spots as a term to describe positive experiences felt by visualizers and their collaborators during the visualization process, while pain points refer to negative experiences.

7.3.1.4.1 Bright Spots

In the context of the proposed framework, "bright spots"—positive experiences felt by visualizers and their collaborators—can be seen as "hot spots" where things have a greater potential for working well, and the conditions are favorable for achieving desired results (assuming the team takes advantage of these opportunities). We group bright spots into five broad categories listed below from B1 to B5; these are further broken down and mapped against each step of the framework in Table 7.3.

B1: Collective Understanding This refers to the shared understanding among team members about the project's goals, expectations, and requirements. When there is collective understanding, everyone is on the same page (i.e., shared definition of success can help to ensure that the project meets all requirements and leads to satisfaction from all stakeholders), which can lead to better collaboration, communication, and decision-making.

B2: Quality Assurance This bright spot involves identifying and addressing issues early in the design process (while the design is still easily editable), as well as reviewing and verifying the accuracy and effectiveness of the final product at checkpoints throughout the process (to ensure the delivery of a high-quality visualization).

Table 7.2 Detailed breakdown of the activities and example outputs at each step of the framework

Steps of the Framework	Activities	Example outputs
Step 1: Orient	It is important to begin with a clear understanding of the visualization objectives, target audience, medium, and venue. This can be achieved through a project kick-off meeting where the project requirements are discussed and realistic expectations are established. It is important to ensure that the project fits within existing knowledge, literature, and reference materials, while also aligning with the needs of the users. Additionally, it is crucial to have the necessary resources in place, including financial support, time, and team members to deliver a successful solution. At this time, it is also important to identify a list of contributors who will be active collaborators and reviewers throughout the project. Finally, a project schedule or plan should be created and shared with the team to ensure everyone is on the same page and working toward the same goals. Following these steps ensures a greater likelihood of success at the outset.	Project brief.
Phase 1: Pre-production		
Step 2: Research & Define	It is important to understand the needs, behaviors, and beliefs of the users and stakeholders. This can be accomplished through a combination of primary and secondary research. Primary research can include user research where the audience is observed and engaged through interviews, surveys, and field research. Secondary research can include collecting existing research documents from the client, conducting a literature review, competitor analysis, and market research. After collecting and synthesizing the research findings, the project can be defined more specifically. This involves confirming or redefining the visualization objectives, target audience, medium, and venue that were established in Step 1: Orient. It is also important to define the problem statement and identify the content, design, and functional requirements for the project. By following these steps, the project can be tailored to meet the needs of the users and stakeholders and result in a successful visualization.	Research notes, key message/story statement, initial treatment ideas. ● Static imagery: Content outline. ● Animation: Script. ● Interactive: Scope document, needs assessment, user personas, context scenarios.
Step 3: Ideate	It is important to generate a variety of potential solutions when one is trying to solve the visualization problem identified in Step 2: Research and Define. A variety of ideas can be generated through brainstorming sessions, mind maps, rough sketches, thumbnails, etc. These methods help with exploring different concepts and refining existing ideas. It is also helpful to collect inspiration from others when working on visual development. This involves gathering examples of successful visualizations, analyzing their effectiveness, and	Thumbnails, concept art, style frames. ● Animation: Rough storyboards, color keys. ● Interactive: Co-creation, prioritization matrices, UX storyboards.

(continued)

Table 7.2 (continued)

Steps of the Framework	Activities	Example outputs
	using this new found knowledge and perspective to inform the development and refinement of new concepts.	
Step 4: Draft	After generating a variety of ideas, it is important to evaluate them and determine which approaches are likely to be the most effective. From there, drafts can be prepared with increasing levels of fidelity to further refine and develop the ideas. It is important to ensure that these prototypes contain the information necessary to solicit meaningful feedback, reactions, and responses.	● Static imagery: Comprehensive draft. ● Animation: Refined storyboards, animatic. ● Interactive: Design document, wireframes, interactive prototype, content inventory.
Step 5: Review	To ensure that the proposed draft meets the visualization goals, it is important to assess its quality informally on a small scale*. This can be accomplished by reviewing the draft and identifying areas that require further refinement and improvement. These reviews can be conducted as a critique session with the project team (as a group or individually) to solicit feedback and identify areas that require further attention. Depending on the project, pilot tests with users can also be conducted to gain insights into how the visualization will be used and its overall effectiveness. Additionally, revisiting the project requirements is essential at this point to determine whether the objectives, target audience, medium, and venue need to be revised based on newly acquired insight. It is also important to conduct a preliminary check for standards compliance, such as venue/outlet specifications, accessibility, and federal/provincial requirements. Based on the insights gained, the prototype can be revised to ensure that it meets the desired objectives and effectively communicates the intended message to the target audience. *Note: In some scenarios, a formal evaluation may be required at this stage.*	Feedback documents, comments.
Phase 2: Production		
Step 6: Build	To build effective and accurate assets, it is important to first collect all the necessary data and reference materials. Once all the required materials are collected, specialized software can be used to visualize the data in a meaningful way.	Asset files ● Static imagery: 2D illustrations. ● Animation: 3D models. ● Interactive: Interactive elements in different states (e.g., buttons).
Step 7: Compile	At this step, it is important to compile all the assets created during the previous steps into a cohesive whole. This involves collecting all the visual and written content, and combining it into a version that effectively communicates the intended message to the target audience. This version can then be used to solicit meaningful feedback, reactions, and responses from stakeholders and users, and ultimately identify areas for improvement.	● Static imagery: Refined comprehensive layout. ● Animation: Playblast (a low-fidelity sample of the animation), test render (high-fidelity sample of the animation). ● Interactive: Software demonstration.
Step 8: Review	Same as *Step 5—Review.*	Feedback documents, comments.

(continued)

Table 7.2 (continued)

Steps of the Framework	Activities	Example outputs
Phase 3: Post-production		
Step 9: Refine	After collecting feedback from stakeholders and making any necessary final edits, it is important to prepare the final visualization for dissemination. This involves cleaning up files, verifying that all dissemination or submission requirements have been met, and ensuring that the final visualization complies with all relevant standards. It is also recommended that the visualization be reviewed by a subject matter expert to verify the accuracy of the content.	Final visualization.
Step 10: Deliver	Once the final visualization has been created and meets all necessary requirements, it is time to export the file(s) for the client in a format that is suitable for dissemination. Additionally, it is crucial to properly save any relevant project documentation and working files; this can aid in future updates or modifications if needed. Lastly, it is important to properly credit and acknowledge any contributors or sources if applicable.	Final visualization files, project documentation.
Step 11: Evaluate	In this final step, it is important to assess the quality and effectiveness of the visualization in achieving the goals set at the start of the project. This can be achieved through formal evaluations with evaluators and users. Although less desirable, an informal evaluation, in the form of a debrief within the team or by oneself can also be helpful in identifying areas for improvement or future development. Finally, it is important to assess the impact of the visualization through analytics, which can provide data on how many people viewed or interacted with the asset, and how they engaged with the content. By following these steps, the quality and effectiveness of the visualization can be evaluated, and areas for improvement for future development can be identified.	Usability report, feedback documents, comments.

Example outputs may differ depending on the media type of the visualization

B3: Preparation Preparation refers to the various points in the design process where the team generates materials and documents that serve as a roadmap for the visualization process (particularly during the pre-production and production stages). These materials may take the form of detailed project plans, timelines, budgets, and other relevant documents that guide the team in the production process. Additionally, preparation involves creating key design artifacts and other documents that are important for soliciting meaningful feedback from collaborators and other stakeholders. These materials provide guidance and clarity for the entire team, streamlining the production process and help to ensure that the project is completed on time, within budget, and to the satisfaction of all stakeholders.

B4: Exploration This bright spot refers to points in the design process where the team investigates a variety of possible design solutions, with the goal of uncovering unexpected, unique, and

Table 7.3 Detailed breakdown of the bright spots and pain points experienced by visualizers and/or collaborators at each step of the framework

Steps of framework	Bright spots	Pain points
Step 1: Orient	(B1, B2) Clarify project expectations: Clients have an opportunity to provide context while visualizers can ask probing questions to further clarify their request. As a result, a shared definition of success becomes more evident for the team. (B1) Build new understanding: By sharing their own perspectives, clients and visualizers may come to a new understanding of the project requirements. (B1) Achieve alignment: Clients and visualizers communicate their expectations, responsibilities, and schedule.	(P1, P3) Time-intensive onboarding: Visualization team may need to invest time to onboard/educate clients and other teammates who are unfamiliar with the design process. (P3, P4) Cutting corners: Negotiate budget, and cutting important steps of the process to accommodate limited resources. (P2, P3) Resistance to changing design approach: Client is set on a certain visualization request and is resistant to exploring different design approaches suggested by the team. On the other hand, the visualization team is set on a certain design approach and is resistant to accommodating client requests. (P1, P3) Lack of shared vocabulary: Client has difficulty in communicating the challenge or problem space. On the other hand, the visualization team is unable to properly interpret the client's request.
Phase 1: Pre-production		
Step 2: Research and Define	(B1) Build deeper understanding: Visualizers acquire a nuanced understanding of the problem, the audience, and the context-of-use through primary and secondary research, exploring various dimensions of the issue at hand. (B1) Achieve alignment: The team becomes more strongly aligned by defining a common problem statement. (B3) Prepare for pre-visualization phase: Generate documents that will serve as a roadmap for the rest of the pre-production stage.	(P2, P3) Resistance to redefining the problem: Client is resistant in changing their preconceived notion of the problem space, and/or target audience. Alternatively, the visualization team may be unwilling to challenge their own assumptions. (P4) Limited resources that affect project scope: Lack of resources to perform research and analysis (expertise, finance, time, access to users, etc.). (P3) Lack of awareness and/or appreciation: Cutting important steps because client and team are not aware and/or do not appreciate the importance and purpose of each step of the design process. (P1) Lack of communication and engagement: A lack of communication and collaboration leads to an inaccurate definition of the problem space and project objectives. This may not be readily apparent, but will cause issues down the line.
Step 3: Ideate	(B4) Open-minded exploration: Uncover unexpected, unique, and potentially effective design solutions by exploring many possible options.	(P1, P2, P3) Jumping to conclusions: Difficulty brainstorming the potential design approaches for the project due to early judgment, devil's advocate, unclear goals, inexperienced facilitations, etc. (P2, P3) Lack of awareness of design possibilities: Client, stakeholders and team do not understand and/or are not aware of the universe of multimedia possibilities or the design approaches that can be employed. (P2, P3) Resistance to partnership and collaboration: Client is set on a certain

(continued)

Table 7.3 (continued)

Steps of framework	Bright spots	Pain points
		visualization idea and treats the team as a vendor (production studio) as opposed to a partner.
Step 4: Draft	(B2, B3) Prepare material for soliciting feedback: Create material used to solicit meaningful feedback from collaborators. (B3) Prepare for visualization phase: Create materials used to guide production for internal team members.	(P1, P3) Client does not understand the draft and/or draft makes the wrong impression: The fidelity of the draft affects judgment. For example, a client may mistake storyboards or animatics for final products rather than artifacts intended for feedback and critique. They may understand the purpose, but focus on the wrong things. On the other hand, the visualization team creates artifacts that are not appropriate for review, which can make it difficult for people to provide meaningful feedback. The draft may be too rough to be comprehensible to reviewers, or too polished, making reviewers feel like their input is no longer needed or valid.
Step 5: Review	(B2) Identify issues: Catch and address issues while the design is still easily editable. (B2) Prevent issues: Ensure the emerging plan is on the right track, and the project is meeting its requirements. (B1, B2) Solicit meaningful feedback: Use the materials created to solicit valuable feedback. (B1) Achieve alignment: An opportunity for collaborators, clients, and users to communicate expectations.	(P4) Limited resources that affect project scope: Lack of resources to carry out review (e.g. Limited or no access to users, other stakeholders, expertise, finance, time, etc.). (P3) Missed opportunities: Project team does not review the draft seriously or thoroughly enough, missing an opportunity to address issues when the project is still easily editable. (P1, P3) Resistance to changing design approach: The client and designers do not meet eye to eye and are resistant to change.
Phase 2: Production		
Step 6: Build	(B2, B5) Create scientifically-informed assets: Create visual interpretations informed by available scientific evidence. (B4) Guided exploration: Explore lighting/texturing, etc. and other stylistic decisions that could not be made in the pre-visualization stages.	(P4) Technical issues, expected and unexpected: Technical issues due to a variety of reasons (lack of expertise, unexpected issues, etc.).
Step 7: Compile	(B5) Realize end product: String assets together into a cohesive preview of the final product. (B2, B3) Prepare material for soliciting feedback: Create material used to solicit meaningful feedback from collaborators. (B3) Prepare for post-visualization phase: Create materials used to guide production for internal team members.	(P1, P3) Client does not understand the preview and/or preview makes the wrong impression: The fidelity of the preview affects judgment. For example, a client may mistake a play blast of an animation for final products rather than artifacts intended for feedback and critique. They may understand the purpose, but focus on the wrong things. On the other hand, the visualization team creates artifacts that are not appropriate for review, which can make it difficult for people to provide meaningful feedback. The preview may be too rough and illegible or too polished, making people feel like their input is no longer needed or valid.
Step 8: Review	(B2, B3) Prepare material for soliciting feedback: Create material used to solicit meaningful feedback from collaborators. (B1,B2) Solicit meaningful feedback: Use the	(P4) Limited resources that affect project scope: Lack of resources to carry out review (e.g. Limited or no access to users, other stakeholders, expertise, finance, time, etc.).

(continued)

Table 7.3 (continued)

Steps of framework	Bright spots	Pain points
	materials created to solicit valuable feedback. (B1) Achieve alignment: An opportunity for collaborators, clients, users to communicate expectations with one another.	(P3) Missed opportunities: Project team does not review the preview seriously or thoroughly enough, missing an opportunity to address issues when the project is still easily editable. (P1, P3) Resistance to changing design approach: The client and designers do not meet eye to eye and are resistant to change.
Phase 3: Post-production		
Step 9: Refine	(B5) Realize end product: Add final touches to the visualization. (B2) Prevent issues: Final opportunity to ensure the project is on the right track and meeting its requirements.	(P1) Last-minute changes: During this period of low editability, major feedback surfaces lead to frustration, a change in direction, and an increase in deadline and resource-related pressures.
Step 10: Deliver	(B2, B3) Prepare material for soliciting feedback: Create material used to solicit meaningful feedback from collaborators.	(P1) Miscommunication: There is difficulty wrapping up a project because project requirements have not been clearly communicated. (P1) Last-minute changes: During this period of low editability, major feedback surfaces leading to frustration, a change in direction, and an increase in deadline and resource-related pressures.
Step 11: Evaluate	(B2, B3) Prepare material for soliciting feedback: Create material used to solicit meaningful feedback from collaborators.	(P4) Limited resources that affect project scope: Lack of available resources to conduct evaluation (e.g. limited access to users, expertise, budget, time, etc.). (P3) Missed opportunities: Team does not see value or reason in evaluating the visualization.

Legends for bright spots: B1: Collective understanding; B2: Quality assurance; B3: Preparation; B4: Exploration; B5: Creation/realization. Legends for pain points: P1: Misalignment; P2: Resistance to change; P3: Difference of awareness in the design process; P4: Lack of resources

effective approaches to solve the challenge. By investing time in the exploration of options, ideas, and approaches, the team can increase the likelihood of creating a final visualization that is more effective and impactful.

B5: Creation/Realization This occurs when the team utilizes all of the insights and materials generated during the previous stages to bring the visualization to life (i.e., actual creation or realization of the project deliverables). This stage involves the use of scientific information to create an accurate visual representation of the subject matter, bringing together various assets into a cohesive preview of the final product, adding final touches to the visualization, and delivering a compelling and impactful visualization that meets the needs and expectations of the project.

7.3.1.4.2 Pain Points

In the context of the proposed framework, "pain points"—negative experiences felt by visualizers and their collaborators—are considered "high-risk zones" where unfavorable circumstances are more likely to occur and cause a situation to deteriorate rapidly (assuming the team does not take the necessary steps to mitigate the potential risks and/or address the issues in a timely manner). The framework details four broad categories of pain points listed below from P1 to P4; these are further broken down and mapped out against each step of the framework in Table 7.3.

P1: Misalignment Misalignment refers to a pain point where different stakeholders or teams involved in the design process have conflicting goals, priorities, or approaches. This may arise due to a variety of reasons, including time-intensive onboarding, lack of shared vocabulary, miscommunication and engagement issues. Ultimately, this misalignment can result in confusion, delays, or suboptimal outcomes.

P2: Resistance to Change This pain point refers to instances in the design process where the client, visualization team, or other stakeholders are hesitant or unwilling to explore/adopt new ideas, designs, workflows, or technologies. This resistance can arise from a variety of factors, such as a lack of familiarity or trust in the new approach, or concerns about the potential costs or risks associated with change. On the client side, this may manifest as a reluctance to explore different design approaches suggested by the team or a resistance to redefining the problem space or target audience. On the other hand, the visualization team may be fixed on a certain design approach and resistant to accommodating client requests. At the core of this pain point is a resistance to partnership and collaboration and lack of trust between the team.

P3: Difference of Awareness in the Design Process This pain point arises when different stakeholders or teams involved in the project have differing levels of knowledge, understanding and/or appreciation of the design process and/or the impact of design strategy upon communication. For instance, many tend to see visual style purely as a feature that drives esthetics and engagement, when it can also have an impact on communication objectives. These issues can include time-intensive onboarding, resistance to changing design approaches, lack of shared vocabulary, resistance to redefining the problem, jumping to conclusions or cutting corners (by skipping critical steps in the process) and missed opportunities to thoroughly review drafts and previews. As a result, the probability of producing an unsatisfactory or ineffective final visualization increases when the team does not recognize the importance of each step in the design process.

P4: Lack of Resources This pain point refers to instances where the team does not have sufficient time, budget, personnel and/or expertise to execute the design process effectively. For example, this might occur when the design team advocates for one solution over another because they lack the requisite skills or resources to implement the design solution best suited to the communication goal. Limited resources can significantly impact the project scope, leading to cutting corners, and the removal of important steps from the design process to accommodate for the lack of resources.

7.4 Potential Applications of the Framework

7.4.1 Planning and Onboarding

Through developing this framework for scientific visualization, we've identified the key steps in the design process practiced by visualization teams as well as the necessary skills, activities, outputs, bright spots, and pain points associated with each step. Practitioners, particularly novices-in-training, can take advantage of these learnings when planning for upcoming projects with their clients. By using this framework, visualizers introduce clients to the complexity and nuances of visualization as well as a shared vocabulary for communicating their ideas effectively. By understanding the role that different activities and outputs play in contributing to the final visualization design, the team will be more inclined to invest time and resources into them. Ultimately, we envision that visualizers, clients, and their peripheral collaborators can build a more robust workflow that helps them anticipate and prepare for potential obstacles during the course of a visualization project. Simply convincing clients that they are investing in a creative process, rather than a singular output like a graphic or an animation, can set the stage for collaboration and successful navigation of the many steps in this creative process.

7.4.2 Workflow Improvement Tools

We can also use the framework to pinpoint areas in the visualization process that can be improved by the development of new workflow tools and resources. For instance, it can be challenging to explore potential visualization approaches with clients during pre-production, especially for those new to visualization. To address this challenge, two of the authors (McGill and Saharan) designed a Multimedia Design Atlas (MDA) (https://multimediadesignatlas.notion.site/) that helps designers and clients learn and discuss the universe of multimedia categories and design possibilities when creating educational materials. By introducing the different media formats and their features, such as their pedagogical affordances and technical specifications, clients are made aware of the range of design options available to them and can make more informed decisions when selecting a media type for the final visualization early in the pre-production process.

7.5 Limitations of the Framework

While the proposed framework has been designed with good intentions, its adoption into practice may be challenging due to a variety of reasons. Below, we discuss how factors such as applicability, resource availability, framework validation, and the inherent complexity of the visualization process can impact the use of our framework in practice.

7.5.1 Lack of Validation

At this time, a limitation of the proposed framework is the lack of validation for its effectiveness and impact. Although the framework draws on an analysis of several conceptual frameworks as well as the author team's combined ~60 years of experiences in scientific visualization, it has not yet been validated in a real-world context. This raises questions about the framework's generalizability and applicability across the current landscape of work in scientific visualization—projects with different contexts-of-use, media types, target audiences, team compositions, and more.

A lack of validation limits opportunities for refining the framework based on feedback and insights from its potential users (i.e., collective experiences of visualizers and clients outside the author team). To address this limitation, the author team aims to evaluate the effectiveness of the framework in diverse contexts (e.g., different audiences, media types, environments, etc.), using existing or new methodologies to assess its usability and value in the real world. Moving forward, the author team hopes that validating this framework with empirical evidence can help to establish its credibility and efficacy, facilitating broader adoption by the scientific visualization community.

7.5.2 Challenges with Applicability

This framework is generalizable and so will need to be tailored to factors such as the project's specific subject matter, media type, team composition, expertise, organizational structure, and more. For example, potential adopters from another creative field may be deterred simply by the use of differing terminology as presented in our framework. Potential adopters may also need to modify their existing workflows and secure additional resources (e.g., budget) to implement our proposed framework. This is a time-consuming investment that is often met with resistance from stakeholders and decision-makers.

7.5.3 Resource Intensiveness

Another limitation of this framework is that it will require an investment of time, money, expertise, and other resources to implement effectively in any given context. Although beneficial, the steps of the framework—from *Orient* to *Evaluate*—are resource intensive. In some cases, projects may require specialized knowledge, access to content experts and/or target users, and acquisition of specific software and hardware, which could exclude potential adopters from implementing the proposed framework. Ultimately, a lack of resources could limit scalability, particularly for teams that have budgetary or time-related constraints. The implementation of this framework may also pose a challenge for individuals or teams who are not trained in the specific set of skills listed in the framework, nor have access to outside expertise ranging from subject matter to technical expertise.

7.5.4 Inherent Complexity of the Visualization Process

Lastly, the inherent complexity of the visualization process (and our interpretation of it) may pose a limitation to potential users of our framework. One example is the reality of collaboration and communication in an iterative design process. The proposed framework is highly iterative and collaborative, and as a result, its success is dependent on continuous and meaningful engagement between team members and stakeholders. Managing these projects can be challenging, particularly when working with a large and diverse group of individuals who have competing priorities. These challenges can lead to common project pitfalls such as misaligned expectations for the final visualization, which can cause frustration and hinder progress.

As presented in this chapter, the framework may be challenging for potential audiences to understand and ultimately implement in their work. Even with sufficient documentation (as presented in this chapter), scientific visualizers may feel discouraged to adopt this framework and practice it on a day-to-day basis. To address this limitation, the author team is in the process of developing a more practical and accessible toolkit version of the chapter, found at sciencecomm.ca. This companion guide will provide scaffolding for practitioners looking to use the framework, giving them the ability to modify and adapt the framework to meet their specific project requirements so they can use it with their clients and within their own teams.

7.6 Conclusions

In this chapter, we present a comprehensive framework for designing, producing, and evaluating scientific visualizations. Drawing on case studies and conceptual frameworks, we illustrate how our proposed framework can support the development of static, animated, and interactive media types, from initial conception to final evaluation. Throughout this process, we emphasize the importance of iterative feedback cycles and their role in refining and improving visualizations. We establish connections between the steps outlined in this framework to the activities, outputs, and individuals that impact design decisions and ultimately the flow of the overall design process. Lastly, we assess each step of the framework for its bright spots and pain points to give readers a clear understanding of the potential benefits and challenges of using this approach.

Our ultimate goal in proposing this framework is to support scientific visualization practitioners in building a design process that meets their objectives and facilitating productive conversations with clients and collaborators about the importance of a robust design process. This in part led us to develop a practical toolkit (located at https://sciencecomm.ca) that provides scaffolding for practitioners looking to implement our framework. However, further research is needed to establish the extent to which this framework is valid and fulfills this goal. Future directions for our research include validating the visualization framework by applying it to real-world projects within the visualization design space and measuring its relative efficacy when compared with current practices and existing design frameworks.

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References

Branch RM (2010) Instructional design: the ADDIE approach. Springer, New York, NY

Bucchi M, Saracino B (2016) Visual science literacy. Sci Commun 38:812–819. https://doi.org/10.1177/1075547016677833

Christiansen J (2023) Building science graphics: an illustrated guide to communicating science through diagrams and visualizations. AK Peters/CRC Press, Boca Raton, FL

Design Council (2019) Framework for innovation: design Council's evolved Double Diamond. https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/. Accessed 28 Oct 2022

Dick W, Carey L (1978) The systematic design of instruction. Scott, Foresman, and Company Glenview, IL

Evagorou M, Erduran S, Mäntylä T (2015) The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing' how science works. Int J STEM Educ 2(1): 1–13. https://doi.org/10.1186/S40594-015-0024-X

Goodsell DS, Jenkinson J (2018) Molecular illustration in research and education: past, present, and future. J Mol Biol 430:3969–3981. https://doi.org/10.1016/j.jmb.2018.04.043

Graham ID, Logan J, Harrison MB et al (2006) Lost in knowledge translation: time for a map? J Contin Educ Health Prof 26:13–24. https://doi.org/10.1002/chp.47

Iwasa JH (2010) Animating the model figure. Trends Cell Biol 20:699–704. https://doi.org/10.1016/j.tcb.2010.08.005

Jantzen SG, Jenkinson J, McGill GG (2015) Transparency in film: increasing credibility of scientific animation using citation. Nat Methods 12:293–297. https://doi.org/10.1038/nmeth.3334

Landau J, Groscurth CR, Wright L, Condit CM (2008) Visualizing nanotechnology: the impact of visual images on lay American audience associations with nanotechnology. Public Underst Sci 18:325–337. https://doi.org/10.1177/0963662507080551

Lynch M (2006) The production of scientific images: vision and re-vision in the history, philosophy, and sociology of science. In: Pauwels L (ed) Visual cultures of science: rethinking representational practices in knowledge building and science communication. Dartmouth College Press, Hanover, New Hampshire, pp 26–40

Marcink TC, Kicmal T, Armbruster E et al (2022) Intermediates in SARS-COV-2 spike–mediated cell entry. Sci Adv 8(33):eabo3153. https://doi.org/10.1126/sciadv.abo3153

McGill GG (2017) Designing instructional science visualizations in the trenches: where research meets production reality. In: Lowe R, Ploetzner R (eds) Learning from dynamic visualization: innovations in research and application. Springer, Cham, pp 119–150. https://doi.org/10.1007/978-3-319-56204-9_6

McGill GG (2022) Knowledge synthesis through scientific visualization. Nat Microbiol 7(185):119–150. https://doi.org/10.1038/s41564-021-01048-x

Reilly C, Ingber DE (2017) Art advancing science: filmmaking leads to molecular insights at the Nanoscale. ACS Nano 11:12156–12166. https://doi.org/10.1021/acsnano.7b05266

Roche J, Arias R, Bell L et al (2021) Taking stock and re-examining the role of science communication. Front Environ Sci. https://doi.org/10.3389/fenvs.2021.734081

Schönborn KJ, Anderson TR (2006) The importance of visual literacy in the education of biochemists. Biochem Mol Biol Educ 34(2):94–102. https://doi.org/10.1002/BMB.2006.49403402094

Stanford d. School (2010) An introduction to design thinking PROCESS GUIDE. Hasso Plattner Institute of Design at Stanford University. Available via Michael Shanks. https://web.stanford.edu/~mshanks/MichaelShanks/files/509554.pdf. Accessed 27 Oct 2022

Tornasi Z, Delaney N, European Commission, Directorate-General for Research and Innovation (2020) Science communication: achievements in Horizon 2020 and recommendations on the way forward. Publications Office of the European Union. Available from https://doi.org/10.2777/518359. Accessed 13 Mar 2023

Trumbo J (1999) Visual literacy and science communication. Sci Commun 20:409–425. https://doi.org/10.1177/1075547099020004004

de Vries RD, Schmitz KS, Bovier FT et al (2021) Intranasal fusion inhibitory lipopeptide prevents direct-contact SARS-COV-2 transmission in ferrets. Science 371:1379–1382. https://doi.org/10.1126/science.abf4896

Part II

Anatomical and Cell Biology Education

Palpation: The Art of Felt Anatomy

8

Janet Philp and Joan Smith

Abstract

This chapter is based around a conversation between the two authors that took place in December 2022 where themes and ideas prompted by, and relating to, the felt anatomical objects produced by Janet Philp were discussed. Quotes from this conversation have been included throughout the chapter to illustrate discussion points. We consider these felt artifacts within the wider contexts of teaching, learning, and public engagement, exploring why Janet has chosen to work with felt and how the material qualities of felt can be used to help explain and develop the understanding of human anatomy. We examine the use of color and scale within the felt objects in relation to the wider field of anatomical visualization and make comparisons with fine art sculpture and painting. We consider the importance of accuracy in anatomical depictions and explore whether more can be learnt about anatomy when we are asked to question what is presented to us in different ways. We conclude by looking at the function of anatomical felts as boundary objects that sit at the edges of the social world of anatomists, inviting interaction. We propose that the felts have the potential to expand understanding in others through prompting conversation and discussion.

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Keywords

Felt · Anatomical · Participation · Engagement · Boundary object · Tactile

"The felted Netter neck is so much more vibrant than the two-dimensional original. The relative depth of structures and the layering of muscles, nerves and blood vessels can be more intuitively appreciated in this form than on the page. I have the model next to my desk, and I always get comments on it from students and visitors. It's a novel way to view anatomy and inspires people to think about anatomical art and how it can be more than just visual—felting provides a tactile element that is more reflective of lab-based anatomy learning." (Fig. 8.1)

– Quote from academic owner of an anatomical felt

8.1 Introduction

This chapter looks at what can be learned by the observation and production of anatomical felts. The felts represent low fidelity models of the body that can be produced manually. Their tactile nature is unusual in the medical field, but their warmth and comfort may bridge a barrier that more precise medical visualizations fail to cross, often falling foul of claims that their depiction of anatomy sensationalizes the subject (Stephan and Fisk 2021). This chapter is based on a conversation between the two authors and their experiences of producing anatomical felts.

L. Shapiro (ed.), *Graphic Medicine, Humanizing Healthcare and Novel Approaches in Anatomical Education*, Biomedical Visualization 3, https://doi.org/10.1007/978-3-031-39035-7_8

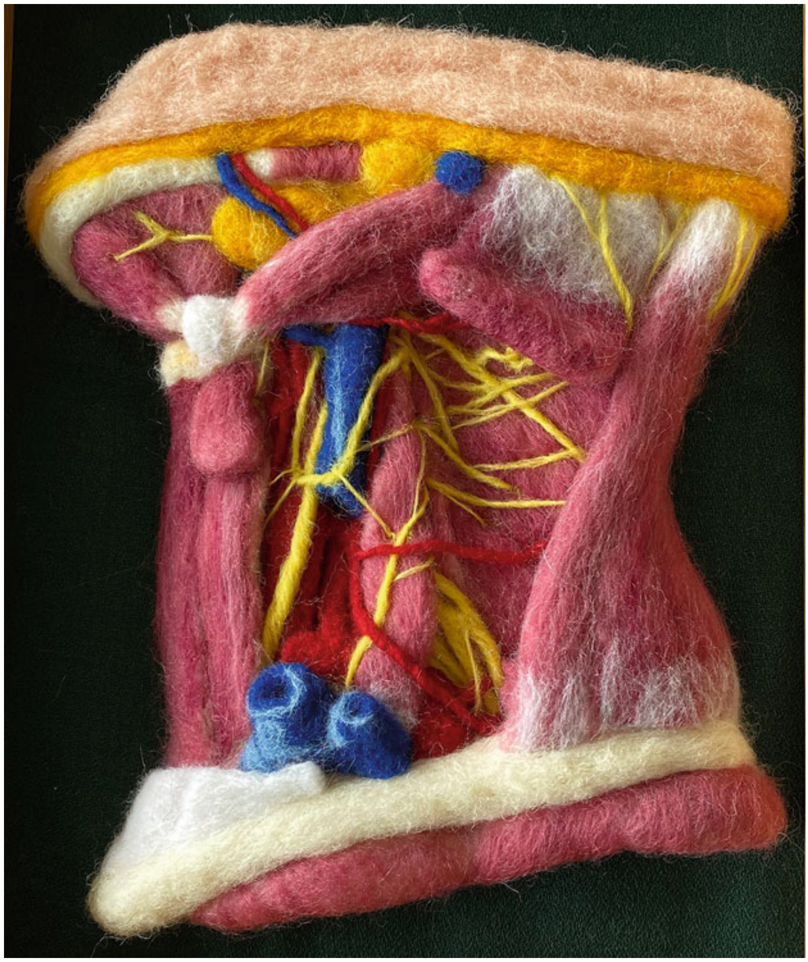

Fig. 8.1 A felt reproduction of a neck dissection from Netter Atlas, sixth edition (photo Janet Philp)

In preparing to write this chapter by discussing Janet's felt objects, we discovered that they fulfilled a purpose that was unanticipated by either of us: that of prompting a conversation that was very wide ranging. In many ways the objects' purpose is ambiguous. They are the result of an enjoyable hobby, a challenge, and a way to relax. The process of making is fundamental to their existence, and it is through this process that new thoughts and realizations are formed, embodying what Ingold describes as "thinking through making," an important element of the art of inquiry (Ingold 2013). The felt objects are exchanged and shared with others who enjoy their complexity and understand them as they relate to their own knowledge. Rather than being used for directly teaching anatomy, they provoke questions about the forms that they represent.

Janet has been studying anatomy for over a decade. She has completed the Anatomical Society of Great Britain's' anatomical teaching program and holds a diploma in anatomical sciences. She is currently undertaking a PhD looking at access to dissecting rooms within the United Kingdom. She is the co-founder of Anatomy Nights, an anatomical public engagement project that has received an innovation award from the American Association for Anatomy to develop resources for global implementation. Her displays for public engagement have used 3D printing, wax and fused glass to represent anatomical structures. Her flower filled felted pelvis was awarded a prize for outstanding creative contribution at the 2021 International Federation of Associations of Anatomists' conference in an exhibition organized by the Federative

International Program for Anatomical Education. She is a member of the International Feltmakers Association as well as several anatomical associations.

Joan is an artist who has had an interest in human anatomy and the history of medicine for many years. Her recent projects include an installation, "Skull Color Chart," an interpretation of the University of Edinburgh's skull collection, "Field Notes" which celebrated the work of the Scottish Women's Hospitals in World War I and an international collaborative research project looking at contentious collections, including human remains, in European museums, "TRACES." She was a Senior Lecturer in the School of Art in the University of Edinburgh until 2021 having taught there for over thirty years. She has taught anatomy for artists for most of her career, including running an undergraduate course in "Anatomy and Art."

Janet and Joan have worked together on several projects to raise awareness of anatomy with artists. They have run workshops for undergraduate students from Edinburgh College of Art, including building the muscles of the head with plasticine, in conjunction with Victoria McCulloch, and discussing the ethics of drawing human remains and of exhibiting artworks in an Anatomical Museum. They have created painted reconstructions of skulls from the University of Edinburgh's collection, including those of Robert Burns, Lord Darnley, and the Cramond murderer, for use in public engagement activities. Both Janet and Joan are members of the Edinburgh-based Art and Science group "Fusion" (fusionartsci.co.uk), and they have exhibited artworks in the Anatomical Museum and other locations. This book chapter builds on a previous text written by the co-authors, "The Fabric of the Human Body" (Philp and Smith 2023).

8.2 Why Felt?

Anatomical models are used to concisely explain the body's complex forms in a clear way. A range of plastic anatomical models are already available, so why does Janet want to make her own, and why, more specifically, would she want to make these complex anatomical models in felt?

Felt has been around for a long time. Its mythical beginnings, where travelers cushioned their feet by filling their shoes with pieces of loose wool which, during the journey with the moistness of the feet and the agitation of walking, transformed into felt, may not be verifiable but the oldest piece of felted fabric has been dated from around 1500 BC (Gordon 1980). Felt can be produced anywhere where fleeced animals are abundant and is thought to originate from the nomadic people of central Asia (Gordon 1980). Every wool fiber is covered in microscopic scales that interlock when the fibers are moist and agitated. The process used to be carried out by hand, or foot, and the resulting piece of fabric agitated by a group of villagers or pulled behind horses across the Tibetan planes. Felt can be produced to a thickness that it is almost impossible to stab through, as was used in medieval armor, or it can be produced so thinly you can almost see through it.

In the industrial era, large machines took over the felt production process and traditional wet felting was replaced with dry felting where thousands of grooved needles were punched into the fibers to produce sheets of material. In the 1980s, artists in the USA removed some needles from felting machines and started to produce needle felt art by hand. This allowed for three-dimensional (3D) objects to be created with fine details added using a variety of needles to produce different effects (Wesley 2019).

Whilst the process of going from raw fleece to workable fibers can be time consuming and messy, workable fibers from numerous animals and plant sources can be readily accessed from suppliers at a reasonable price. Felting is an accessible activity that can be used to craft multiple forms.

An online search of available educational anatomy toys returns many examples of aprons or templates on which felt shapes representing organs can be placed to aid in basic anatomical understanding. Thin sheets of felt have been used to represent structures for undergraduate teaching very effectively (Advolodkina et al. 2017) but what is being discussed in this chapter are mainly 3D models produced by needle felting as opposed to uses of commercially available sheets of felt fabric.

> "the move from felting cuddly animals to anatomical structures was inspired by the work of Stephanie Metz. I came across her work when Anatomy Nights were running a Halloween anatomical competition, trying to address the anatomically incorrect decorations you get at that time of the year. She produces teddy bear skulls that have bone ears. I tried producing one of those as the prize for our competition. It may be the anatomical proportions of a teddy bear that resulted in people finding it cute rather than disturbing, but I continued from there, producing a dog (Fig. 8.2) and then a unicorn (Fig. 8.3) before turning my attention to a human skull."—JP

The production of anatomical felts undoubtably addresses dual purposes. At the end of a busy day, it is relaxing to undertake a creative craft project. Janet's anatomical study has been intertwined around her administrative role in higher education and therefore it should surprise no one that anatomy finds a way of appearing in her crafts as well; relaxing whilst producing something which also embeds knowledge. The production of the Netter neck dissection felt picture—Fig. 8.1 required hours of observing the Netter image (Netter 2014) and noting which structures overlapped with which, supported by Janet's ongoing study of the head and neck area. The production of this felt was an additive process; structures placed on top of others until the final low relief sculpture was completed in a sort of reverse dissection, that embedded the knowledge acquired through several different modes of learning.

> "Trying to produce an anatomical structure in felt helps you to appreciate the complexity of the human body. It is not an effective teaching tool because it is too time consuming, but it offers another modality that can be useful. Many institutions offer craft sessions in an effort to offer some mental downtime, a way to reduce cognitive overload. By working with felt to slowly build up a structure that you should understand, you have the opportunity to appreciate the form, recreate it, to embed the knowledge and compound your understanding without it feeling like you are learning."—JP.

8.3 Nature's Fibers

The technical process of making an anatomical felt can vary depending on the sort of structure that is required. For the Internal Structure of the Cell (Fig. 8.4), the cell wall was made by wet felting around a balloon. To wet felt, very thin layers of wool are layered on top of the balloon, each layer having fibers perpendicular to the previous layer. These layers are moistened with soapy water and then agitated either by hand or through a layer of bubble wrap or netting. This agitation causes the fibers to knit together. In making the cell membrane, this process was repeated three times to give a striped appearance that represented the lipid bilayer. This structure was made firmer by popping the balloon within the felt, turning the felt inside out and inserting another balloon so that the fabric could be felted from both sides. Once this had dried, incisions were then made to create the cut-away appearance of the cell membrane. The nuclear envelope was made with the same technique. The cytoplasm was created with a technique called Nuno felting which was developed by Polly Stirling, a fiber artist from New South Wales, Australia in 1992 (Sergeyeva and Sergeyev 2019). In this technique the wool fibers are felted onto a sheer silk gauze. As the fibers interlock during the felting process, they pull the fabric up to give a crumpled appearance. To give the appearance of a section cut out of the cell's surface, the fabric had to be held in place using strands of invisible thread.

> Joan—So did you have to come up with solutions to problems in a similar way to nature?
>
> Janet—I guess the invisible thread holding it all in place is like the cytoskeleton within the cell. It's part of the challenge as to how to represent these anatomical features within the model.

The challenge of representing an intricate anatomical feature was made more apparent in the construction of the spine (Fig. 8.5).

> "I started off producing one of each vertebra for a retirement gift (Fig. 8.6) and then you produce a few more and quickly you are at the point where you are only a few vertebrae away from a spine and so you begin to wonder if it can be done. You think that you have all of those processes in the right

Fig. 8.2 A felted dog skull (photo Janet Philp)

Fig. 8.3 A felted unicorn skull. The unicorn is the national animal of Scotland (photo Janet Philp)

Fig. 8.4 "Internal Structure of a Cell" produced as part of the international felt swap, organized by the International Felt Makers Association 2022 (photo Janet Philp)

> place but when it comes to construction you appreciate how everything lines up and how exact each of those bony projections needs to be to ensure the spine can function. It's a wonder that things don't go wrong more often in the human body."—JP

Most of Janet's felt models are produced through needle felting where the fibers are bonded together by repeated stabbing. The structure becomes firmer the more it is stabbed, and its dimensions shrink in the direction in which it is being stabbed. This allows for quite intricate details to be produced and any shape can be replicated with patience. By varying the amount and intensity of needle felting, bony elements can be made firmer than the surrounding tissue, an important subtlety that is missing in hard plastic models.

When making the Netter construction (Fig. 8.7), a recreation of plate 32 from the Netter Atlas sixth edition (Netter 2014), different techniques were adopted.

The basic shape was marked out on the background fabric with core wool. This was used for the bones and to bulk up areas to create the 3D effect. The blood vessels were added in their classic colorings. Unless they are shown as cut in the final picture, the complete blood vessel was made so that any muscles overlying that structure lay correctly. Each muscle was constructed independently and then fixed into place. This requires an understanding of the layering of the structures so that nerves and blood vessels can be placed in the correct position. In the third picture of the series, the internal jugular vein had to be put in place before the digastric muscle was laid across and similarly the nerves and blood vessels were put in place before being covered by the trapezius muscle. This process is additive and is the

Fig. 8.5 The continuation of the spinal project with a life size spine. Each vertebra was individually produced and stacked onto a metal support that runs in place of the spinal cord (photo Janet Philp)

opposite of dissection where structures are removed to reveal what lies deeper to them.

8.4 Color

Wool is produced in many colors, and these can be blended together to produce an almost infinite palette. The expressive potential of color has been widely discussed in the history of art. That color is also used for expressive means in science is perhaps less obvious, as scientific imaging and visualization can be assumed to be "the truth" and the colors used "real." However, when examining a prosection of the human body or an image of a dissected heart, for example, it soon becomes clear that without some means of highlighting and enhancing the various structures with color, it can be very difficult to tell one structure from another. A balance must be struck because, whilst a highly realistic digital image would be anatomically correct, it might provide so much information that it overwhelms the viewer and produces cognitive overload.

In artifacts that combine art and science, such as Janet's felt models, the use of color straddles both expression and observation. In some of the felt objects, such as the "Internal Structure of a Cell" (Fig. 8.4), Janet's use of color imitates that of the original image. In others, she uses the colors conventional to anatomical diagrams: red for arteries, blue for veins, yellow for nerves, and so on. In Janet's "Heart," (discussed later) the colors are as naturalistic as the wool color palette will allow. In many ways this mixed approach to the use of color is reflective of the broad diversity of approaches to visualization within the field of human anatomy. Artificial staining to enhance specimens, digital imaging, photography, and drawing bring with them their own color palettes and corresponding benefits and limitations (Fig. 8.8). Plastic anatomical models either simplify the natural colors of tissue and bone or avoid them altogether, using instead a primary color palette to help define different structures.

The bright colors of some of the dyed wool also lend themselves to representing artificial staining in histological slides or computer images.

In other examples of Janet's felts, color can be limited to striking effect. In the head MRI, various shades of white felt have been built up on a black velvet background (Fig. 8.9).

> "I used velvet because I wanted as rich a black as I could find. The different intensities of the image were then built up with varying layers of white wool. With the different sheep varieties there are many shades of white. Trying to portray the wispiness of the nasal sinuses and the bright white of some of the central brain structures involved a lot of different shades of white."—JP.

The use of color coding in anatomy diagrams and illustrations appears to have evolved rather

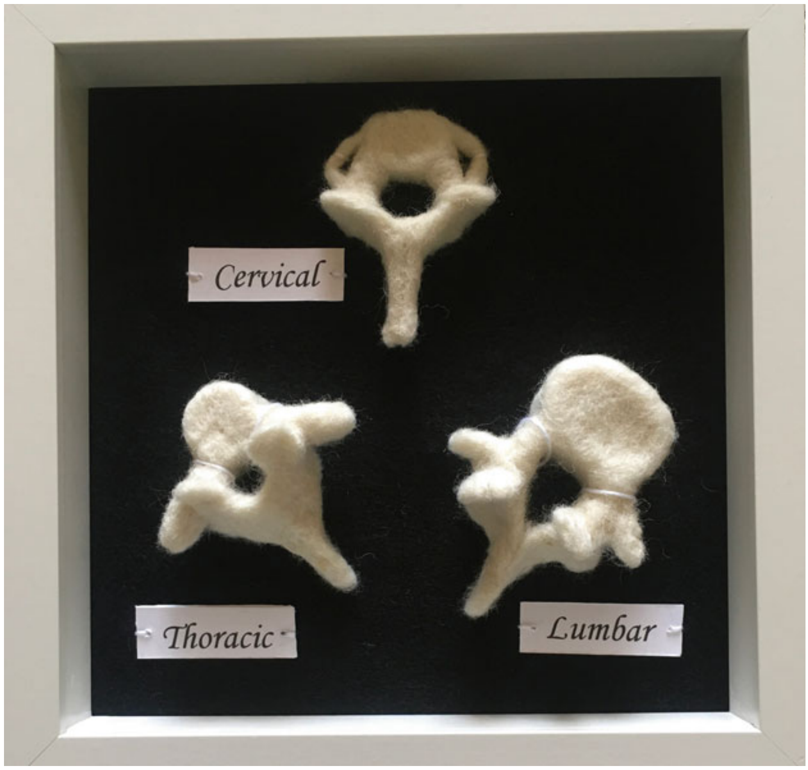

Fig. 8.6 Three different vertebrae, produced and framed as a retirement gift (photo Janet Philp)

than been designed, and there is a collective understanding within the field of anatomy of the conventional ways of using color. The use of color in early anatomical atlases such as Fabricius' *Tabulae Pictae* with its large-scale illustrations painted in oils (Conti et al. 2010), and Gaspare Aselli's four-color-printed wood cuts, tended to be naturalistic, rather than symbolic, and based on observation. The use of symbolic primary colors—red and blue—to represent arteries and veins, respectively, appears to have been derived from Bernhard Siegfried Albinus' use of colored wax injected during dissections prepared for illustration. Yellow was adopted as representative of nerves in the 1887 edition of Gray's Anatomy, where three plate color printing aligned with these colored waxes (Pole 1790; Assen 2015).

The example below shows the same illustration from two early editions of Gray's Anatomy (1858 and 1887) (Fig. 8.10). In the original 1858 version, the monochrome drawing details the anatomy of the neck, using text to define and differentiate arteries, veins, and nerves. In the colored drawing from 1887 these structures can be clearly seen and easily differentiated at first glance. The introduction of color in the 1887 edition of Gray's Anatomy helped make its illustrations more easily understood. Mass production of colored printing processes led to more widespread standardization in the use of color in anatomical diagrams. Arguably, the 1887 diagram with a few highlighted structures is easier to comprehend than the full color pictures used in more recent editions.

8.5 Scale

It is interesting to consider the use of scale in Janet's felt objects. Most of Janet's felts are produced in life size format; the purpose of the object is to reflect as closely as possible the scale of the actual anatomical form. This can be seen in the vertebral column and skulls, for example. In others, the felt model helps to show the detail of

Fig. 8.7 A series of pictures from top left to bottom right that show the stages in the production of the Netter neck dissection felt (photo Janet Philp)

something that is so small it could not possibly be made life sized in felt, such as the "Internal Structure of the Cell" (Fig. 8.4).

> "the cell was produced for an international felt association swap where the theme was structure. Trying to produce the internal structure of a cell seemed like a challenge. When you produce something like a cell there obviously has to be some degree of magnification. For the other anatomical felts actual size seemed the obvious fit, that way I have something to compare it to when making it."—JP

It has been suggested that the size of an anatomical model affects one's ability to learn from it, as does the ability to handle it (Yang et al. 2021). One of the advantages of working with felt is that it is unbreakable and therefore can be handled. The "Internal Structure of the Cell" could be handled and if dropped it would absorb the impact. Whilst a larger scale makes it easier to see all the internal structures of a microscopic entity such as the cell, working to life size can also be impactful.

This proved to be the case in the felt heart which Janet made according to the actual size of a human heart, held within a skeletal hand to draw attention to the size of the organ (Fig. 8.11), and the conversation it prompted:

> Janet—so partly this project was about color. If you look at the arteries and veins in the heart, you would need to know which is which to tell them apart. I haven't used the classic red and blue

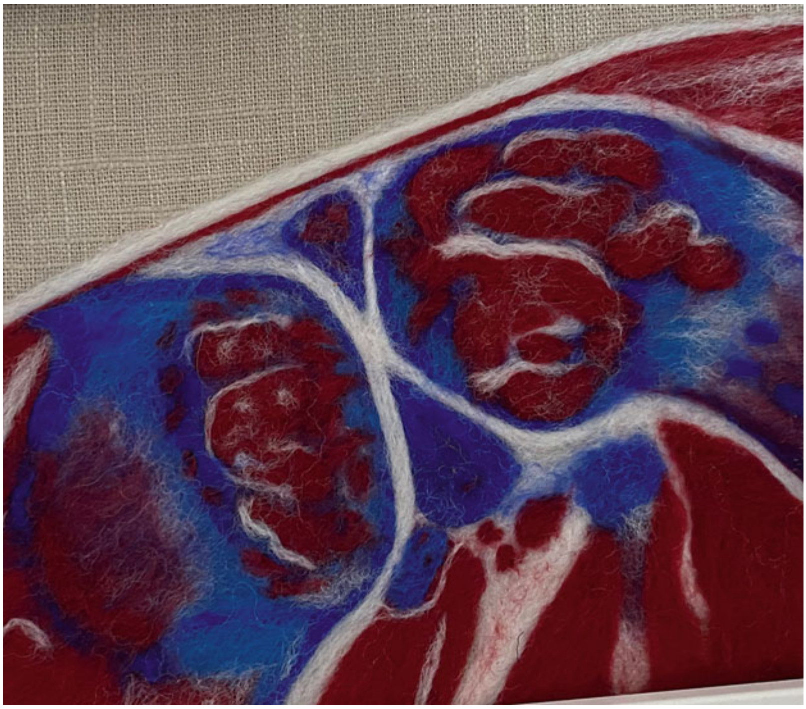

Fig. 8.8 A felted reproduction of a histology slide of a knee joint stained with trichrome. The femur is on the right and the tibia and fibula on the left. Original image supplied by Dr. Jamie Chapman (photo Janet Philp)

coloring for the veins which makes the yellow of the fat stand out. But, actually, the talking point of this piece has been this little artery down here. This is the left anterior descending artery. It's called the LAD artery or the widow maker. If that gets blocked then the chance of surviving that heart attack is small, it provides blood to a significant proportion of the heart muscle. Look how small it is.

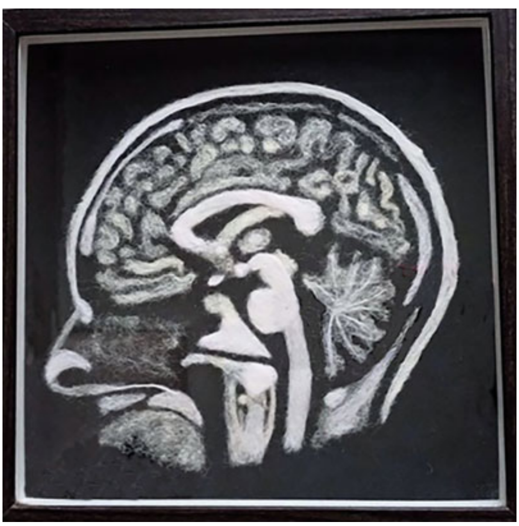

Fig. 8.9 A felted reproduction of an MRI on black velvet. Original picture supplied by Dr. Amanda Meyer (photo Janet Philp)

Joan—I know it's a bit scary, isn't it, that your life depends on that tiny structure not getting blocked up? But I also think there's something interesting about the scale, you know, the fact that you're likening the scale of the heart to the scale of the hand. I've seen something similar in other artworks, such as Gabriel Orozco's sculpture, *My Hands are My Heart* where his hands have squashed a piece of clay into the shape of a heart, leaving the imprint of his fingers in the clay.

Also, the combination of heart and hand is seen a lot in memento mori, religious iconography, heart health publicity and symbols of love and caring across a wide range of cultures. It taps into a lot of different contexts. Would you use it to teach about the heart?

Janet—The size of the heart is the size of your clenched fist which a lot of people don't know. You know, a loosely clenched fist, maybe. Even that small thing, for people to understand that that is the scale of your heart is interesting.

Joan—I think that that's an easy way to get to grips with it. For something that your whole body relies on for functioning, it's such a small thing. It's the

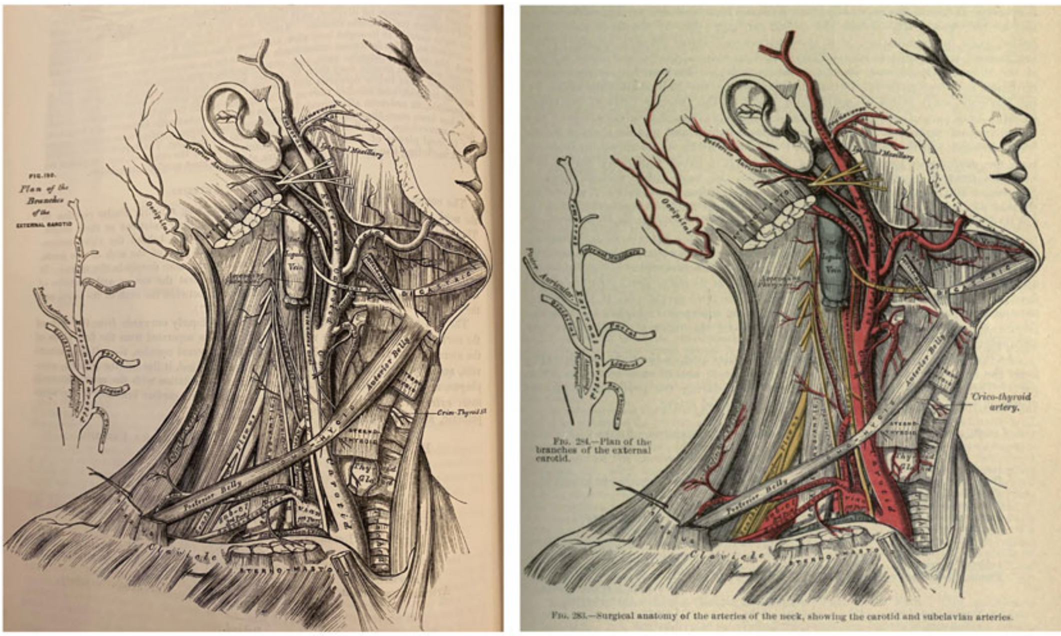

Fig. 8.10 A comparison of diagrams from Gray's Anatomy first edition 1858 and Gray's Anatomy 26th edition 1887. 1858 image reproduced with permission from The Royal College of Surgeons of Edinburgh. 1887 image sourced from Biodiversity Library

> pump that's driving the whole body. The way the skeleton hand constricts the heart makes it look painfully like it is having a heart attack—a sort of warning about the importance of looking after your heart.

8.6 Sculpted Anatomy

Needle felting is an additive process where structures are gradually built up and strengthened by working with a specialized needle to create tight bonds between wool fibers. The additive process allows objects to be understood from the inside out as forms are built up in layers.

The process allows time for the maker to think about the interconnection between form and function. As the felt objects grow, the maker can literally feel the solutions that nature has evolved, gradually taking shape.

In additive sculptural practices such as clay modeling, where the artist is working with relatively soft materials, an armature might be used as internal reinforcement, allowing other materials to be added to it to create a form. Similarly, in the human body one of the roles of the skeleton is to be an internal framework, a structure that allows movement through the actions of muscles attached to bones using tendons. The artist often must come up with solutions that mimic those found in nature. For example, the fibrous nature of felt can be compared to bone. In compact bone, fibers are tightly bonded together for strength; in spongy bone, they are more loosely bonded to reduce weight and density. The varying density means that compact bone has more fibers packed into it than in a similar area of spongy bone. Depending on the amount of time spent in the needle felting process, felt can similarly vary in density and be as tough as wood or as soft as wool. By constructing the anatomy of the body appropriately, for example incorporating the spinal curves, a felt can be produced with no internal armature (Fig. 8.12).

Clay modeling has been used by students as an alternative to dissection (Haspel et al. 2014;

Fig. 8.11 A life size heart that is held within a skeletal hand to demonstrate the size of the organ (photo Janet Philp)

Bareither et al. 2013; Correia et al. 2022) with no significant decrease in test scores, suggesting that the reductive process of a dissection is no more effective as a teaching method than the additive process of forming clay sculptures; both require an understanding of the relationship between anatomical structures. A combination of reductive and additive processes where students dissect out structures such as a bronchial tree and then form resin casts from the dissections has also been found to be effective as a teaching aid (Hermiz et al. 2011).

One of the arguments as to why medical students should continue with dissection is that they need to realize what has been removed when they look at a prepared prosection of the human body (Jones 1997).

In dissection, unneeded matter is cut away to expose the desired anatomical structure. A surgeon must remove whatever is in the way so that they can access the part of the body on which they need to operate. This process aligns with reductive sculptural practices such as stone or wood carving where the artist starts with a block of material, which they gradually carve away, using a range of tools. In most cases, the sculptor would have made a maquette, a small version of the planned sculpture, to act as a visual aid to help plan the reductive process. Measurements based on comparison with the maquette would be marked on the surface of the block so that the sculptor knew where to cut in. Working with more and more refined tools over time, the sculptor would reveal intricate forms and details as if freeing the sculpture from the block. This process can be compared to the anatomist who dissects, having previously studied a prosection. The aim

Fig. 8.12 A small figure that demonstrates that if the anatomy is correct, it is not always necessary to use a metal armature. A standing figure can be made self-supporting by applying the correct foot structure and spinal curves—as promoted by fiber artist Anna Potapova (potapovaanna.com). This figure was produced in anatomical position and then the stance created by felting in the direction of muscle contraction to shorten the wool fibers and cause the limbs to reposition (photo Janet Philp)

is to reproduce the display of structures seen in the prosection or the anatomical atlas (Fig. 8.13).

In the eighteenth and early nineteenth centuries another sculptural practice closely aligned with anatomy and dissection became popular: the creation of écorchés or "life casts" of flayed human bodies. Used as teaching tools, écorchés allowed artists to access dissected human bodies in the form of plaster or bronze casts that could be repeatedly viewed over time. Working from these casts helped them to develop a good understanding of superficial human anatomy. The casts were created by anatomists, often working closely with sculptors, as in the case of William Hunter, who worked with Agostino Carlini to create the famous écorché, "Smugglerius" for the Royal Academy of Art in London in 1776 (Black 2007). Hunter taught

Fig. 8.13 Dorsal surface of hand showing arrangements of tendons and muscles (photo Janet Philp)

anatomy to art students using écorchés as a reference, comparing them to a life model, a human skeleton, and anatomy diagrams (Fig. 8.14).

In the twenty-first century Gunther von Hagens' exhibition "BodyWorlds," performs a similar role, using donated bodies as anatomical sculptures. Whilst his displays have attracted millions of visitors worldwide, they continue to court controversy over the use of human remains (Lantos 2011). More recent events that have used human dissection as a form of "edutainment" have caused similar outcries (Keet et al. 2023). Public engagement events that try to combine learning with enjoyable activities must hit the right balance and tone appropriate to the participants and the subject being explored (Wilmshurst et al. 2023). To reach the public, the engagement level must be heightened as people attend these events for different reasons. Varying levels of experience and knowledge can make multi-modal approaches particularly desirable. Felt can be used to cross that barrier between different social worlds as it is relatively unthreatening. Whilst there is something deeply unsettling about eating a cake that's designed to look like a brain, there is little that is unsettling about touching a felted piece of internal anatomy; in fact, using fabric models in anatomical education has been found to reduce the anxiety of students (McConnell et al. 2023). Felt anatomical objects can act as talking points and prompts for discussion about many issues relating to the body.

8.7 Learning, Teaching, Touch, and Making

In Janet's making process, she works closely with source material such as models or plastic skeletons so that she can compare her felt objects with anatomical forms, by both sight and touch or feel. While the use of sight is usually fundamental in creating any objects, the sense of touch is equally important. Touch is unburdened by extraneous information. It is intimate: fingertips can (literally) get closer to the surface of the object than eyes so that tiny details can be felt and compared to assist with learning (Reid et al. 2018). By feeling and comparing, Janet can gain a deep level of understanding of the scale, texture and form of an object, a skill she enhanced on a haptic drawing course although she rarely draws before making a felt model. She can draw on her knowledge of anatomy but is also often surprised at what she finds out by using touch and by trying to recreate the form in felt.

For example, when making a model of the human spine in felt, Janet had to consider how the bodies of the individual vertebrae and their boney processes aligned. When she came to the sacrum, which had seemed like a solid structure, she had to find where the holes would be placed that would allow the nerves to fit through. Through making the form in felt she had started to think about an anatomical puzzle that had not occurred to her before.

> "I guess I hadn't given it much thought before but when you are faced with modeling a sacrum you realize that there has to be a route for the nerves to exit from the spinal canal, so that ridge on the posterior surface is actually the roof of a tunnel that has to connect to all of the holes on both the anterior and posterior surface of the sacrum. Once you appreciate that it becomes a much harder shape to sculpt"(Fig. 8.15).—JP

Fig. 8.14 Hunter lecturing at the Royal Academy (1772), using an écorche, life model, and skeleton. Johann Zoffany, Public domain, via Wikimedia Commons

Professor Tom Gillingwater is the Chair of Anatomy at the University of Edinburgh and a Fellow of the Royal Society of Edinburgh. He takes a keen interest in education and public engagement, including public anatomy workshops. While attending some of these workshops, Janet and Joan observed Tom's hands-on teaching style, where he encouraged his students to touch prosections and bones to gain greater understanding of the anatomical forms. When asked about this later he explained that this teaching and learning method was instilled in him at an early stage of his career:

> "I vividly recall doing it during my undergraduate degree… I remember it being in the head and neck session where we were being tutored by dentists… we were doing the base of the skull and the base of the skull's not easy at the best of times…and the quality of the specimens we were learning from wasn't great… and it was one of the dentists who said, well, close your eyes and run your thumb around it. And see if you can build up a kind of touch memory of it."—TG

In the laboratory, it is often difficult to see the details described in anatomical illustrations. By moving from the sense of sight to that of touch, structures that cannot be seen can be perceived:

> "The classic one is the groove on the back of the humerus. All the textbooks have it drawn on beautifully as a spiral shaped groove on the back. I don't think any of us has seen a decent one in the lab, but the minute you close your eyes and actually run your fingers around the back of it, you can feel for where it is."—TG

Recent research has shown that encouraging students to touch specimens in the laboratory has a positive impact on their test results (Dennis and Creamer 2022). The importance of touch is also

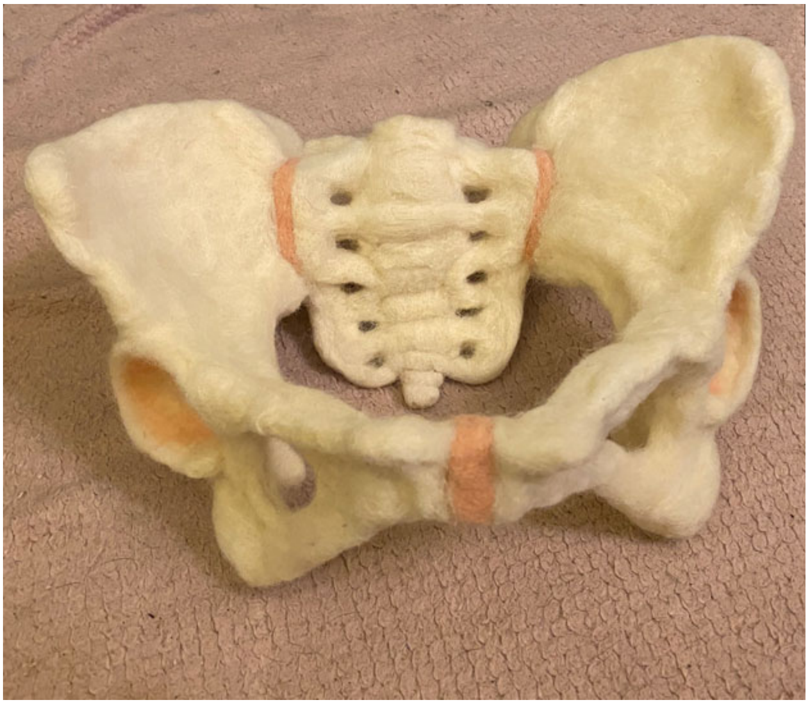

Fig. 8.15 The felted sacrum in place in the finished pelvic girdle. Ensuring that there was a passage for nerves to pass through all the holes in the sacrum made the bone much more of a challenge to recreate (photo Janet Philp)

acknowledged in software and technological innovation related to the human body.

Dr. Christopher Rynn [1] is a forensic craniofacial anthropologist specializing in facial approximation/reconstruction based on the skull, who works for international police and museums using 3D digital sculpture software (Freeform, Oqton/Geomagic) and a haptic feedback interface (Touch/Phantom). This provides not only the ability to interact physically in 3D, which is a distinct advantage over a 2D mouse, but also the sense of touch, which allows small anatomical features (e.g., Whitnall's tubercle, where lateral eyelid ligaments attach) that often cannot easily be seen, to actually be palpated on digital skull models made from CT data*.

Touch is fundamental to feltmaking as the material is manually held in place whilst it is felted. Joan experienced this during a vertebra making session.

> "The body of the vertebra started as a flattened off ball of wool. By repeatedly working the ball with the felting needle, I was able to begin to vary its form. I noticed that when I squashed the body with my fingers the upper and lower surfaces of the body became more concave, and the walls pulled in slightly—I stabbed the felt to make it retain this form. If I had made this in clay the walls would probably have bulged when the shape was squashed because it would not have the variable internal structure that the felt object had. I began to consider how gravity working on a human's weight affects the skeletal form and why living bone is dynamic, spongy in places and rigid in others, in contrast to the plastic skeleton."—JS

This is an example of learning and teaching by stealth. Whilst modeling a felt vertebra, a workshop participant may think they are mainly exploring a creative technique through copying a plastic bone, but they are, at the same time, learning about the structure and properties of the bone they are copying. This notion is now referred to as "gamification."

Gamification is often seen in card or board games or even virtual reality escape rooms that have an undeniable anatomical theme (See 2020). Originally a concept from the video game industry, it has also been portrayed in its wider context, known colloquially as the "wax on wax off"

[1] Personal communication from Dr. Christopher Rynn

principle, from the 1980's classic film Karate Kid (Avildsen, 1984). In the film a bullied child, Daniel, befriends a caretaker, Mr. Miyagi who teaches him karate moves by stealth by asking Daniel to paint fences and clean cars. The basic idea is that the person becomes so engrossed in the activity that they are unaware that they are acquiring information. Whilst learning by video games and virtual reality may be relatively new, learning through play has been referred to since the early 1900s (Lillard 2013).

8.8 Art and Anatomy

Dissected bodies have been recorded through anatomical illustration for centuries. In most cases, an illustrator worked alongside a surgeon or anatomist to record the process of dissection. However, in some cases, the illustrator would be the surgeon himself. Leonardo da Vinci was both an artist and a scientist and he was able to record his dissections by drawing the forms he saw before him in the laboratory (Clayton and Philo 2013). But his drawings were more than illustrations. They were a means through which Leonardo da Vinci could puzzle out what he was observing on the dissection table. Drawing and dissection were equally important in the analysis of the human body. This hands-on approach is familiar to artists. Observation and recording are key skills learned in artistic training and artists are expected to experience the world around them if they are to express ideas about it. If a subject can be touched or held it will be, all the senses are utilized where possible.

Anatomy for artists tends to focus on the superficial forms, and "landmarks" of the body that are seen in a living person. Overly complex images of the dissected body can be too detailed and confusing, especially when showing multiple dissected layers in one illustration.

> "When I was teaching anatomy to art students and showed them these kinds of illustrations from books, quite often they couldn't get their heads round the fact that the body is not really like the cut-away image. They believed the truth of it but didn't understand what they were looking at."—JS

Many artists use the body as an inspiration for their work. Danny Quirk produces stunning paintings on the skin that accurately portray what is beneath the surface in the same manner as the anatomical atlases from which they are copied (Schnalke 2019) and there are also numerous other artists who use the anatomy as a stepping stone into more fanciful creations (Evans 2016). Anatomists and artists will endlessly debate the hidden anatomical message within the work of Michelangelo (Meshberger 1990; Campos 2019) whilst more obvious anatomical issues have been debated about the subjects of art. It was suggested that the model of the *Venus de Milo* might have had a spinal deformity (Kevlian et al. 2018) and the impossibility of the spine in both Parmigianino's *Madonna with the long neck* and Ingres *Valpinçon Bather* has suggested at least two extra vertebrae (Lee 2010). Botticelli's depiction of Venus with an extraordinary long neck in *The Birth of Venus* (Fig. 8.16) might have been hinting at the otherworldliness of the goddess but this anatomical inaccuracy has been perpetrated in our model depiction of the female form with Barbie retaining the swan like proportions (Norton et al. 1996).

Whilst pointing out the anatomical inaccuracies of such painters, other medical professionals are willing to accept the accuracy of Botticelli, some going so far as to diagnose illnesses based on his work (Ashrafian 2022). Arguably one of the greatest anatomical paintings known, *The Anatomy Lesson of Dr Nicholas Tulp* by Rembrandt contains its own inaccuracies. The doctor is depicted pulling on the flexors in the forearm to show the movement in the fingers. But these tendons are shown as originating from the lateral epicondyle of the humerus, rather than the anatomical correct medial epicondyle (Masquelet 2011).

In Pauwels' collection of essays on the production of scientific images (Pauwels 2006), we are reminded that "there is no state where things are perceived in an uncolored and unbiased form. . .science is not about copying nature and culture but about revealing it. We therefore should neither expect nor demand from a representation that it matches reality." How close we

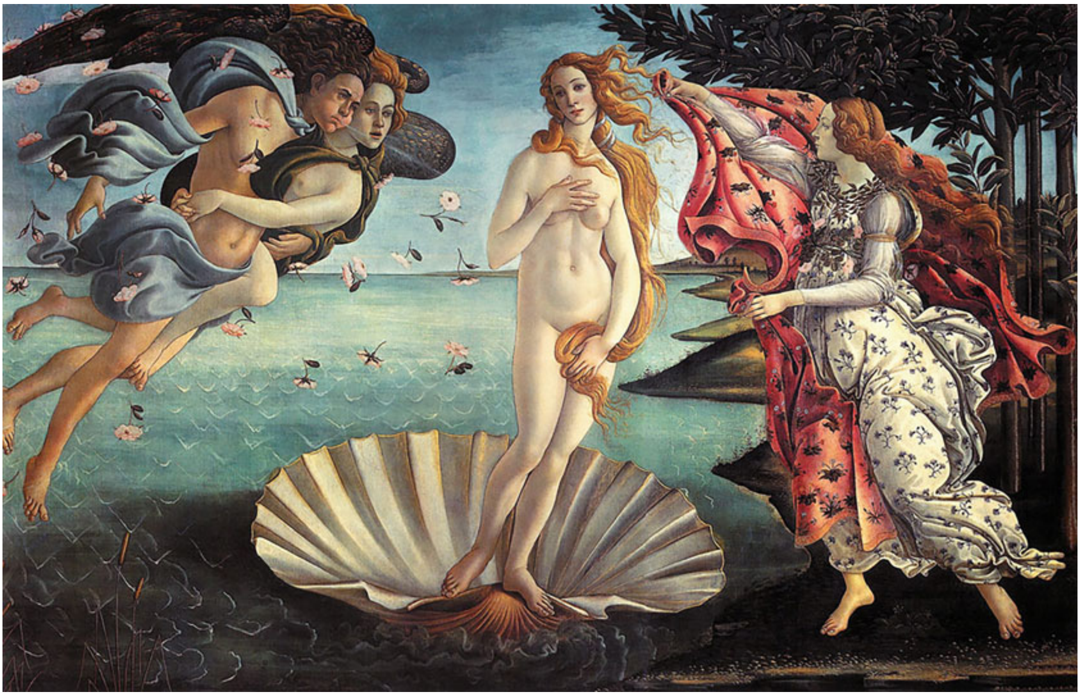

Fig. 8.16 The Birth of Venus by Sandro Botticelli (FrDr, CC BY-SA 4.0 via Wikimedia Commons)

would like images or models to be to reality depends on what they are being used for.

8.9 Low Fidelity Models

Where some see anatomical inaccuracies, others may see teachable moments. Dr. Scott Paterson has been using the debate about the anatomy of mythical animals to challenge his students to demonstrate a deeper understanding of the bodily systems.* By asking the students to design a chimera, comprising at least 3 animal forms but with a functional bodily system, be it urinary, cardiac or respiratory, the students must draw on their understanding of the components of those systems, the interaction with other body parts and movement to ensure their chimera could, theoretically at least, exist. By presenting an anatomical subject in an unexpected form, the opportunity is presented to engage the viewer in more of a discussion around anatomy.

The use of low fidelity models in anatomical teaching is rife, whether this is a paper model of a pelvis to show muscle attachments (Downie 2008), a paper brain hat to show functional areas of the organ (British Neuroscience Association bna.org.uk/make-a-brain-hat), the pipe cleaner version of the brachial plexus (Yu and Husmann 2021), or the videos on social media, where Dr. Jessica So teaches her young son surgery using play dough, that have been viewed by millions of people. Chan suggests that there is a place in education for low fidelity structures (Chan and Cheung 2011) and they have many advantages that are shared by the production of anatomical felts. One advantage is that they aid memory. A production process such as felt making that engages someone for hours as opposed to the minutes taken to study a model is very likely going to be a more memorable experience. What causes people to remember certain information is debated. Boeckers suggests that some of the retention from learning by dissection may actually be due to the stress of the situation, likening it to a heightened experience due to trauma (Boeckers and Boeckers 2016). For items such as the cross section of the spinal cord

Fig. 8.17 Cross section of spinal cord. All ascending pathways are shades of green and all descending pathways are shades of red. This is an example where color ought to help retention of knowledge. In a dissection these pathways would be hard to differentiate (photo Janet Philp)

(Fig. 8.17), logic informs us that the addition of colors ought to aid memory. In this example all of the ascending, sensory, or afferent pathways are colored with shades of green and all descending, motor, or efferent pathways are colored with shades of red. Although cognitive theory (Spence et al. 2006) indicates that color ought to play a part in memory recall, Finn has discovered in her work on anatomical body painting that it is difficult to produce data that confirm this (Finn et al. 2011).

Perhaps the benefit of working with color in body painting relates more to the process of painting than the color itself. Paint lends itself to portraying blocks of color. In body painting, these blocks of color highlight the shapes perceived under the skin as solid forms which overlap or sit next to one another. The painted shapes combine to create a map, but it is the solidity of the forms which aid understanding of the structure and mass of the body. Having taught life drawing (the drawing of a nude human posing) for many years, Joan noted that students who had had some experience of modeling a human figure in clay demonstrated a much greater understanding of human anatomy in their drawings. They could literally feel their way through, having previously experienced making the figure in 3D.

8.10 Communication and Sharing

Science communication has developed into a field in its own right. However, there are highly regarded scientists who can't communicate what they do and presenters who alienate their audience by using jargon. It is important to find ways to effectively engage an audience in order to encourage its members to find out more about the subject.

A great deal of work is taking place in anatomy museums in an attempt to engage with the public. These museums were traditionally closed to the public; visitors had to request permission to view the exhibits and they were often puzzled by the material on display. At Surgeons Hall Museum in Edinburgh, an extensive refurbishment in 2014 focused on making the exhibits more accessible and included much more comprehensive interpretation than was previously the case. Educational events, outreach, and temporary exhibitions complement the permanent collection. Today, it is commonplace to find contemporary artistic interpretations sitting alongside traditional displays. In the Wellcome Collection in London, the permanent exhibition, "Being Human," features "…50 artworks and objects…a refugee astronaut carrying their belongings to an unknown destination, sniff a perfumed bronze sculpture that smells of breast milk, listen to an epidemic jukebox, and watch a fast-food outlet slowly flood" (Wellcome Collection 2023). At "Anatomy Connect 23," pre-conference workshops were run on the use of fabric in anatomy teaching, providing educators with alternative methods with which to engage their students in learning (Fig. 8.18). Clearly, there is an appetite for fun and quirky (yet highly effective) ways to learn about the human body.

"When you teach in an indirect way, almost by stealth, the exciting part is that light bulb moment when someone sees through the actual activity and the pieces drop into place. This can be the appreciation of the different colored threads that were used in the Plexus workshop and what that means for nerves that are damaged or it can be when someone presses the vertebra they are felting and sees the effect of pressure on the structure or the appreciation that each part of the human anatomy is that shape for a reason."—JP.

"After a lesson from Janet in needle felting, I tried to make a human vertebra in felt. I used a plastic bone as a reference. The slowness of the process allowed me a lot of time to think about the details of the bone: the almost hoof-like structure of the body of the vertebra, the fineness of the spiny processes, how much the bone resembled a giraffe's head! I became much more aware of the different angles within the bone when I had to try to make a copy. I measured the thicknesses of various points on the bone using feel, holding the bone in one hand and my felt copy in the other. Felt is an accessible medium and one which can be put aside and returned to, later, with ease. I could imagine

Fig. 8.18 People using various craft techniques to learn anatomy of the brachial plexus and embryonic folding at "Anatomy Connected 23," Conference of the American Association for Anatomy, 2023 Washington DC. Workshop organized by Janet Philp and Sarah McConnell

becoming quite obsessed by trying to get the details of the felt closer to the original."—JS.

The phrase "social worlds" has been in use since the early days of the Chicago School of Sociology. A social world is a group of people interested in a common cause; Strauss suggests they have one primary activity in common (Strauss 1978). They may have unspoken joint understandings and maybe even a common language use in place.

This is the case for anatomists. Their joint activity is the teaching of anatomy. They have joint and often unspoken understandings around the respect due to body donors. The anatomical language is so niche that there are often preliminary lectures or book chapters to explain the niche terms that are in use. Fleischmann suggested that anatomical educators could be viewed as a social world (Fleischmann 2006) and Brassett's book on the language of anatomy states that "the anatomical language isn't designed to be exclusive, the preserve of the elite" whilst later admitting that it may appear foreign if you are not a classical scholar, suggesting that although it may not be designed that way, it is elitist (Brassett et al. 2017).

Tomatsu Shibutani suggested an aspect that defines a social world is a cultural area where its boundaries are "set neither by territory nor formal membership but by the limits of effective communication" (Shibutani 1955) and so science communication, by definition, sets itself at the boundary of a social world.

In the anatomical world, this could be seen by the control exercised over who can enter dissecting rooms or who can join professional societies. In contrast, items or people who can cross these boundaries can facilitate communication between social worlds. These are known as "boundary objects." According to the work of Latour (1987) and Callon and Law (2005) these boundary objects could be people but could also be inanimate objects and together with allowing communication between social worlds they may also have an effect upon the social world themselves. Rödder suggests that boundary objects can also have the opposite effect and inhibit communication between social worlds (Rödder 2017). Recent events have seen some people approach anatomical engagement with the use of human remains (Keet et al. 2023). In some cases, this has been dealt with in a sympathetic manner that enhances the medical narrative being told (Robinson 2022). In other instances, concern about consent and respect has caused a public backlash that has changed legislation (Keet et al. 2023). Instances such as these can work to redefine boundaries and cause people in one social world to protect their boundaries from others. Anatomical felts can act as boundary objects between the professional anatomical educator's world and the amateur-interested public social world, in the same way that natural history specimens in the study by Star and Griesemer brought professional and amateur social worlds together (Star and Griesemer 1989) during the development of Berkeley's Museum of Vertebrate Zoology.

8.11 Conclusion

We suggest that the anatomical felt is an abstract representation that can function in multiple worlds. The soft, familiar tactile experience of wool welcomes people and invites participation in a way that a visceral dissection or a hard plastic model never could. As non-threatening and accessible objects, the felts can be handled and discussed, prompting conversations on a wide range of topics and allowing them to have the potential to function as boundary objects that break down barriers.

References

Advolodkina P, Chahine EB, Advolodkina P, Chahine EB (2017) interactive pelvic anatomy model. Obstet Gynecol 130:877

Ashrafian H (2022) Differential diagnosis of a thyroid mass, facial malar rash and ptosis on the flora in the Primavera by Sandro Botticelli (1445–1510). J Endocrinol Investig 45:687–689

Assen S (2015) Red, Blue and Yellow [Online]. www.albertadoctors.org. (Accessed 18/03/2023)

Bareither ML, Arbel V, Growe M, Muszczynski E, Rudd A, Marone JR (2013) Clay modeling versus written modules as effective interventions in understanding human anatomy. Anat Sci Educ 6:170–176
Black P (2007) "My Highest Pleasures" William Hunter's Art Collection, The Hunterian University of Glasgow Paul Holberton Publishing
Boeckers A, Boeckers T (2016) The dissection course – a psychological burden or an opportunity to teach core medical competencies: a narrative review of the literature. Eur J Anat 20:287–298
Brassett C, Evans E, Fay I (2017) The secret language of anatomy. Anatomy Boutique Books
Callon M, Law J (2005) On qualculation, agency, and otherness. Environ Plan D Soc Space 23:717–733
Campos D (2019) A hidden rib in Michelangelo Buonarroti's fresco the creation of Adam. Clin Anat 32:648–653
Chan LK, Cheung MMW (2011) An analysis of the educational value of low fidelity anatomy models as external representations. Anat Sci Educ 4:256–263
Clayton M, Philo R (2013) Leonardo da Vinci. The Mechanics of Man, London, Royal Collection Trust
Conti G, Loy F, Riva A, Solinas P (2010) The evolution of anatomical illustration and wax modelling in Italy from the 16th to early 19th centuries. J Anat 216:209–222
Correia JC, Baatjes KJ, Meyer I (2022) Student-perceived value on the use of clay modelling in undergraduate clinical anatomy. Biomed Visual 12
Dennis JF, Creamer BA (2022) To touch or not to touch: evaluating student laboratory outcomes of hands-on versus visual examination of prosected cadavers. Educ Sci 12:519
Downie SA (2008) Build-your-own paper model of the pelvic diaphragm and perineum. FASEB 22
Evans E (2016) Anatomy Rocks – Flesh and Bones in Contemporary Art, France, Cernunnos
Finn GM, White PM, Abdelbagi I (2011) The impact of color and role on retention of knowledge: a body-painting study within undergraduate medicine. Anat Sci Educ 4:311–317
Fleischmann KR (2006) Boundary objects with agency: a method for studying the design-use interface. Inf Soc 22:87
Gordon B (1980) Feltmaking. Watson-Guptill Publications, New York
Haspel C, Motoike HK, Lenchner E (2014) The implementation of clay modeling and rat dissection onto the human anatomy and physiology curriculum of a large urban college. Anat Sci Educ 7:38–46
Hermiz DJ, O'Sullivan DJ, Jlujan HL, Dicarlo SE (2011) Constructivist learning of anatomy: gaining knowledge by creating anatomical casts. Anat Sci Ed 4:98–104
Ingold T (2013) Making. Routledge, London
Jones DG (1997) Reassessing the importance of dissection: a critique and elaboration. Clin Anat (New York, NY) 10:123–127
Keet K, Pillay P, Billings BK, Satyapal KS, Kramer B (2023) Profiting from public dissection: a new era of unethical practices. Anat Sci Ed 00:1–7
Kevlian A, Iwanaga J, Loukas M, Chapman J, Oskouian RJ, Tubbs RS (2018) Does the Venus de Milo have a Spinal Deformity? Curēus (Palo Alto, CA) 10:–e3219
Lantos JD (2011) Controversial Bodies. Thoughts on the public display of plastinated corpses. John Hopkins University Press, Baltimore
Latour B (1987) Science in action: how to follow scientists and engineers through society. Harvard University Press, Cambridge, MA
Lee C (2010) Observing the body. Irish Arts Rev (2002) 27:102–105
Lillard AS (2013) Playful learning and Montessori education. Am J Play 5:157
Masquelet AC (2011) The anatomy lesson of Doctor Tulp. Bull Acad Natl Med 195:773–783
Mcconnell SEA, Mooney CJ, Gdowski MJ (2023) A crocheted embryonic folding model activity reduces embryology-related anxiety in medical students. Anatomy Connected 23, Washington DC
Meshberger FL (1990) An interpretation of Michelangelo's creation of Adam based on neuroanatomy. JAMA 264:1837–1841
Netter FH (2014) Atlas of human anatomy. Elsevier, Philadelphia
Norton KI, Olds TS, Olive S, Dank S (1996) Ken and Barbie at life size. Sex Roles 34:287–294
Pauwels L (2006) Visual culture of science: rethinking representational practices in knowledge building and science communication, Hanover
Philp J, Smith J (2023) The fabric of the human body. In: Varsou O (ed) Teaching, research, innovation and public engagement. Springer
Pole T (1790) The anatomical instructor. Crouchman and Fry, London
Reid SJ, Shapiro L, Louw G (2018) How haptics and drawing enhance the learning of anatomy. Anat Sci Ed 12
Robinson S (2022) My dead body. Channels 4. https://www.channel4.com/programmes/my-dead-body
Rödder S (2017) The climate of science-art and the art-science of the climate meeting points, boundary objects and boundary work. Minerva 55:116
Schnalke T (2019) Anatomy – exploring the human body. Phaidon Press, London
See C (2020) Gamification in anatomy education. In: Chan LK, Pawlina W (eds) Teaching anatomy. Springer
Sergeyeva H, Sergeyev SV (2019) Glowing felt textile. Opt Mater Express 9:1915–1921
Shibutani T (1955) Reference groups as perspectives. Am J Sociol 60:562–569
Spence I, Wong P, Rusan M, Rastegar N (2006) How color enhances visual memory for natural scenes. Psychol Sci 17:1–6
Star SL, Griesemer JR (1989) Institutional ecology, 'translations' and boundary objects: amateurs and

professionals in Berkeley's Museum of vertebrate zoology, 1907–39. Soc Stud Sci 19:387–420

Stephan CN, Fisk W (2021) The dubious practice of sensationalizing anatomical dissection (and death) in the humanities literature. J Bioethical Inquiry 18:221–229

Strauss A (1978) A social worlds perspective. Stud Symbolic Interact 1:119–128

The Karate Kid (1984) Directed by Avildsen, J. G.: Columbia Picture Industries

Wellcome Collection (2023) Being human [Online]. Available: https://wellcomecollection.org/exhibitions/XNFfsxAAANwqbNWD (Accessed 30/03/2023)

Wesley N (2019) Next level felting, nan.c designs

Wilmshurst L, Brand K, Parsan Chand C, Edum-Fotwe A, Clunie L, Sanders KA (2023) Balancing entertainment and education in anatomy public events: anatomists' perspective. Anatomy Connected 23, Washington DC

Yang JX, Deyoung V, Xue Y, Nehru A, Hildebrand A, Brewer-Deluce D, Wainman B (2021) Size matters! Investigating the effects of model size on anatomy learning. Anat Sci Ed 00:1–13

Yu CI, Husmann PR (2021) Construction of knowledge through doing: a brachial plexus model from pipe cleaners. Med Sci Educ 31:1053–1064

Teaching Histology with Analogies

9

Quenton Wessels and Adam M. Taylor

Abstract

Students find histology both visually and conceptually challenging. The use of analogies has the potential to scaffold learning, foster students' interest, and promote recall. Analogies serve to introduce foreign and difficult concepts through the use of familiar ideas and serve as a scaffold for students to build on and gain an understanding of an unknown concept (target). The current chapter explores the use of analogies in histology education and provides an outline to the use of analogies toward the facilitation of students' learning and visualization of histology. It also addresses the role of analogies in students' engagement in the learning process of histology. The authors draw on pre-constructed analogies used in histology textbooks and explore the use of analogies toward an analogy-enhanced approach. Also explored are the application of the Teaching With Analogy (TWA) model, its integration in learning environments, as well as aspects of promoting and utilizing collaborative learning in the form of student-generated analogies.

Keywords

Histology · Analogy · Teaching with analogies · Visualization

9.1 Introduction

Visualization of histology can be very challenging to students (Akison et al. 2022). Some of the strategies to improve students' understanding have been suggested in a study by García et al. (2019). One highlighted aspect relates to the need to make histology more compelling (García et al. 2019). One potential intervention to promote students is the use of metaphors, analogies, and similes (Kanthan and Mills 2012). Metaphors and analogies, according to Tibell and Rundgren (2010), are frequently used to aid the visualization of concepts within the field of molecular life sciences. Mitochondria, for instance, are analogously referred to as the power plants of the cell (Tibell and Rundgren 2010). James Watson and Francis Crick famously conceptualized the double helix structure of deoxyribonucleic acid (DNA) based on its analogous structure with a twisted ladder (Brown and Salter 2010). The twisted ladder model illustrates the role of visualization as a conceptual tool in research, data analyses, modeling, and communication (Kozma

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et al. 2000). Furthermore, the importance of visualizations within the domain of molecular life sciences is highlighted by the plethora of illustrations in academic textbooks (Tibell and Rundgren 2010). This visualization brings structures well beyond the capacity of the naked eye to the forefront of the mind, relating it to something that is larger and relevant to the brain. The same holds true for histology, also known as microscopic anatomy, which relies on the visualization and communication of the microscopic structure of tissues.

The study of human histology forms an integral component of undergraduate education in the basic sciences curriculum for most health professions education programs, as well as providing the platform for speciality training in some health fields, including histopathology and microbiology. It bridges the gap between gross anatomy and physiology and epitomizes the relationship between structure and function (Chapman et al. 2020). Curricular delivery of human histology varies among institutions. Two distinct approaches have been adopted. Histology, as a component of anatomy, is either offered as stand-alone and independent or as part of integrated and organ-based courses or modules (Drake et al. 2009, 2014; Hortsch and Mangrulkar 2015). Histology has faced numerous challenges on two fronts. Firstly, programmatic challenges associated with the facilitation of histology include a reduction in content due to curriculum reforms and a global shortage in anatomists (Ali et al. 2015; Dickman et al. 2017; Gribbin et al. 2022; Tubbs et al. 2014). Secondly, students find histology particularly challenging to conceptualize and visualize (Akison et al. 2022; Cracolici et al. 2019; García et al. 2019). A recent study by García and colleagues (2023) explored the difficulties that students faced with undergraduate histology education. Their questionnaire-based study included 139 undergraduate biology students and the primary challenges with histology that were cited include the terminology used and insufficient teaching time (García et al. 2019).

However, the challenges associated with teaching histology provide opportunities for innovative strategies. Technological advances transformed the facilitation of histology over time from the use of traditional benchtop microscopes to online self-directed learning via digital histology or virtual microscopy platforms (Chapman et al. 2020; Thompson and Lowrie Jr 2017). Innovations in teaching histology primarily focus on interactive instructional approaches that are student-centered. Some of these include students use of visual art to draw or paint digital or virtual microscopy slides as adjunct in histology education (Cracolici et al. 2019). The value of visual thinking strategies has also been explored and demonstrates how students' exposure to a novel artwork can improve their observational skills of histology (Akison et al. 2022). Drawing has been shown to improve learning by promoting model-based reasoning and enabling students to form an abstract working model of the subject matter (Van Meter et al. 2006; Quillin and Thomas 2015; Pickering 2017; Backhouse et al. 2017). Furthermore, engaging students through drawing can improve their retention of knowledge and strengthen their reasoning (Balemans et al. 2016; Reid et al. 2018; Shapiro et al. 2019). Student-centered activities such as these capture the essence of participatory and engaging learning, and meaningful learning.

Meaningful learning, according to Ausubel (2000), is an active process and requires students to reconcile and challenge existing concepts with the new knowledge they learn. Analogies strategically serve the purpose of spanning the gap between the known and the unknown. The use of analogies requires the learner to cognitively map the similarities and differences between the two domains (Ausubel 2000). For example, between the domains of biology and physics, the human eye could be analogous to the optics of a camera (Glynn 2008). Analogies have been shown to aid students' ability to visualize abstract or new information and thus promotes meaningful learning (Iding 1997; Venville and Treagust 1997; Orgill et al. 2015). Surprisingly, there has been relatively little information in the literature on the use of analogies in the facilitation of histology in higher education. The aim of the current chapter is to provide detailed background to the use of analogies in scientific, particularly histological, education and to outline the use of analogies toward the facilitation of students' learning and visualization of histology. The chapter also details the effective use of analogies in teaching and how their implementation could complement existing teaching approaches. Furthermore, the current chapter provides a number of analogies used in the instruction of histology along with examples from pathology. These analogies might serve useful within the context of collaborative teaching and learning.

9.2 Analogies in Teaching and Learning of Histology

9.2.1 Defining Analogies

The definition of analogies, as it is used in teaching and learning, warrants disambiguation. Some sources use the terms *metaphor* and *analogy* synonymously (Glynn et al. 1989). However, analogies explicitly express comparisons between two things whereas metaphors do so implicitly (Duit 1991). A further distinction between the two is that metaphor is used within the content of literature (e.g., he has a heart of gold) whereas analogies are used within a scientific context (Glynn et al. 1989). For example, an analogy linked to the cardiovascular system considers the heart analogous to a pump and the blood vessels to the pipes that are connected to the pump (Brown and Salter 2010; Niebert et al. 2012). Additional distinctions are required between an analogy and *similarity*. Analogies rely on a cognitive connotation between two different domains while sharing variable levels of association as well as specific characteristics (i.e., drawing a comparison between similar features). Similarities are like analogies but differ in that they not only share concepts, but a literal similarity also shares object attributes (Gentner and Kurtz 2006; Pena and Andrade-Filho 2010). In its simplest form, an analogy aims to compare similarities or connections between two concepts or objects and the more these resemblances are shared, the more the analogy becomes a literal similarity (Pena and Andrade-Filho 2010). A literal similarity would therefore be a complete match at all levels (Gentner and Kurtz 2006).

Analogies serve to introduce difficult and novel ideas through the use of familiar concepts (source or analog) and serve as a scaffold for students to build on and gain an understanding of an unknown concept (target) (Keri and Elbatarny 2021). Analogies thus permit the transfer of information from a familiar domain to an unfamiliar domain (Gentner 1983; Gentner and Kurtz 2006; Hofstadter 1995). The value of analogies in education and students' learning and understanding of scientific subjects has been highlighted by various authors (Aubusson et al. 2006; Gentner 1983; Gentner and Kurtz 2006; Hofstadter 1995; Pena and Andrade-Filho 2010). Evidence supports the use of pictorial analogies, with those being taught by them in science education scoring significantly better. For instance, a study by Lin et al. (1996) found that, through the use of Glynn's model (Glynn et al. 1989), pictorial analogies significantly improved students' scores compared to a control group without the intervention (Lin et al. 1996). Pictorial analogies were generated by the authors to introduce the target concept through a quasi-experimental study. Importantly, their findings also demonstrated that when analogies were used, poor performing students in the test group benefited more compared to the top achievers (Lin et al. 1996).

However, research points toward varied results on the efficacy of analogies to foster learning of science-related subjects (Glynn et al. 1989; Oliva et al. 2007; Pramling 2009). For instance, a study conducted by Glynn and Takahashi (1998) employed an elaborate analogy between an animal cell (target) and a factory (analog). Their analogy was verbally and visually compared with the analog and this is known as *mapping*. Through the process of mapping, their analogy became elaborate and attention was given to seven cellular elements and their functions (Glynn and Takahashi 1998). Their study focused on schoolchildren in their sixth and eighth grades from the same school. An analogy-enhanced approach was used for the test groups and consisted of an analogy in text and graphic form. Both the eight and six graders demonstrated retention directly after the analogy-enhanced intervention as reflected by their recall of the target concept. Recall after a two-week interval was also markedly better for both grades compared to their respective control groups. However, their study found that the sixth graders benefited more from the analogy-enhanced approach. The latter aspect reflects the transitional nature in cognitive development between the two grades and the lack of content-area knowledge associated with the sixth graders (Glynn and Takahashi 1998).

The study of Glynn and Takahashi (1998) demonstrates how mapping the features of a familiar analog renders the target concept more memorable due to a better level of comprehension (Glynn and Takahashi 1998). A more recent study (Keri and Elbatarny 2021) assessed the value of 53 analogies used in anatomy, physiology, and clinical chemistry in an undergraduate nursing program. Findings from this study demonstrated that the majority of students (85%) found that analogies helped them understand the scientific content. Furthermore, 77.5% of the students indicated that the analogies were engaging and 60% stated that analogies aided their recall of anatomical structures and physiological functions (Keri and Elbatarny 2021). However, the majority of literature on the benefits of teaching with analogies are qualitative in nature and further quantitative data are required (Asay 2013).

The next section will explore the use of analogies in histology, a primer toward an analogy-enhanced approach. This section will present a number of analogies in popular histology textbooks and publications making use of histopathological analogies.

9.2.2 Analogies Used in Histology and Histopathology

Educators naturally use analogies when teaching and they are also found within a variety of scientific textbooks (Glynn 2008; Glynn and Takahashi 1998; Paris and Glynn 2004). The richness in the use of simple analogies in histology is well documented and sometimes taken for granted by educators. Such analogies draw on similarities and typically relate to the shape of cells such as cuboidal, goblet-shaped, columnar, squamous, and umbrella cells. With the exclusion of histological similarities, e.g. stereocilia that resemble microvilli, and the cap and bell stages of tooth development (Kumar and Bhaskar 2018), molecular resemblance is also used. An example is "beads on a string" which analogously refers to DNA that is wrapped around histones (Mescher 2009). However, there exists a paucity of analogies in science textbooks (Asay 2013) and the same holds true for histology textbooks. The analogies captured from a survey of seventeen histology textbooks, published between 2003 and 2019 are presented in Table 9.1. Analogies in textbooks, as outlined in Table 9.1, and those employed in an educational setting should be intended to foster the construction of relations between the *source* and *target*. The deliberate inclusion of analogies in textbooks is believed to serve as instructional tools. Yet, Iding (1997) found that there exists a lack of supporting material to existing analogies and highlights the need for further expansion of analogies in textbooks. Iding further noted that these missing links, in the form of supporting material, are important to both students and instructors (Iding 1997).

Most analogies in histology textbooks are used to visually convey the morphology of an organ or tissues as visualized through various forms of microscopy (Table 9.1). Few analogies refer to structure and functional relationships and are typically reserved for sections dedicated to the function of the cells. An excellent example has been provided by Kumar and Bhaskar (2018) where they explain the function of fibroblasts associated with the periodontal ligament, i.e. the fibrous ligament that anchors the root of a tooth. Their analogy illustrates how the contractile filaments of the fibroblasts and the interconnected nature of the cells can exert a force on the collagen of the periodontal ligament. Their analogy is based on the findings of *in vitro* fibroblast cultures that have been demonstrated to contract

Table 9.1 Instructional analogies used in popular histology textbooks

Analogy	Description
Barrel hoops	The arrangement of fusiform contractile myoepithelial cells around the secretory ducts of exocrine glands (Lowe et al. 2015)
Balloons or flasks	The distended cisterna of the rough endoplasmic reticulum (Keuhnel 2003)
Bees in a honeycomb	The configuration of vesicles and vacuoles within the Golgi complex (Ovalle and Nahirney 2013)
Blades of a turbine	The morphology of microtubule triplets as viewed in a transverse section (Ovalle and Nahirney 2013)
Bunch of grapes	The appearance of clustered adipocytes (Ovalle and Nahirney 2013)
Car tire	The ground substance of hyaline cartilage, which resists compressive forces, is analogous to the rubber of the tire and the collagen fibers (the threads of a tire) act to resist tensional forces (Vasudeva and Mishra 2014)
Citrus kernels	The arrangement of cells in a taste bud (Ovalle and Nahirney 2013)
Clock-face/cartwheel/spokes of a wheel	The chromatin of a fully differentiated plasma cell or immunoglobulin-secreting B-cell present as four or five clumps that resemble a clock face or cartwheel (Lowe et al. 2015; Ross and Pawlina 2015; Vasudeva and Mishra 2014)
Closed zipper	Interdigitations of apical surface membranes from adjacent cells that interdigitate (urinary bladder) (Ross and Pawlina 2015)
Cobble stones	The arrangement of tightly-bound epithelial cells as viewed HRSEM (Ovalle and Nahirney 2013) Slight elevations of the gastric mucosa (Ross and Pawlina 2015)
Drinking straws	The cylindrical nature of microtubules (Ovalle and Nahirney 2013)
Drinking straw in a balloon	Secretory centroacinar cells (balloon) and the associated intercalated duct (drinking straw) (Ross and Pawlina 2015)
Egg carton	The relief of the epidermal-dermal junction (Ovalle and Nahirney 2013)
Escalator	The combined function of the ciliated columnar cells and mucus from the goblet cells which acts as a mucociliary escalator (Sontakke 2019)
Filter paper/blotting paper	Filtration associated with the fenestrated endothelium of glomerular capillaries (Ovalle and Nahirney 2013)
Finger-like projections	The pedicles of the podocytes associated with the renal glomerulus (Keuhnel 2003).
Fish scales	The appearance of the semi-transparent keratinized squamous cells of the cuticle of a hair (Vasudeva and Mishra 2014) The arrangement of the ossicles of the scleral ring of birds (Liebich 2019) The appearance of a cross-sectional view of tooth enamel (Chandra et al. 2010; Kumar and Bhaskar 2018; Ross and Pawlina 2015)
Fish trap	Cryoelectron tomography of the nuclear pore complex and nuclear basket (Ross and Pawlina 2015)
Grapes on a stem	The arrangement of exocrine secretory acini (Cui et al. 2011)
Growth rings of a tree	The histomorphology of the collagen and bone cells to form a lamella that resembles the rings of a tree (Treuting et al. 2018) A similar analogy is used for the striae of Retzius which are growth lines or bands seen in enamel of a tooth (Gartner 2016)
Hairs of a paintbrush	The microscopic appearance of stereocilia (stereovilli) (Ross and Pawlina 2015)
Hexagonal prisms	The morphology of retinal pigment epithelial cells (Ovalle and Nahirney 2013)
Honeycomb	The appearance of the lumen of seminal vesicle lumen due to elaborate folds (Ovalle and Nahirney 2013)
Jigsaw puzzle	The interconnected nature of osteons (Treuting et al. 2018)
Labyrinth	The convoluted mucosa in cross-section of the uterine tube (Mescher 2009)
Nails in wood	Sharpey's perforating fibers of a tendon that penetrates bone (Vasudeva and Mishra 2014)
Octopus on a capillary	The pedicles of the podocytes associated with the renal glomerulus (Ovalle and Nahirney 2013)

(continued)

Table 9.1 (continued)

Analogy	Description
Onion	The histological appearance and layered nature of the concentric layers of Pacinian corpuscles (Ovalle and Nahirney 2013) A similar analogy is used for Vater's corpuscles (Liebich 2019).
Open Pouch	Alveoli of the lung (Mescher 2009, p. 356)
Pine cone	The concave-arranged tubules of tubular horn around the medulla (Liebich 2019) Pineal gland—due to the formation of incomplete lobules by prominent intralobular fibrovascular stroma extending from the pineal gland capsule (Treuting et al. 2018)
Roof tiles	The overlapping morphology of flattened keratinized cells of the cuticle of a hair (Liebich 2019)
Rosette	The morphology of a transverse section parenchyma of the parathyroid gland in dogs (Liebich 2019)
Rough cocklebur	The similarity of spinous cells of the epidermis (Kumar and Bhaskar 2018)
School of fish	The visual appearance of the densely packed connective tissue cells in the ovaries (Keuhnel 2003).
Signet ring	The appearance of an adipocyte under a light microscope. The cytoplasm resembles a thin ring and the nucleus is pushed to the side due to the space-occupying fat droplet (Vasudeva and Mishra 2014)
Spider legs	The appearance of cementocytes with their cytoplasmic processes (Chandra et al. 2010)
Spot welds	The configuration of cadherin protein molecules that form part of desmosomes which mediates cell-to-cell adhesions (Ovalle and Nahirney 2013)
Stacked of coins	The arrangement of proliferative chondrocytes in the proliferative zone of a cartilaginous growth plate (Ovalle and Nahirney 2013)
Stack of flat membrane sacs	The basic unit of the Golgi apparatus is known as a dictyosome and resembles a stack of membrane enclosed sacs (Keuhnel 2003).
Stairway (risers and steps)	Intercalated discs of cardiac muscle (TEM) (Ross and Pawlina 2015)
Staves of a barrel	The histomorphology of the support cells of a taste bud (Ovalle and Nahirney 2013)
Swiss cheese	The three-dimensional structure of red pulp within the spleen (Young et al. 2013)
Tearing a sheet of postage stamps	The purpose of specific demarcation channels within a megakaryocyte which permits the fragmentation of the cell into platelets (Ovalle and Nahirney 2013)
Teeth of a saw blade	Myoepithelial cells in cross-section (Ross and Pawlina 2015)
Tennis racket	Birbeck granule appearance within Langerhans cells of the skin (Young et al. 2013)
Tightly-matted shag rugs	The apical surface of enterocytes as viewed via HRSEM (Ovalle and Nahirney 2013)
Tongue-in-groove	The nail bed in seen in a transverse section which demonstrates the interdigitating epithelium with the papillary layer of the dermis (Treuting et al. 2018)
Twisted skein of wool	The appearance of Meissner's corpuscle because of the orientation of Schwann cells (Ross and Pawlina 2015; Vasudeva and Mishra 2014)
Walls of a building	Liver parenchyma and the spaces (rooms) are the sinusoids (Ovalle and Nahirney 2013)

collagen-based gels. The authors analogously refer to a sailor as the fibroblast that pulls the rope (collagen fibers) which in turn is connected to a sail (tooth). The stationary sailor pulls the rope and coils it on the deck. This represents collagen contraction and remodeling and the sail is moved by the sailor as a result. Thus, tooth eruption is mediated by a series of events including the role of collagen producing fibroblasts, the role of fibroblast-associated fibronexuses and the extracellular compartment in order to facilitate tooth movement (cited in Kumar and Bhaskar 2018).

The construction of relations between and within domains is a cognitive process and is known as *elaboration* (Glynn and Duit 1995). The process of elaboration serves to increase information that bridges the gap between the unknown and the students' existing knowledge. The process of elaboration illuminates the relations between the source and target (Hamilton 1997). For instance, an analogy drawn between a seed in soil and stem cells and their microenvironment by Young et al. (2013) serves as an example. Their analogy serves to portray the complex interplay between stem cells and a cellular niche formed by the microenvironment toward the differentiation of cells (Young et al. 2013). The assertion is that students are aware of the role of the cellular microenvironment in determining the fate of cells. However, it is important to note that an instructional scaffold is required for students to understand the underlying idea. Glynn (2008) states that analogies used in instruction are limited to “simple assertions” and that sometimes lack an explanation of the analogy (Glynn 2008). An educator might accept that the similarities between two domains are obvious, but analogical examples might not be obvious to a student. This highlights the importance of prompting and explicitly encouraging students to engage in analogical reasoning (Vendetti et al. 2015). Furthermore, the choice of the source of the analogy is dependent on the cultural background and prior experiences of the students (Andrade-Filho Jde and Pena 2001). The analogy that is used should therefore take these factors into account and should be contextually relevant.

The importance of contextual relevance is key and is an important factor in histopathology, which is seen as the next level of histological learning for those in the medical field. Histology bridges the gap between the normal microanatomy and the pathological changes associated with disease (Johnson et al. 2015). In this context deviation from what is considered normal histology is being assessed (looked for) and recognized as having deviated from what would typically be expected by the learner. In histopathology, this deviation or abnormality (of a cell or tissues) is aided in being identified by certain distinguishing features that are given an analogy to help them stand out from the rest of the contents of the image/field of view (the surrounding normal cells). The effectiveness of analogies in teaching general pathology is beneficial for exams (Seto and Zayat 2022), but less is known about the effectiveness of histopathology analogies. However, there are many that are in use and have been so for many decades in some cases (Table 9.2). Culinary medical analogies and metaphors such as coffee-bean nuclei (Borah et al. 2011), donut cells (Singh et al. 2012), salt and pepper chromatin (Pena and Andrade-Filho 2010), nutmeg liver and strawberry gallbladder (Andrade-Filho, 2010), rice water and pea soup diarrhea (Masukume and Zumla 2012) serve as some vivid examples of analogies used in anatomical and clinical pathology. The fact that histopathology is to pathology what histology is to anatomy means that analogies are more likely to assist in the recognition of variation from the norm. This aspect could prove useful in educational approaches such as collaborative learning.

The importance of analogies remains key for learning and recognition in histology and histopathology. Some might suggest that machine learning might see the end of, or reduction in the need for human intelligence and input in histological identification, but until the glitches that remain are rectified, including those relating to standardization and normalization, all the help we can give individuals to recognize histological and histopathological differences and learn will remain invaluable (Cui and Zhang 2021). In histology and histopathology, due to the microscopic and variable nature of the human sample content, many learners new to this field are likely to rely on relating to lived targets; things they have seen or experienced in life, to be able to identify the concept being taught or structure being identified. The next section will consider some models of teaching with analogies.

9.2.3 Teaching Histology by Analogy

Analogies simplify the visualization of a target domain that is often abstract and novel (Duit 1991). The current section will use the work of Glynn et al. (1989) and later works of Glynn (Glynn 1991, 2008; Glynn and Duit 1995) as a scaffold to consider the use of analogies in histology education.

Glynn’s model of elaborate analogies requires mapping (Glynn 2008). Mapping is an important

Table 9.2 Analogies used in histopathological literature

Analogy	Description
Banana bodies	The presence of ochre colored banana-shaped fibers in the dermis (Bhattar et al. 2015)
Banana-shaped gametocyte	The presence of *Plasmodium falciparum* gametocytes demonstrating the characteristic banana-shape (Dixon et al. 2012; Nacher 2004)
Bite cells (degmacytes)	The appearance of abnormally shaped mature red blood cells with small "bites" missing from them due to removal of denatured hemoglobin (Shantzer and Davidson 2020)
Coffee-bean nuclei	The appearance of a longitudinal groove in some nuclei of cells in malignant ovarian Brenner tumor (Lang et al. 2017)
Doughnut cells	The presence of T-lymphocytes which are anaplastic and large, seen in anaplastic large cell lymphoma (Singh et al. 2012)
Drumstick appendage	The presence of small nuclear mass of material connected to the body of the nucleus, typically associated with neutrophils, but seen in any of the leucocytes (Mittwoch 1964)
Fried egg	The appearance of either oligodendrogliomas or the appearance of the bone marrow in hairy cell leukemia (Cortazar et al. 2017; Wesseling et al. 2015)
Herringbone pattern	The arrangement of atypical fibroblasts in malignant fibrosarcoma of bone (Kalil 2020)
Kidney bean shaped diplococci	Gram negative, coffee-bean shaped intracellular diplococci bacterium (*Neisseria gonorrhoeae*) responsible for gonorrhea (Yeshanew and Geremew 2018)
Lollipop sign	Seen as classical presentation of Castleman disease, hyaline vascular type, where increased lymphoid follicles are penetrated by hyalinized capillaries, giving the lollipop appearance (Dupin et al. 2000)
Oat cell	Small cell lung cancer, where cells have a sparse cytoplasm giving an oat grain appearance (Semenova et al. 2015)
Popcorn cells	Arise as malignant cells of nodular lymphocyte predominant Hodgkin lymphoma, they originate from centroblastic germinal center B-cell (Aragao et al. 2020)
Salt and pepper chromatin	Typically seen in neuroendocrine tumors where the chromatin appears pepper like against a plain white background (Marinova et al. 2016)
Sandwich sign	Classical presentation seen in dermatophytosis where fungal hyphae seen between two layers of cornified cells (Park et al. 2014)
Spaghetti and meatball appearance	Pityriasis (Tinea) versicolor is a skin eruption caused predominantly by the fungus *Malassezia globosa*. Under the microscope with a potassium hydroxide stain they present a "spaghetti and meatball" appearance (Cho et al. 2022)
Tart cells	Typically seen in bone marrow with phagocytosed nuclear material located within its cytoplasm (Sathiavageesan and Rathnam 2021)

tool as it aligns the analog concept with the target concept, allowing the learner to undertake a comparison in either verbal or visual nature that hopefully relates to their lived experience (Asay 2013; Glynn 2008). The teaching with analogy (TWA) model and concept mapping relies on six operations (Glynn et al. 1989; Glynn 1991; Glynn and Takahashi 1998):

1. Introduction of the target concept.
2. Recollection of the analog concept.
3. Identification of similar features between the source and target.
4. Mapping of similarities.
5. Specifies where the analogy breaks down.
6. Reasoning toward a conclusion.

Introduction of the target concept can occur via a flipped classroom. For instance, the content of histology can be delivered outside the classroom through multiple formats in electronic form such as narrated slide presentations, digital histology, videocasts, and animations (Aristotle et al. 2021). Self-efficacy and self-directed learning are therefore promoted and collaborative learning could be introduced in the pre-class phase. This in turn is known to foster interdependence and promote the expression of alternative views among members (Janssen et al. 2012; Shin et al. 2022). One way of ensuring students' engagement with the target concept is to employ aspects of a team-based learning approach. With such an approach, students are assessed through an individual readiness assurance test before the actual synchronous interaction. This determines their engagement with the pre-class resources prior to then attending class or learning activity where a knowledge level or pre-exposure to certain material and a level of competency in that material is assumed, based on having undergone the individual readiness test (Guillot et al. 2016).

The source or analog requires careful selection when employing the TWA model in order to activate students' prior learning (Asay 2013). Textbooks and peer-reviewed scholarly works typically contain pre-constructed analogies related to histology as cited in this chapter. Introducing the source will enable recollection and elaboration, and the intent of the use of the analog and its elements should be clear and well understood by both the lecturer and students (Asay 2013; Brown and Salter 2010). It is important to gauge and consider students' familiarity and understanding of the source in order to prevent a loss of interest and possible misconceptions (Harrison 2006). To accomplish this, students should receive an explanation of the analogy (Mason 1994), and more than one analogy could be used to convey the concept (Harrison and De Jong 2005). The use of more than one analogy rests upon the work of Clement (1993) where bridging analogies are employed to ensure incremental gains in students' understanding (Clement 1993). Students thus master the target concept analogy by analogy (Asay 2013). Figure 9.1 represents two possible analogies drawn between the duodenum (target) and sea anemone or a pine forest (sources). Both sources resemble the epithelial micro-projections (villi) and collectively increase the surface area of the marine invertebrate organism or the forest, respectively. A convoluted ocean-bed or terrain could be adopted in both instances to represent the circular folds of the duodenum (plica circularis).

An alternative to the TWA model is to challenge students to generate an analogy (student-generated analogies) which breaks away from their interpretation of pre-constructed analogies (Bellocchi and Ritchie 2011). This in turn has the potential to address current gaps in research on analogies as few studies have focused on student-generated analogies (Tise et al. 2023). Research into students' generation of analogies might shed light on their developing understanding of the subject matter and academic performance in the subject. These factors are of importance as they could benefit students' metacognition, helping them to understand their own processes, planning and monitoring of the task and how they have performed (Tise et al. 2023). When using student-generated analogies, it is important to map the similarities and differences, as outlined in the TWA model, in order to prevent misconceptions. Student-generated analogies could serve as a formative assessment tool to gauge comprehension of abstract ideas.

The identification of similarities between the source and target, based on Glynn's model of operations, captures the essence of an analogy—it is a comparison (Glynn et al. 1989; Glynn 1991). Alignment of similarities occurs through analogical reasoning (Duit 1991). Glynn (1991) notes that the exploratory power of an analogy is proportional to the level of similarity between the source and target. In other words, the ability to explain the target increases with more similarities (Glynn 1991). Prompting the explicit drawing of comparisons during the TWA model aids students' abstract reasoning and their ability to recognize analogous cases. It is therefore important to support students during the process of comparison, and evidence suggests that this guidance can help them form better linkages (Vendetti et al. 2015). Guidance can be in the form of an explicit comparison, visual aids, or prompting questions (Catrambone and Holyoak 1989; Richland and McDonough 2010).

Systematically constructing alignment between shared features is known as mapping (Gentner et al. 2001; Glynn 2008; Glynn and Takahashi 1998). Examining Fig. 9.1, both sources share an array of similarities. Yet, the process of mapping does not consider the number of similarities or relationships, nor does mapping require all of the similarities to be mapped (Gentner et al. 2001; Glynn 2008; Glynn and Takahashi 1998). Mapping relies on a mental representation of relationships, underlying

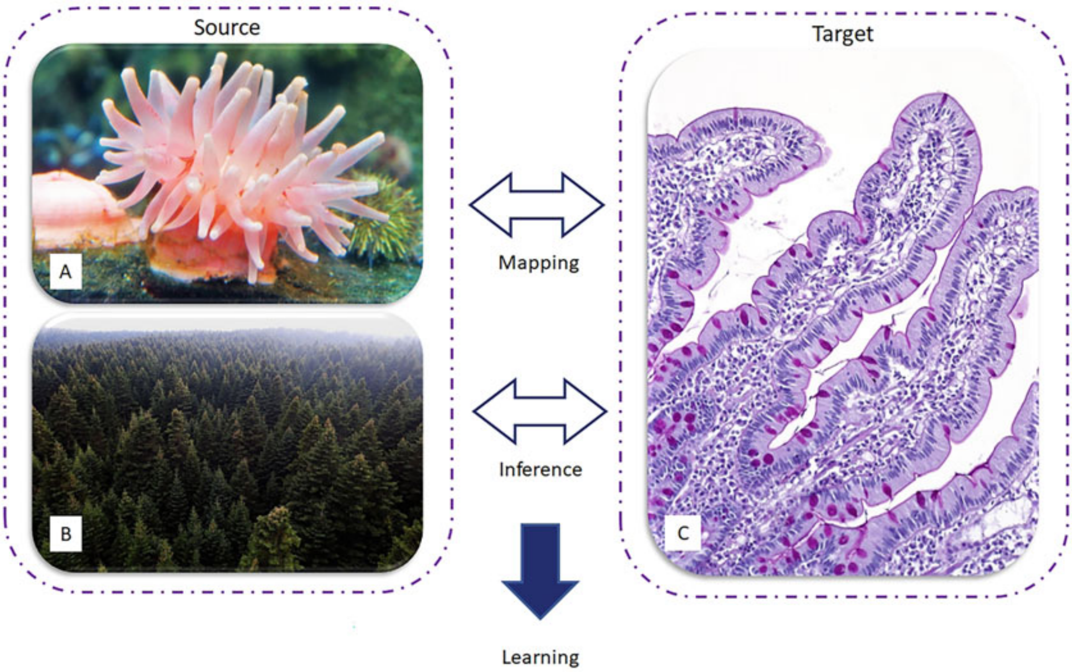

Fig. 9.1 Examples of analogical sources (**a**: a sea anemone; **b**: a pine forest) aimed at explaining the hair-like projections (villi) of the duodenal mucosa (**c**), its increased surface area, and the relationship between structure and function

structure, or principles as outlined in Fig. 9.2 (Duit 1991).

Working memory is involved during mapping in order to make connections between the elements of the source that are known with that of the target (Duit 1991). Furthermore, mapping relies more on the goal and meaning of the comparison. It considers semantic relationships, thus the organization of information within long-term memory, as opposed to syntactic correspondence (Asay 2013; Duit 1991; Markman and Gentner 2000). It is important to note that notable similarities aids recall but hampers analogical reasoning (Goswami 1991; Vosniadou 1989). Similarly, when the source is too abstract it might hinder recall despite its possible advantage of fostering analogical reasoning (Gick and Holyoak 1983). Of interest is that mapping, in the views of some authors, also includes the differences between the source and target (Gick and Holyoak 1983; Markman and Gentner 1993; Markman and Moreau 2001).

If correctly mapped, students will realize that the analog is no longer sufficient and will eventually break down (Bellocchi and Ritchie 2011). Comparing the differences and active participation through discourse will ultimately lead to the breakdown of the analogy. The pine forest analogy (Figs. 9.1 and 9.2) does not address the nature of the epithelial layer sufficiently. Nor does the analogy explore the relationship between structure and function. One might argue that the large surface area of the forest canopy ensures optimal photosynthesis in the same way nutrient absorption is mediated by the enlarged epithelial surface. However, the mechanisms involved in the analog and target are physiologically different. There also exists little similarity between the arrangement of the columnar cells and the needles of the pine trees. This is where the analogy breaks down. After all, the more resemblances are shared, the more the analogy becomes a literal similarity (Gentner and Kurtz 2006; Pena and Andrade-Filho 2010).

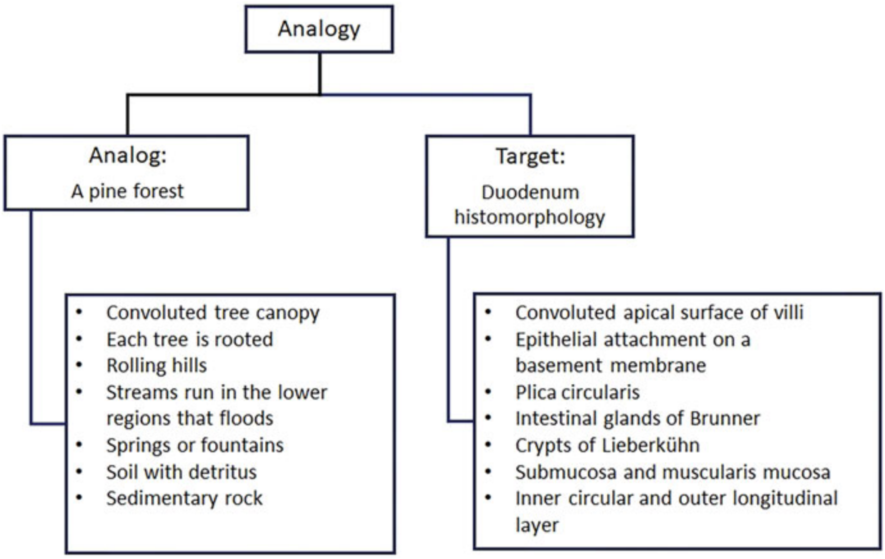

Fig. 9.2 Mapping of the similarities between the analog (a pine forest) and the target (the duodenal histomorphology)

The final operation of the TWA model is the construction of a conclusion (Glynn et al. 1989; Glynn 1991; Glynn and Takahashi 1998). The model, as Asay (2013) states, is instinctively valuable but makes no reference to a specific learning theory (Glynn 1991, 2008; Glynn et al. 1989; Glynn and Takahashi 1998; Paris and Glynn 2004). However, it could be argued that the model follows a social constructivist approach with the emphasis around the construction of new knowledge. It moves away from the static nature of behaviorism (Hassad 2011). This is especially true when room is made for collaborative learning as outlined previously. Furthermore, the TWA does not cater for reflective practice. Careful consideration of the TWA model led Treagust et al. (1998) to develop a model which caters for reflective practice. Their FAR (Focus, Action, and Reflection) model relies on the following operations (Treagust et al. 1998):

- Focus:
  - Concept—Characterization of the target concept, its abstraction and difficulty.
  - Students—Assess what students know about the target concept.
  - Analog—Determine students' familiarity with the source.
- Action:
  - Likes—The features of both the target and analog are discussed and similarities are mapped.
  - Unlikes—The dissimilarities between the analog and target are discussed.
- Reflection:
  - Conclusions—Reflect on the clarity of the analogy.
  - Improvements—Reflect on possible improvement of the analog, its mapping, and the positioning during the intervention could be improved.

The FAR model serves as a guide to educationalists to employ analogies effectively (Treagust et al. 1998). However, the model also provides an opportunity for implementation by students toward student-generated analogies. The co-construction of analogies within the context of collaborative learning follows a social constructivist approach. Students' engagement in the construction of analogies permits comparison. This in turn holds tremendous cognitive benefit toward students' learning, transfer of knowledge, and critical thinking (Vendetti et al. 2015).

9.2.4 Opportunities and Pitfalls of Analogies

Teaching with analogies can be inspirational, particularly where it relies on learners' lived experiences, it may help bring an intrinsic interest to the forefront of learners' minds (Casakin and van Timmeren 2014). The value of analogies in instruction rests upon two important factors. Firstly, Asay (2013) asserts that analogies are valuable if learning occurs. Secondly, an analogy is deemed valuable if sufficient relations can be drawn between the target and the analog (Asay 2013).

One possible barrier of the implementation of student-generated analogies relates to a lack of time. Time as a constraint among students has been highlighted by studies that employed innovations in body painting in anatomy and art intervention in histology (Cracolici et al. 2019; Jariyapong et al. 2016). Time constraints should also be considered when other analogy-based interventions are employed. Asay (2013) advises that instructors should critically assess the impact of TWA on resources such as teaching time (Asay 2013). The use of student-generated analogies as an assignment and group activity as alternative to a conventional pre-determined assignment might be a solution. In this instance, social constructivism comes into play but students will require clear guidance and the TWA framework of Glynn could serve as a model.

Contrasting within an analogy can be very useful in supporting analogical reasoning. However, some differences might lead to misconceptions (Vendetti et al. 2015). In such instances, the analog features are not appropriately or accurately representative of those which may appear on the target. It is therefore important to indicate where the analogy breaks down (Glynn 1991). The oversimplification of analogies can also be an issue, where there is a simple statement without elaborating on how or why the description fits, such as a cell being described as a city or factory without indicating the similarities or differences (Glynn and Takahashi 1998). While the initial descriptor fits, there are multiple layers that need to be explained beneath the simple analogy, by following up the analogy with "this is because... ." Analogies can also be superfluous if the learner already has a sound understanding of the topic being discussed but could serve as reinforcement of their knowledge. The process of mapping in such instances could prove invaluable to rule out any misconceptions and ensure clarity when using analogies.

Finally, analogies should not only be contextually relevant but language can also be problematic where, for example, food-based analogies may be specifically recognized by the country where that food is eaten, but may be completely irrelevant in other countries. This has been shown to have detrimental impact on the recognition of certain conditions in African medical students when challenged with culinary descriptors in European texts (Ahmed et al. 1992). A classroom of students, as Gray and Holyoak (2021) pointed out, are not uniform. Students do not share the same level of prior knowledge, expectations, or cognitive ability (Gray and Holyoak 2021). However, the variation among students provides an opportunity to explore and develop contextually and socio-culturally relevant analogies which considers cultural differences as well.

9.3 Conclusions

The current chapter explores the role of analogies in histology education as a method to create bridges between the known and the unknown. Histology as a subject, like embryology, continues to form an integral component of undergraduate medical education (Carneiro et al. 2023). Yet, many students find histology both visually and conceptually challenging (Akison et al. 2022). Analogies are known to promote visualization of abstract concepts, spark interest, and activate prior learning (Duit 1991). The use of analogies as presented in this chapter has the potential to scaffold learning, foster students' interest, promote recall, promote collaboration, and foster critical thinking.

References

Ahmed H, Ogala WN, Ibrahim M (1992) Culinary metaphors in Western medicine: a dilemma of medical students in Africa. Med Educ 26:423–424

Akison LK, Pattia J Ainscougha L, Colthorpe K (2022) Embedding art in histology teaching: Visual thinking strategies (VTS) to enhance visual literacy. In: Abstracts of the Proceedings of The Australian Conference on Science and Mathematics Education (2022), University of Western Australia, University club, 28–30 September 2022

Ali A, Khan ZN, Konczalik CP, El Sayed S (2015) The perception of anatomy teaching among UK medical students. Bul R Coll Surg Engl 97(9):397–400

Andrade-Filho Jde S, Pena G (2001) Analogies in medicine. Int J Surg Pathol 9:345–346

Aragao A, Kilic I, Velankar MM, Pambuccian SE (2020) "Popcorn cells" in intraoperative touch imprints of nodular lymphocyte-predominant Hodgkin lymphoma. Diagn Cytopathol 48(2):177–180

Aristotle S, Subramanian S, Jayakumar S (2021) Effectiveness of flipped classroom model in teaching histology for first-year MBBS students based on competency-based blended learning: an interventional study. J Educ Health Promot 20(10):152. https://doi.org/10.4103/jehp.jehp_467_20

Asay L (2013) The importance of explicitly mapping instructional analogies in science education. Dissertation, University of Nevada, Las Vegas

Aubusson PJ, Harrison AG, Ritchie SM (2006) Metaphor and analogy. In: Aubusson PJ, Harrison AG, Ritchie SM (eds) Metaphor and analogy in science education. Springer, Dordrecht, pp 1–9

Ausubel DP (2000) The acquisition and retention of knowledge: a cognitive view. Kluwer Academic, Dordrecht, p 11

Backhouse M, Fitzpatrick M, Hutchinson J, Thandi CS, Keenan ID (2017) Improvements in anatomy knowledge when utilizing a novel cyclical "observe-reflect-draw-edit-repeat" learning process. Anat Sci Educ 10:7–22

Balemans MC, Kooloos JG, Donders AR, Van der Zee CE (2016) Actual drawing of histological images improves knowledge retention. Anat Sci Educ 9:60–70

Bellocchi A, Ritchie SM (2011) Investigating and theorizing discourse during analogy writing in chemistry. J Res Sci Teach 48:771–792

Bhattar PA, Zawar VP, Godse KV, Patil SP, Nadkarni NJ, Gautam MM (2015) Exogenous Ochronosis. Indian J Dermatol 60(6):537–543

Borah T, Mahanta RK, Bora BD, Saikia S (2011) Brenner tumor of ovary: an incidental finding. J Midlife Health 2:40–41

Brown S, Salter S (2010) Analogies in science and science teaching. Adv Physiol Educ 34(4):167–169

Carneiro BD, Pozza DH, Tavares I (2023) Perceptions of medical students towards the role of histology and embryology during curricular review. BMC Med Educ 23:74. https://doi.org/10.1186/s12909-023-04019-4

Casakin H, van Timmeren A (2014) Analogies as creative inspiration sources in the design studio: the teamwork. AJA 1(1):51–64

Catrambone R, Holyoak KJ (1989) Overcoming contextual limitations on problem-solving transfer. J Exp Psychol Learn Mem Cogn 15:1147–1156

Chandra S, Chandra S, Chandra M, Chandra G, Chandra N (2010) Textbook of dental and oral histology with embryology and multiple choice questions, 2nd edn. Jaypee Brothers Medical Publishers, New Delhi

Chapman A, Lee LMJ, Swailis NT (2020) From scope to screen: the evolution of histology education. Adv Exp Med Biol 1260:75–107

Cho O, Unno M, Aoki K, Takashima M, Sugita T (2022) Malassezia display a hyphae-like "spaghetti-and meatballs" configuration in keratotic plugs. Med Mycol J 63(3):81–84

Clement JJ (1993) Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. J Res Sci Teach 30:1241–1257

Cortazar JM, DeAngelo DJ, Pinkus GS, Morgan EA (2017) Morphological and immunophenotypical features of hairy cell leukaemia involving lymph nodes and extranodal tissues. Histopathology 71(1): 112–124

Cracolici V, Judd R, Golden D, Cipriani NA (2019) Art as a learning tool: medical student perspectives on implementing visual art into histology education. Cureus 11(7):e5207. https://doi.org/10.7759/cureus.5207

Cui M, Zhang DY (2021) Artificial intelligence and computational pathology. Lab Investig 101:412–422

Cui D, Naftel JP, Daley WP, Lynch JC, Haines DE, Yang G, Fratkin JD (2011) Atlas of histology with functional and clinical correlations, 1st edn. Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia

Dickman N, Barash A, Reis S, Karasik D (2017) Students as anatomy near-peer teachers: a double-edged sword for an ancient skill. BMC Med Educ 17(1):156. https://doi.org/10.1186/s12909-017-0996-y

Dixon MW, Dearnley MK, Hanssen E, Gilberger T, Tilley L (2012) Shape-shifting gametocytes: how and why does P. falciparum go banana-shaped? Trends Parasitol 11:471–478

Drake RL, McBride JM, Lachman N, Pawlina W (2009) Medical education in the anatomical sciences: the winds of change continue to blow. Anat Sci Educ 2: 253–259

Drake RL, McBride JM, Pawlina W (2014) An update on the status of anatomical sciences education in United States medical schools. Anat Sci Educ 7:321–325

Duit R (1991) On the role of analogies and metaphors in learning science. Sci Educ 75(6):649–672

Dupin N, Diss TL, Kellam P, Tulliez M, Du MQ, Sicard D, Weiss RA, Isaacson PG, Boshoff C (2000) HHV-8 is associated with a plasmablastic variant of Castleman disease that is linked to HHV-8-positive plasmablastic lymphoma. Blood 95(4):1406–1412

García M, Victory N, Navarro-Sempere A, Segovia Y (2019) Students' views on difficulties in learning histology. Anat Sci Educ 12(5):541–549

Gartner LP (2016) Textbook of histology, 4th edn. Elsevier, Philadelphia

Gentner D (1983) Structure-mapping: a theoretical framework for analogy. Cogn Sci 7:155–170

Gentner D, Kurtz KJ (2006) Relations, objects, and the composition of analogies. Cogn Sci 30(4):609–642

Gentner D, Bowdle B, Wolff P, Boronat C (2001) Metaphor is like analogy. In: Gentner D, Holyoak KJ, Kokinov BN (eds) The analogical mind: perspectives from cognitive science. MIT Press, Cambridge, MA, pp 199–253

Gick ML, Holyoak KJ (1983) Schema induction and analogical transfer. Cogn Psychol 15:1–38

Glynn SM (1991) Explaining science concepts: a teaching-with-analogies model. In: Glynn SM, Yeany RH, Britton BK (eds) The psychology of learning science. Lawrence Erlbaum, Hillsdale, NJ, pp 219–240

Glynn SM (2008) Making science concepts meaningful to students: teaching with analogies. In: Mikelskis-Seifert S, Ringelband U, Bruckmann M (eds) Four decades of research in science education: from curriculum development to quality improvement. Waxmann, Munster, pp 113–125

Glynn SM, Duit R (1995) Learning science meaningfully: constructing conceptual models. In: Glynn SM, Duit R (eds) Learning science in the schools: research reforming practice. Erlbaum, Mahwah, NJ, pp 3–33

Glynn SM, Takahashi T (1998) Learning from analogy-enhanced science text. J Res Sci Teach 35:1129–1149

Glynn SM, Britton BK, Semrud-Clikeman M, Muth KD (1989) Analogical reasoning and problem solving in science textbooks. In: Glover JA, Ronning RR, & Reynolds CR (eds), Handbook of creativity. Perspectives on individual differences. Springer, Boston, MA, p 383–398

Goswami U (1991) Analogical reasoning: What develops? A review of research and theory. Child Dev 62:1–22

Gray ME, Holyoak KJ (2021) Teaching by analogy: from theory to practice. Mind Brain Educ 15:250–263

Gribbin W, Wilson EA, McTaggart S, Hortsch M (2022) Histology education in an integrated, time-restricted medical curriculum: academic outcomes and students' study adaptations. Anat Sci Educ 15(4):671–684

Guillot G, Condon KW, Brokaw JJ (2016) Urinary and respiratory systems: a team-based learning module for histology. MedEdPORTAL 12:10360. https://doi.org/10.15766/mep_2374-8265.10360

Hamilton RJ (1997) Effects of three types of elaboration on learning concepts from text. Contemp Educ Psychol 22:299–318

Harrison AG (2006) The affective dimension of analogy. In: Aubusson PJ, Harrison AG, Ritchie SM (eds) Metaphor and analogy in science education. Springer, Dordrecht, pp 51–63

Harrison AG, De Jong O (2005) Exploring the use of multiple analogical models when teaching and learning chemical equilibrium. J Res Sci Teach 42:1135–1159

Hassad RA (2011) Constructivist and behaviorist approaches: development and initial evaluation of a teaching practice scale for introductory statistics at the college level. Numeracy 4(2). https://doi.org/10.5038/1936-4660.4.2.7

Hofstadter D (1995) Fluid concepts and creative analogies. Basic Books, New York

Hortsch M, Mangrulkar RS (2015) When students struggle with gross anatomy and histology: a strategy for monitoring, reviewing, and promoting student academic success in an integrated preclinical medical curriculum. Anat Sci Educ 8(5):478–483

Iding MK (1997) How analogies foster learning from science texts. Instr Sci 25:233–253

Janssen J, Erkens G, Kirschner PA, Kanselaar G (2012) Task-related and social regulation during online collaborative learning. Metacogn Learn 7:25–43

Jariyapong P, Punsawad C, Bunratsami S, Kongthong P (2016) Body painting to promote self-active learning of hand anatomy for preclinical medical students. Med Educ Online 21:30833. https://doi.org/10.3402/meo.v21.30833

Johnson S, Purkiss J, Holaday L, Selvig D, Hortsch M (2015) Learning histology – dental and medical students' study strategies. Eur J Dent Educ 19(2):65–73

Kalil RK (2020) Fibrosarcoma of bone. In: Santini-Araujo E, Kalil RK, Bertoni F, Park YK (eds) Tumors and tumor-like lesions of bone. Springer, Cham, pp 459–463

Kanthan R, Mills S (2012) Using metaphors, analogies and similes as aids in teaching pathology to medical students. J Int Assoc Med Sci Educ 16(1):1–27

Keri Z, Elbatarny HS (2021) The power of analogy-based learning in science. HAPS Educator 25(1):13–20

Keuhnel W (2003) Color atlas of cytology, histology and microscopic anatomy, 4th edn. Thieme, New York

Kozma R, Chin E, Russell J, Marx N (2000) The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. J Learn Sci 9:105–143

Kumar GS, Bhaskar SN (eds) (2018) Orban's oral histology and embryology, 14th edn. Elsevier

Lang SM, Mills AM, Cantrell LA (2017) Malignant Brenner tumor of the ovary: review and case report. Gynecol Oncol Rep 22:26–31

Liebich H-G (2019) Veterinary histology of domestic mammals and birds: textbook and colour atlas. In: Klupiec C (ed) Histology of domestic mammals and birds: textbook and colour atlas, 5th edn. 5m Publishing, Sheffield

Lin HS, Shiau BR, Lawrenz F (1996) The effectiveness of teaching science with pictorial analogies. Res Sci Educ 26:495–511

Lowe JS, Anderson PG, Stevens A (2015) Stevens & Lowe's human histology, 4th edn. Elsevier/Mosby, Philadelphia

Marinova L, Malinova D, Vicheva S (2016) Primary neuroendocrine carcinoma of the breast: histopathological criteria, prognostic factors, and review of the literature. Case Rep Pathol 2016:6762085. https://doi.org/10.1155/2016/6762085

Markman AB, Gentner D (1993) Splitting the differences: a structural alignment view of similarity. J Mem Lang 32:517–535

Markman AB, Gentner D (2000) Structure mapping in the comparison process. AJP 113:501–538

Markman AB, Moreau CP (2001) Analogy and analogical comparison in choice. In: Gentner D, Holyoak KJ, Kokinov BN (eds) The analogical mind: perspectives from cognitive science. MIT Press, Cambridge, MA, pp 363–399

Mason L (1994) Cognitive and metacognitive aspects in conceptual change by analogy. Instruct Sci 22:157–187

Masukume G, Zumla A (2012) Analogies and metaphors in clinical medicine. Clin Med 12(1):55–56

Mescher AL (2009) Junqueira's basic histology: text & atlas, 13th edn. McGraw-Hill Medical, New York

Mittwoch U (1964) Frequency of drumsticks in normal women and in patients with chromosomal abnormalities. Nature 201:317–319

Nacher M (2004) Does the shape of Plasmodium falciparum gametocytes have a function? Med Hypotheses 62(4):618–619

Niebert K, Marsch S, Treagust DF (2012) Understanding needs embodiment: a theory-guided reanalysis of the role of metaphors and analogies in understanding science. Sci Educ 96(5):849–877

Oliva JM, Azcarate P, Navarrete A (2007) Teaching models in the use of analogies as a resource in the science classroom. Int J Sci Educ 29:45–66

Orgill M, Bussey TJ, Bodner GM (2015) Biochemistry instructor's perceptions of analogies and their classroom use. Chem Educ Res Pract 16:731–746

Ovalle WK, Nahirney PC (2013) Netter's essential histology, 2nd edn. Saunders/Elsevier, Philadelphia

Paris NA, Glynn SM (2004) Elaborate analogies in science text: tools for enhancing preservice teachers' knowledge and attitudes. Contemp Educ Psychol 29:230–247

Park YW, Kim DY, Yoon SY, Park GY, Park HS, Yoon HS, Cho S (2014) 'Clues' for the histological diagnosis of tinea: how reliable are they? Ann Dermatol 26(2):286–288

Pena GP, Andrade-Filho JS (2010) Analogies in medicine: valuable for learning, reasoning, remembering and naming. Adv Health Sci Educ Theory Pract 15(4):609–619

Pickering JD (2017) Measuring learning gain: comparing anatomy drawing screencasts and paper-based resources. Anat Sci Educ 10:307–316

Pramling N (2009) The role of metaphor in Darwin and the implications for teaching evolution. Sci Educ 93:535–547

Quillin K, Thomas S (2015) Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. CBE Life Sci Educ 14:es2. https://doi.org/10.1187/cbe.14-08-0128

Reid S, Shapiro L, Louw G (2018) How haptics and drawing enhance the learning of anatomy. Anat Sci Educ 12(2):164–172

Richland LE, McDonough IM (2010) Learning by analogy: discriminating between potential analogs. Contemp Educ Psychol 35:28–43

Ross MH, Pawlina W (2015) Histology: a text and atlas with correlated cell and molecular biology. Lippincott Williams & Wilkins, Philadelphia

Sathiavageesan S, Rathnam S (2021) The LE cell—a forgotten entity. Indian J Nephrol 31(1):71–72

Semenova EA, Nagel R, Berns A (2015) Origins, genetic landscape, and emerging therapies of small cell lung cancer. Genes Dev 29(14):1447–1462

Seto C, Zayat V (2022) A spoonful of eponyms helps the pathology go down: using food eponyms and visual mnemonics in preclinical pathology education. Med Sci Educ 32(1):131–140

Shantzer L, Davidson K (2020) Bite cells abound the hematologist 17(2). https://doi.org/10.1182/hem.V17.2.10299

Shapiro L, Bell K, Dhas K, Branson T, Louw G, Keenan ID (2019) Focused multisensory anatomy observation and drawing for enhancing social learning and three-dimensional spatial understanding. Anat Sci Educ 13(4):488–503

Shin S, Kwon K, Jung J (2022) Collaborative learning in the flipped university classroom: identifying team process factors. Sustainability 14(12):7173. https://doi.org/10.3390/su14127173

Singh S, Gupta N, Tekta GR (2012) Imprint cytology facilitating the diagnosis of primary cutaneous anaplastic large cell lymphoma of iliac fossa. J Cytol 29:267–269

Sontakke YA (2019) Textbook of human histology: with color atlas 3D illustrations and flowcharts. CBS Publishers & Distributors, New Delhi

Thompson AR, Lowrie DJ Jr (2017) An evaluation of outcomes following the replacement of traditionalhistology laboratories with self-study modules. Anat Sci Educ 10:276–285

Tibell LAE, Rundgren C-J (2010) Educational challenges of molecular life science: characteristics and implications for education and research. CBE Life Sci Educ 9(1):25–33

Tise JC, Sperling RA, Dann MS, Young TM (2023) Teaching postsecondary students to use analogies as a cognitive learning strategy: an intervention. CBE Life Sci Educ March 1, 2023 22:ar10. https://doi.org/10.1187/cbe.22-05-0084

Treagust D, Harrison A, Venville G (1998) Teaching science effectively with analogies: an approach for pre-service and in-service teacher education. J Sci Teacher Educ 9:85–101

Treuting P, Dintzis SM, Montine SM (eds) (2018) Comparative anatomy and histology: a mouse, rat, and human atlas, 2nd edn. Academic Press, New York

Tubbs RS, Sorenson EP, Sharma A, Benninger B, Norton N, Loukas M, Moxham BJ (2014) The development of a core syllabus for the teaching of head and neck anatomy to medical students. Clin Anat 27:321–330

Van Meter P, Aleksic M, Schwartz A, Garner J (2006) Learner-generated drawing as a strategy for learning from content area text. Contemp Educ Psychol 31:142–166

Vasudeva N, Mishra S (2014) Inderbir Singh's textbook of human histology: with colour atlas and practical guide, 7th edn. Jaypee Brothers Medical Pub, New Delhi

Vendetti MS, Matlen BJ, Richland LE, Bunge SA (2015) Analogical reasoning in the classroom: insights from cognitive science. Mind Brain Educ 9(2):100–106

Venville GJ, Treagust DF (1997) Analogies in biology education: a contentious issue. Am Biol Teach 59:282–287

Vosniadou S (1989) Analogical reasoning as a mechanism in knowledge acquisition: a developmental perspective. In: Vosniadou S, Ortony A (eds) Similarity and analogical reasoning. Cambridge University Press, New York, pp 413–437

Wesseling P, van den Bent M, Perry A (2015) Oligodendroglioma: pathology, molecular mechanisms and markers. Acta Neuropathol 129(6):809–827

Yeshanew AG, Geremew RA (2018) Neisseria Gonorrhoae and their antimicrobial susceptibility patterns among symptomatic patients from Gondar town, north West Ethiopia. Antimicrob Resist Infect Control 17(7):85. https://doi.org/10.1186/s13756-018-0376-3

Young B, Woodford P, O'Dowd G (2013) Wheater's functional histology. A text and colour atlas, 6th edn. Elsevier Churchill Livinstone, Philidelphia

Using the Hands for Learning Anatomy 10

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Abstract

The field of anatomy entails a significant reliance on spatial visualization for understanding its complex subject matter. Effective teaching methodologies in the field should focus on the engagement of students and the facilitation of student learning. Augmenting lectures with various teaching aids, such as blackboards, charts, models, and two- and three-dimensional projections, enhances the effectiveness of the lecture. In low- and middle-income countries, the prohibitive costs of advanced technologies such as three-dimensional projectors and virtual reality, coupled with limited financial resources, make it necessary to adopt more cost-effective teaching materials to reach every student.

Hands play a crucial role in teaching and learning, as they can serve as simple yet effective tools for teachers and students alike, alone or in conjunction with other methods, to convey accurate explanations of the topic of interest. They move in harmony with our thoughts and speech to create images in our minds or that of the listener. Hand movements and various hand gestures, such as iconic, deictic, metaphorical, and sign, can form the shape of objects, trace, point, and direct the "mind's eye" to form an image.

Anatomy teachers must create clear mental images of structures being described by making appropriate gestures for size, shape, and relationships, as well as demonstrating the movement of the anatomical part, while equally ensuring that students can form a mental picture for a thorough understanding and subsequent recollection of the concepts taught. Teachers can make the best use of gestures if they follow visualization principles with their hands in order to convey their thoughts. The conscious and subconscious focus of the student's mind on these movements and gestures aids in reproducing images in their minds. The visual sequence created by the gestures enables students to build a continuum of thoughts and ideas, thereby improving their understanding and recall of the material beyond their mere reading or listening to the lecture.

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Although limitations exist for the use of this simple hand and gesture method, it remains an effective approach when used in combination with other teaching methods to convey anatomical ideas, thereby promoting an improved teaching and learning environment.

Keywords

Gestures · Hand movements · Anatomy education · Motor memory · Cognitive load theory · Spatial learning

10.1 Anatomy: The Significance of Visual Representation

Anatomy has been an essential scientific discipline in medical education since ancient times (McLachlan and Patten 2006). The teaching and learning of anatomy has progressed over the ages from utilizing human cadaveric dissection (Elizondo-Omaña et al. 2005; Ghosh 2017), dating back to the time of Vesalius, to modern-day cutting-edge teaching methods using virtual reality, augmented reality, mixed reality, and extended reality (Kurt et al. 2013; Keenan and ben Awadh 2019; Patra et al. 2022).

This evolution is apparent in the way anatomy is taught and learned, as evidenced by two images: one from the seventeenth century, a painting by the Dutch Baroque painter Rembrandt, depicting the traditional method of anatomy teaching (Fig. 10.1a), and the other, from the cover of an anatomy education journal in the twenty-first century, featuring three-dimensional (3D) virtual stereoscopic modeling being used to teach anatomy (Fig. 10.1b; with permission from original publisher).

Figure 10.1a depicts the pedagogical endeavors of Dr. Nicholas Tulp, wherein the dissemination of anatomical knowledge is being imparted to a cohort of learners by means of dissection and demonstration. Meanwhile, in Fig. 10.1b, the scholarly pursuits of Dr. Cui and Dr. Chen are showcased, who employ avant-garde 3D virtual stereoscopic modeling techniques to facilitate teaching at the esteemed University of Mississippi Medical Centre.

Although these images are vastly different, the fundamental principle of anatomy learning is based on a solid foundation of visualizing complex structural relationships in the body to create clear mental representations (Stull et al. 2009). The term "visualization" implies that vision plays a central role in this process; however, creating a "mental picture" involves various elements and cognitive processes that go beyond visual input. This underpins the statement made by the renowned American Anatomist and author, Henry Hollinshead, in his textbook (Rosse et al. 1997), emphasizing the irreplaceable role of mental representations in anatomy learning. He states that,

> "Anatomy is a visual science. It is essential for the student to engage the mind's eye. The time spent on repeated reading of the text will be less effective than . . . visualizing a structure and its relation to other parts or regions."

The term "mind's eye" pertains to the cognitive faculty that enables the human mind to generate visual representations, conjuring up images in our imagination or conceptualizing them mentally (Cambridge English Thesaurus 2022). The majority of anatomy coursework is concerned with comprehending the intricate 3D spatial orientations of bodily structures at both microscopic and macroscopic scales (Li et al. 2012). Virtually every endeavor to devise more effective or novel pedagogical approaches in anatomy seeks to stimulate the "mind's eye" by employing novel strategies beyond those conventionally used (Triepels et al. 2020). However, visualization is not necessarily limited to visual perception alone. The learner's cognitive processes can effortlessly construct a lucid and well-defined mental picture through multiple senses, modalities, maneuvers, and activities.

10.2 Challenges in Anatomy Education

The acquisition of knowledge in the field of anatomy poses a significant challenge due to a diverse

Fig. 10.1 The evolution of anatomy learning over four centuries. (**a**) The Anatomy Lesson of Dr. Nicolaes Tulp (1632). Oil on canvas painting by Baroque artist, Rembrandt. Source: Public Domain. https://commons.wikimedia.org. (Attribution: Rembrandt, Public domain, via Wikimedia Commons) (**b**) Dr. Cui and Dr. Chen teach anatomy using 3D virtual stereoscopic modeling at the University of Mississippi Medical Centre (Published with permission from Dr. Cui and Anatomical Sciences Education, Wiley; License Number 5473540517742 License date Jan 21, 2023)

array of factors. These include the inherent complexity of the spatial nature of the subject matter, the spatial aptitude of the learner, the mode of learning, and the teaching or learning methodologies employed (Smith et al. 2014). These difficulties also extend to anatomy educators, who must navigate the complexities of the subject matter to provide effective instruction.

In order to establish a successful anatomy pedagogy, it is vital to mitigate the cognitive load experienced by students and to present the subject matter in a manner that is both comprehensible and clinically relevant. Furthermore, anatomy instructors must consider the accessibility, potential expenses, and cost-effectiveness of their chosen teaching method. For example, techniques proven to be effective in a western system of medical education, such as the Anatomage table (Baratz et al. 2019) or virtual microscopy workstations (Kuo and Leo 2019), may be unfeasible in low- or middle-income country (Yohannan et al. 2019; Somera dos Santos et al. 2021). Similarly, while a dissection-based anatomy course may be appropriate for regions where cadavers are readily available, it may raise significant challenges for medical schools in areas where there is a scarcity of cadavers (Ravi 2020; The Economist 2021; The Guardian 2023).

The diversity of learning scenarios and individual learners, including their linguistic, cultural, socioeconomic, and cognitive preferences, has rendered a universal approach to learning impractical. As a result, Universal Design for Learning (UDL) (Trostle Brand et al. 2012), has emerged as a promising framework for accommodating such diversity in higher education, including anatomy learning (Dempsey et al. 2021, 2022). UDL guidelines emphasize the optimization of engagement, representation, and expression in learning (CAST 2018). To that end, the guidelines advocate for the provision of multiple means of representation to offer diverse options for perception (Goldman 2003; CAST 2018). Visual methods, such as images, illustrations, animations, and video, are deemed optimal for presenting the information clearly because visual representation is believed to convey concepts and any kind of information in a clearer way. In addition, non-visual alternatives, such as touch equivalents, physical objects, and spatial models, should also be provided when conveying visual content (CAST 2018). These guidelines are applicable to all forms of higher education, and they are highly relevant to the field of anatomy learning.

A singular "magic formula" for anatomy education is neither feasible nor desirable, thereby creating a need to investigate new, cost-effective, simplified, and accessible modes of visualization that are conventional or semi-conventional and suitable for use across diverse settings. The following account aims to discuss how hand movements and gestures can be utilized as a simple, cost-effective (in fact—no cost!), and universally accessible method to teach and learn complex spatial anatomy.

The "manus," or human hand, is a highly sophisticated anatomical structure that has played a critical role in human survival and tool-making. In addition to its functional importance, the hand is also a powerful sensory tool with a high concentration of sensory receptors. The etymology of words such as manuscript, manipulate, and maneuver highlights the centrality of the hand in human activities. The cortical homunculus, which represents the motor and sensory territories of the body in the brain, reaffirms the pivotal role of the hand. In this description, we consider two distinct ways in which hands are used in teaching and learning.

The first is through gestures, which are primarily visual in nature. For instance, a teacher may make a hand gesture to describe the shape of a ball while teaching a class about the head of the femur. The second way is through kinesthetic and motor memory of hand movements, where the learner's hands help in their own learning. Both approaches can aid in the teaching and learning process, independently and in combination.

10.3 Gestures in Human Communication

The phenomenon of human communication is understood to encompass two fundamental domains, namely the verbal domain and the visual/motor domain (Rose et al. 2017). It is noteworthy that communication may rely solely on either one of these domains, such that gestures or body movements can serve as a potent mode of language, particularly in circumstances where the use of spoken language may present certain limitations. Such scenarios may include but are not limited to, communication among the hearing-impaired population, wherein sign language is the preferred mode of communication (Fig. 10.2a), or in situations where factors such as ambient noise or distance hinder the use of spoken languages, such as in minefields, airport runways (Fig. 10.2b), shipyards, and sports grounds (Fig. 10.2c). Conversely, it is possible to communicate verbally without the concomitant use of hand movements, as exemplified in telephone conversations.

Gesture production is a frequently occurring feature of human communication that is a powerful tool in conveying meaning. This phenomenon is observed across various age groups and cultures globally, as documented by Kita (2009). Even though listeners may not be visually present (Cook 2018), speakers often gesture while speaking, indicating that the intention behind these gestures may not necessarily be to convey visual information, but rather reflect cognitive processes that underlie the production of language (Rimé and Schiaratura 1991). Studies investigating scenarios in which listeners are either visible or invisible have provided evidence supporting the speaker-internal as well as communicative roles of hand gestures (Alibali et al. 2001). Gestures are beneficial in educational contexts that require students to interpret complex language, develop new ways of thinking, and analyze content that contains rich spatial and directional information (Cook 2018).

The mode of communication known as body language has been recognized as a particularly effective tool for medical educators (Hale et al. 2017). In addition to facilitating learner engagement and involvement, body language has been shown to infuse the process of teaching and learning with energy and passion. Specifically, in the context of an Anatomy classroom, various types of gestures have been found to be relevant (Chytas et al. 2022). Further investigations have demonstrated that co-speech gestures—i.e.,

Fig. 10.2 Communicating with the hands in various scenarios. (**a**) Participants at a Wikipedia training for students with hearing impairment at the Special Education at the University of Education Winneba. (Source: Wikimedia commons. This file is licensed under the Creative Commons Attribution-Share Alike 4.0 International license). (**b**) Airport runway gesture: (Source: Wikimedia commons. This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.) (**c**) A "wide" signal in a game of cricket. Source: https://www.flickr.com/photos/diongillard/2621286164. Author: Dion Gillard. This file is licensed for use under the Creative Commons Attribution 2.0 Generic license

gestures that accompany speech—used by teachers or learners can significantly enhance information retention, compared to situations where such gestures are absent (Clough and Hilverman 2018). While spoken language and co-speech gestures are typically considered to be complementary and symbiotic, the latter can often convey additional meanings that were not explicitly conveyed through spoken words (Clough and Hilverman 2018).

10.4 Hand Gestures: Classical Descriptions and Classifications

Based on the extensive research conducted by McNeill (1992), co-speech gestures have been classified into four distinct categories, namely iconic gestures, deictic gestures, metaphoric gestures, and beat gestures, as elucidated in Fig. 10.3.

Iconic gestures create images or visual depictions. For instance, when referring to a globe in geography, a sphere in geometry, or an eyeball in anatomy, the corresponding iconic gesture involves curling the fingers of one or both hands to create a spherical shape (Fig. 10.3a). *Deictic* (pronounced as *dike-tic*) gestures, also known as pointing gestures, are employed to indicate or trace a specific object or location, thus drawing the listener's attention toward it. These gestures can involve pointing to a particular point on a shape or tracing a line or curve (Fig. 10.3b). Metaphoric gestures are utilized to impart a gestural form to an abstract concept. For instance, an individual may point to their own head with an index finger to indicate that they

Fig. 10.3 The four main co-speech gestures. (**a**) Both hands create an *iconic* gesture in the formation of a ball. Note that the gesture conveys information indicating the size and the curvature of the ball. Iconic gestures often convey details beyond the words that are spoken. (**b**) An anatomy teacher points to the right auricular appendage using a *deictic* gesture. (**c**) A *metaphoric* gesture where the right hand pointing near the head indicates that the person is thinking. (**d**) The speaker in a conversation moves his right hand according to the rhythm in *beat* gestures. Models in the image here are the authors

are thinking about something (Fig. 10.3c). A gesture indicating the need to speak up can be executed by directing a hand forward from the mouth. Beat gestures involve hand movements that are synchronized with the rhythm and cadence of speech (Fig. 10.3d). Although they may not directly convey language, beat gestures can contribute to emphasizing spoken language (Bosker and Peeters 2021). Additionally, there exist emblematic gestures such as the thumbs up (👍) and peace sign (✌), which are highly influenced by cultural factors and have persisted over time (Matsumoto and Hwang 2013).

10.5 Hand Actions on Objects: A Cognitive Load Perspective

Cognitive load theory (Sweller et al. 2011; Paas and van Merriënboer 2020) draws on Geary's (2008) distinction between two fundamentally different categories of knowledge. The first, *biologically primary knowledge*, emerges as a natural consequence of human genetic heritage; examples include learning to listen to and speak in a "mother tongue," recognize faces and produce a range of nonverbal behaviors (including gestures). Knowledge and skill of this kind is held to be acquired with little or no conscious effort. In contrast, *biologically secondary knowledge* is typically constructed in the student's long-term memory through a slow and effortful process. Educational institutions such as schools and universities have emerged specifically to support large numbers of students in developing these culturally important but historically recent forms of knowledge, such as reading, writing, mathematics, and science. Such forms of knowledge are culturally important because individuals need them, at least to some extent, to operate in modern societies, while many cultural developments (e.g., scientific and technological innovations) also build on such knowledge. As a theory of instructional design focused on the educational implications of human cognitive architecture, cognitive load theory has historically been concerned with enhancing the design of educational materials and activities for biologically secondary topics. Paas and Sweller (2012) argued that biologically primary knowledge, with its minimal load on working memory, might support students in learning biologically secondary knowledge. They identified several bodies of educational scholarship—including collaborative learning, embodied cognition, and gesture—consistent with this framing.

Gestures, whether produced in conjunction with speech (i.e., while communicating) or not (co-thought gestures; Galati et al. 2018), typically involve making hand movements in space. Gestures thus stand in contrast to *actions on objects* (Congdon et al. 2018), where learners use their hands to act directly on objects in the environment for the purpose of learning. Much of the educational research on such actions has focused on the design and impact of *manipulatives*, particularly in early childhood and primary school education (for reviews, see Carbonneau et al. (2013); Laski et al. (2015)). Montessori education has placed particular emphasis on teacher-guided use of manipulatives, and while many of these manipulatives are three-dimensional, some of the core materials for both literacy and numeracy—*sandpaper letters* and *sandpaper numbers* (Montessori 1912)—are two-dimensional. Working with these lesson materials, students are encouraged by teachers to make tracing actions, moving the index finger across the surface of the letter or number, to learn the form of the abstract symbol. Montessori (1912) argued "…touching the letters and looking at them at the same time fixes the image more quickly through the cooperation of the senses" (p. 266). Experimental research has supported this practice with letter learning and phoneme identification (e.g., Hulme et al. (1987)) as well as recognition of geometrical shapes by kindergarten children (Kalenine et al. 2011).

Research framed by cognitive load theory on tracing out specified elements of worked examples (e.g., Hu et al. 2015; Wang et al. 2022) and pointing and tracing while studying text and diagrams (Macken and Ginns 2014; Ginns and Kydd 2019; Ginns and King 2021) has proposed several potential mechanisms through which actions on objects with the index finger might enhance learning. First, Hostetter et al.'s (2007) information-packaging hypothesis suggests gestures aid in "chunking" to-be-learnt information. Through this chunking process, the overall complexity of the information to be learned, and therefore intrinsic cognitive load decreases (Hu et al. 2015). Second, pointing and tracing actions may assist in focusing and directing the learner's attention (Reed et al. 2006; Cosman and Vecera 2010; Skulmowski et al. 2016), reducing extraneous cognitive load. Third, humans have inherent motivational biases to engage in learning in "folk domains"—including nonverbal behaviors—because developing such biologically primary knowledge has historically underpinned survival (Geary 2008). Thus, the benefits of incorporating biologically primary knowledge into lessons focused on biologically secondary knowledge (cf. Paas and Sweller 2012) may in part arise from increased intrinsic motivation (e.g., enjoyment and interest) for the lesson. We review research on acting on objects for anatomy learning (Macken and Ginns 2014; Ginns and Kydd 2019) in the following section.

10.6 The Role of Touch in Anatomy Lessons

When a student studies a static anatomical diagram combined with explanatory text, they face several challenges, including identifying and integrating related elements of the text and diagram into a coherent knowledge representation in long-term memory, as well as understanding key dynamic processes such as the flow of blood through specific chambers and valves of the heart. Macken and Ginns (2014) hypothesized that pre-lesson instructions to students to use their hands to help them learn would assist students in understanding and learning about the anatomy of the human heart. Prior to studying a paper-based lesson on the human heart, students in the experimental condition received the following guidance:

"Please use your hands where you need to make a link between text and an associated part of the diagram. Some ways you might like to do this are:

- Point at the word in the text, then point at the corresponding location on the diagram.
- Leave your finger on the diagram as you read about the corresponding element in the text.
- Use more than one finger to simultaneously point to parts of text and the diagram that are related.
- Where you see arrows indicating blood flow of the heart, use your hands to trace along the arrows."

In contrast, the control group received the following instructions: "Please do not use your hands while you learn this material. To assist you keeping in your hands still, please:

- Sit on your hands.
- Only use your hand to turn the page."

Participants in both conditions were then given the opportunity to practice following the above instructions, by studying a diagram of the human eye accompanied by 57 words of expository text. In the 25-minute lesson phase, students learnt about the human heart from a 12-page document adapted from Dwyer (1972), approximately 2000 words long accompanied by black and white diagrams. Following the lesson, students completed self-reports of cognitive load, then a 20-item multiple choice test on terminology covered in the lesson, followed by a 20-item multiple choice test evaluating comprehension of the lesson. The two experimental groups did not differ in their cognitive load self-reports. However, the group that used their hands to act on the lesson answered more terminology and comprehension test questions correctly than the group that did not use their hands.

The above study might be criticized for requiring students in the control condition to sit on their hands. While this aspect of the study's design assured a clear distinction between the use of students' hands across the two conditions, students do not typically sit on their hands while studying. In a follow-up study, prior to the lesson, Ginns and Kydd (2019) instructed the control condition to interact with the lesson materials as follows:

"Please do not use your hands while you learn this material. To assist you keeping in your hands still, please:

- Place your hands next to the materials you will be studying.
- Only use your hands to turn the page."

In order to provide a more sensitive test of the cognitive load hypothesis, students studied each page of the lesson for a standardized time, then rated how easy or difficult the content of that page was to understand and learn, using a Likert scale ranging from 1 (extremely easy) to 9 (extremely difficult). Students who interacted with the lesson materials with their hands reported lower cognitive load across the lesson, and consistent with Macken and Ginns (2014), also solved more terminology and comprehension test questions correctly. The results of this study thus replicate those of Macken and Ginns (2014) under more ecologically valid conditions (hands next to the lesson materials).

The most recent study testing the effects of the above pointing and tracing instructions was not conducted with anatomy lesson materials, but its results nonetheless replicate and extend those discussed above. Ginns and King (2021) invited university students to study a 9-slide PowerPoint-based lesson on the formation of stars, with pre-lesson instructions similar to those used by Ginns and Kydd (2019); the only major difference was that control condition students were asked to place their hands in their laps. Participants who used their hands while studying reported higher levels of interest in and enjoyment of the lesson; reported lower extraneous load; and solved more retention and transfer test questions.

Taken together, the results of these studies confirm that simple pre-lesson instructions to "use your hands to help you learn" enhance learning from paper-based anatomy lessons. If the results from Ginns and King (2021) can be extrapolated to anatomy learning, then it is to be expected that such pre-lesson instructions will (a) support computer-based learning, while (b) also reducing extraneous cognitive load while raising interest and enjoyment for the lesson. Encouraging students to make tracing and pointing actions on the surface of lesson materials with one or both index fingers is thus an easy, zero-cost design that medical educators can implement in a range of settings.

10.7 When the Hand Becomes a Model

The hand, possessing a unique design, highly mobile digits, opposable thumbs, and significant human creativity, provides remarkable flexibility that can imitate diverse physical profiles. This feature forms the basis for the engaging playful activity of hand shadow play, as reported by Almoznino and Pinas (2002). Additionally, the hand has been utilized as a physical model to simulate complex anatomical structures.

Oh et al. (2011) introduced "digit anatomy" in their article, which could be utilized for teaching a range of topics, including branches of the arch of the aorta, subclavian and axillary arteries, brachial plexus, heart and coronary arteries, lumbar plexus, sacral plexus, coeliac trunk, superior mesenteric artery, their branches, and formation of the portal vein. In this method, both hands and the ten fingers are utilized to represent blood vessels, nerves, bones, and muscles in each model. Learners can easily replicate this method and employ it in self-directed learning later. A series of gestures used by Oh et al. (2011) is depicted in Fig. 10.4 (with permission from Original Publisher).

The principle underlying this approach is not solely based on the visual element created by the formation, like that of shadow play. This method shifts declarative memory to motor memory, which could aid students in retaining their knowledge for an extended period. This is similar to how we effortlessly type our passwords on a computer, change gears while driving, play musical instruments, or conduct suturing during surgery. Learning a motor skill involves training the procedural circuits in the brain, which involves the basal ganglia and cerebellum, in addition to the motor and premotor areas of the cerebral cortex. Such motor memories are typically long-term memories, and the brain has the ability to have multiple parallel long-term procedural motor memories, as exemplified by the fact that we do not forget how to drive, swim, ride a bike, or play a sport, once we learn it (Krakauer and Shadmehr 2006).

Similar motor memory exercises are common in anatomy teaching and learning practices, such as learning the superficial muscles in the anterior compartment of the forearm, rotator cuff muscles with respect to the tubercles of the humerus, and the terminal branches (pes anserinus) of the facial nerve (Moore and Dalley 2018). These exercises should be highly encouraged, given that they invoke procedural memories. Hand models also provide an opportunity for teachers to comprehend students' spatial understanding of a structure by requesting them to replicate the models with their own hands. Thus, this method aids teachers in monitoring students' knowledge and provides an opportunity to modify it.

10.8 Blending Physical Objects with Gestures

The incorporation of gestures with physical objects is a popular approach in multimodal teaching, as evidenced by numerous examples in the literature. Skinder-Meredith (2010) utilized various techniques to blend physical objects with gestures, (a) building C1 and C2, T1 and T2, L1 and L2 vertebrae with the major landmarks using modeling clay or play dough, (b) drawing the skeletal structures, fascia and muscles of respiration on a t-shirt, (c) making a larynx using a cardboard tube and clay, (d) coloring the facial muscles used for lip and jaw movement on a partner's face, (e) identifying structures for phonation, articulation, and resonance on cadavers and isolated tongues and larynges. The use of clay modeling in particular enabled students to learn from deep to superficial structures, as opposed to the traditional method of superficial to deep structures employed in dissection practical sessions. This method was found to be enjoyable and useful by the students and

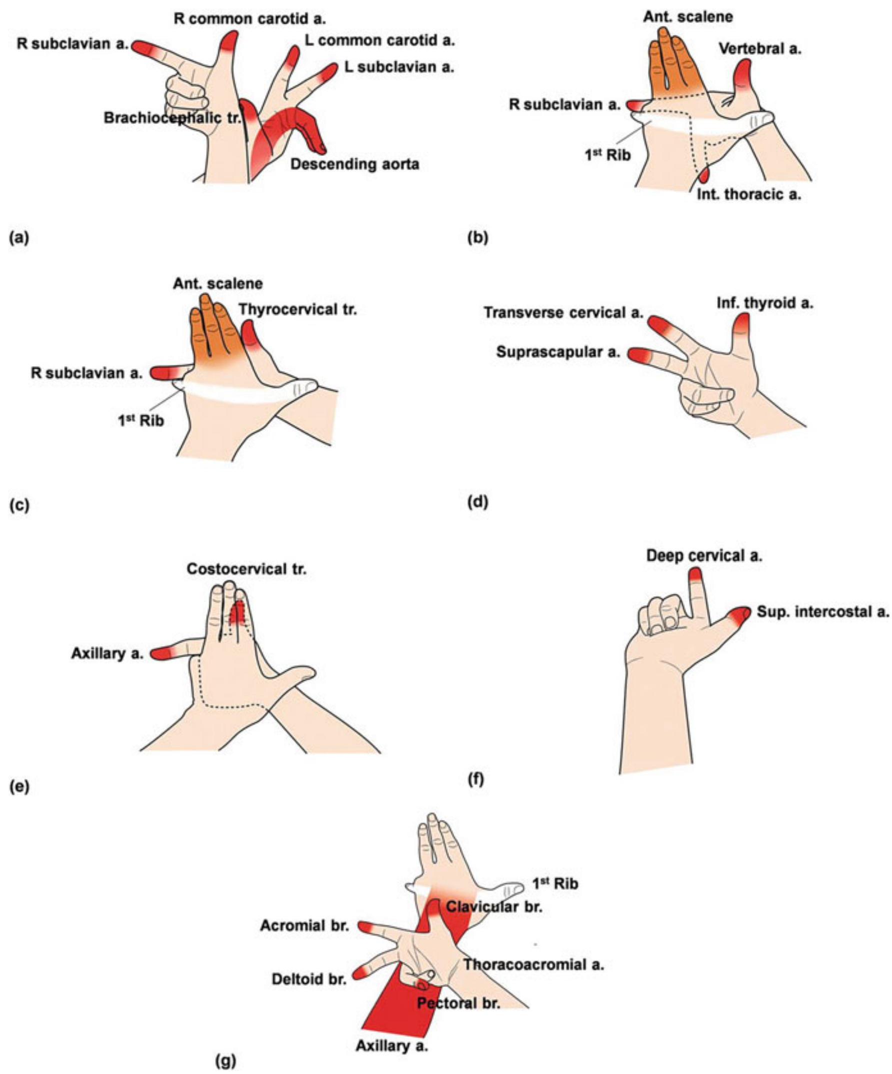

Fig. 10.4 The "Digit anatomy" technique as described by Oh et al. (2011). Here, the gestures are representing the aortic arch, subclavian, and axillary arteries and their branches. (Published with permission from Anatomical Sciences Education, Wiley; License Number: 5474120841938; License date: Jan 22, 2023; John Wiley and Sons)

increased their participation and effectiveness in the learning process.

In medical education, demonstrating the action of muscles on joints in the hands, particularly the digital extensor mechanism, can be challenging. A dynamic functional model is crucial for teaching these concepts due to the complex kinesthetics associated with multiple joints. Cloud et al. (2010) introduced a functional model for the digital extensor mechanism using two hair bands applied to the hand.

Oh et al. (2009) postulated that the comprehension of cross-sectional anatomy could be enhanced through the utilization of clay models. According to their research, pupils who employed clay models exhibited greater proficiency in comprehending 3D structures and cross-sectional anatomy in comparison with those who used cut surfaces of the clay models to study CT or MR images. Teachers encounter challenges in imparting three-dimensional knowledge via two-dimensional cross-sectional images; however, the aforementioned difficulty was somewhat resolved through the process of clay modeling. The addition of gestures to this method enables the teacher to facilitate increased student engagement, since obtaining consecutive sections in clay models, similar to CT or MRI images, is arduous. Thus, through the fusion of the clay modeling technique with gestures, teachers can ensure heightened student involvement (Oh et al. 2009).

In Chan's (2010) study, a demonstration of midgut rotation was conducted utilizing a low-tech model consisting of a tube with marked foregut, midgut, and hindgut that was sewn onto an apron. This model can serve as an engaging educational tool for both educators and students, with the instructor's hands being able to manipulate what he called as a midgut-rotation apron to visually depict the developmental rotation of the gut tube. The tube is worn as an apron, which may be fashioned from any commercially available apron of a solid color, and can be readily manipulated by hand to showcase various phenomena such as gut rotation, physiological herniation, and rotational anomalies. It was noted that students' interest and engagement levels were notably heightened when witnessing the instructor donning a "special dress/prop" during a lecture and demonstrating a complex and relevant concept. While the pure apron method may have its limitations concerning the number of anatomical topics that can be taught, such limitations may be overcome through the incorporation of gestural techniques into this method.

10.9 When the Hands Guide Carving an "Air" Model

Up until this juncture, the preceding sections have expounded upon the utilization of gestures in association with tangible models or visually detectable objects. Nevertheless, taking into account the evolutionary and biological outlooks as previously mentioned by Geary (2008) and Paas and Sweller (2012), gestures represent a fundamental knowledge domain and can alleviate cognitive burdens during the process of learning. Additionally, gestures possess a highly visual nature, enabling the conveyance of spatial information through independent, gesture-based teaching. By way of example, when a teacher employs an iconic gesture (such as mimicking the shape of a ball) in conjunction with the spoken word "ball," students can more readily apprehend spatial information than when presented with the word "ball" in isolation. The gestural representation can convey additional spatial data beyond mere spoken words, such as size, curvature, and location (Clough and Hilverman 2018). Consequently, this gestural spatial information can serve as a supplementary means of conveying information in tandem with spoken words.

This combination of deictic (pointing) and iconic gestures can create a 3D, hologram-like virtual form of an anatomical structure, which we have termed "Air Anatomy" (Yohannan et al. 2022). When the instructor directs their gaze toward this virtual structure, it further enhances this illusion, given the powerful social cues provided by gaze (Pi et al. 2019, 2022; Stull et al. 2021). These types of illusionary play are common in theatrical performances, such as nonverbal art forms like pantomime (Carels 1981) or Hasta Mudras (Sanskrit for hand gestures) in Indian classical dances (Carroll and Carroll 2012). As these types of performances often imitate basic "folk domains," such as folk psychology and folk physics (Geary 2008), they hold the potential to increase enjoyment, motivation, and interest among learners.

The model of gesturing known as Air Anatomy provides a teacher with adequate freedom and flexibility. The hand constitutes a crucial medium for creating gestures such as pointing, tracing, and abstract representations of objects in space, among others. The use of hand gestures, when employed in conjunction with gaze and descriptive speech, has been shown to yield superior outcomes compared to their independent and isolated usage. A combination of these modalities can create a hologram in space that captures more viewer attention than a conventional verbal description.

Air Anatomy gestures can be used to express various attributes of an idea or thought. For instance,

- The location of an imaginary object in a discussion can be better explained by utilizing the forearms as the *x*, *y*, and *z* axes in a coordinate space to define three planes.
- The shape of objects can be demonstrated by using hand and arm movements; for instance, a two-dimensional shape like a circle can be traced on air using a finger, while three-dimensional shapes like spheres or cubes can be demonstrated using one or both hands.
- The size of the subject of interest can be reflected by the distance between the hands representing the sides of the object. Hand movements can also be used to illustrate connections or pathways between objects, as well as their length, size, and orientation.
- The spatial relationship between multiple objects can be explained by sequentially repeating the individual object gesture one by one, aided by verbal descriptions.
- Rotational motion, translational motion, and changes in position can be effectively explained using hand gestures.
- Complex ideas and multiple objects can be expressed by multiple people performing hand gestures simultaneously on the same stage. For example, one person could maintain a gesture for a reference axis, a second person could fix the objects of discussion, and a third person could show the pathways connecting them. This provides a platform for interaction, teamplay, collaboration, and engagement.

A set of Air Anatomy gestures for teaching diverse topics in anatomy is illustrated in Fig. 10.5.

In this educational investigation, we sought to examine whether the implementation of simple gestures by instructors during lectures could influence students' spatial perception of anatomy. Participants were randomized into two groups: one receiving a standard lecture on the extraocular muscles and their role in eye movement, and the other exposed to the same lecture accompanied by Air Anatomy gestures. To evaluate participants' spatial abilities, a mental rotation test (Vandenberg and Kuse 1978; Peters et al. 1995) was administered, and their perceived cognitive loads and satisfaction with the lecture were also assessed. Finally, a comprehensive examination covering both basic recall and clinical applications of anatomical knowledge was administered.

Our findings revealed that participants who received the Air Anatomy gestures exhibited improved performance on both basic recalls and applied knowledge of the extraocular muscles. Furthermore, participants reported a greater perceived cognitive load when exposed to the Air Anatomy gestures. Notably, students rated the Air Anatomy teaching method significantly higher than the standard lecture.

10.10 Gestures to Learn; Gestures to Teach

The learning and teaching processes are characterized by the ubiquitous presence of gestures, either consciously or unconsciously employed. While spatial information is conveyed through iconic and deictic gestures, non-spatial and abstract concepts are represented by metaphorical gestures (McNeill 1992). The former type of gesture serves both a narrative (iconic) and grounding (deictic) purpose, enabling the creation of a spatial depiction of verbal commentary. The latter type of gesture, however, leverages the human ability to imagine and embody abstract concepts without physical counterparts, thus facilitating the construction of further explanations and cognitive processes (Roth 2001). Thus, gestures endow the presented information with shapes and forms, acting as a binding agent that unites various forms of concrete and abstract information. Furthermore, gestures not only activate neural networks involved in learning but also are deeply intertwined with other cognitive faculties, making

Fig. 10.5 "Air Anatomy" technique by the first author and colleagues. The first row shows the orientation of heart chambers. (**a**) An attitudinally inappropriate "valentine heart" (Mori et al. 2019) in an anterior view. The atria are seen directly above the ventricles; (**b**) Transposing the "heart" to an attitudinally appropriate anatomical position, the instructor gazes at right atrium on the right side; (**c**) Right ventricle on the anterior aspect of the "heart." Second row shows the right thalamus. (**d**) Both hands are cupped to "grip" the right thalamus; (**e**) Left hand "holds" the pointed anterior end medially, by huddling the fingers and right hand "holds" the rounded posterior end (pulvinar) laterally, by widely cupping the fingers; (**f**) The right-hand gestures to "slice" the thalamus coronally. Third row shows structures related to the left axilla. (**g**) Right hand spreading out to represent the rib cage and left hand curving like holding the upper end of the humerus; (**h**) The "wide" origin of pectoralis major muscle (spread out fingers of left hand) from the rib cage; (**i**) The insertion of pectoralis major muscle (converging fingers of left hand) to the humerus. *LA* left atrium, *LV* left ventricle, *RA* right atrium, *RV* right ventricle. (Author's work. Model in the image here is the first author. Published with permission from publisher, Wiley; License Number: 5474051045018; License date: Jan 22, 2023; John Wiley and Sons)

them an essential tool in learning and teaching, rather than a mere supplementary addition (James and Swain 2011; Dick et al. 2012).

10.10.1 Gestures in Learning

The utilization of gestures can be employed both individually and in group learning settings. Its implementation during the learning process leads to the allocation of additional cognitive resources toward acquiring knowledge, thereby increasing the germane cognitive load associated with learning, independent of the intrinsic cognitive load of the subject matter. As a result, it leads to improved comprehension of the topic. The use of gestures facilitates the expression of the learner's thinking, enabling them to structure, clarify, and enhance their thoughts (Kita et al. 2017. Additionally, it supports thinking and reasoning by providing an interface for manipulating mental representations and facilitates the organization of information into units that are suitable for further cognitive operations (Kita et al. 2017).

Moreover, co-gestured learning has been shown to enhance memory retention of the study material (Stevanoni and Salmon 2005). When applied in academic group discussions, gestures provide a focal point for exposition and participation. Participants can utilize appropriate gestures to support and expand upon their ideas and explanations (Novack and Goldin-Meadow 2015), allowing them to construct and explain complex concepts with reduced cognitive load, and providing a medium upon which further scientific discourse can develop (Roth and Welzel 2001).

Gestures have been observed to trigger memory recall of a searched word or even a broader detail during circumlocutory speech compensations. They assist in filling lexical search pauses during explanations, which is particularly useful for individuals with language impairments (Lavelli and Majorano 2016). Therefore, the use of gestures is beneficial for individuals to organize, think, comprehend, memorize, and communicate concepts more efficiently and effectively (Stefanini et al. 2008; Lacombe et al. 2022).

The act of gesturing has been posited to afford young children a means to augment their currently limited lexicon in explicating learned concepts before they acquired verbal articulation (Lacombe et al. 2022). Furthermore, it has been suggested that gestures may function to promote the generalization of acquired knowledge, thereby facilitating its application within distinct contexts or novel problem types, rather than being confined solely to a particular setting (Novack and Goldin-Meadow 2017).

It has been observed that juvenile learners have the propensity to encounter innovative ideas through the gestures they generate or perceive from the instructor. This ability permits them to exploit their cognitive resources for resolving problems in a novel and more proficient manner (Alibali 2005). It has also been observed that children who acquire new problem-solving techniques through gestural explanations perform significantly better in mathematical assessments that they were unable to succeed in previously (Broaders et al. 2007). Thus, promoting the practice of gesturing among children may augment their learning abilities and enhance their potential for problem-solving.

A study had explored the responses of children to moral reasoning tasks (examining their take on scenarios involving cheating, stealing, etc.) when clubbed with gestures. In the study, the cohorts who were encouraged to gesture during their reasoning in these scenarios considered the viewpoints of more than one individual (multi-perspective thinking) in a scenario when compared to those who were instructed not to gesture (Beaudoin-Ryan and Goldin-Meadow 2014). Hence, incorporating gestures into the learning process may instigate a multi-perspective thinking and reasoning approach in children, particularly in the context of ethical dilemmas. Therefore, encouraging the use of gestures may be deemed a beneficial pedagogical tool for cultivating diverse cognitive skills in young learners (Broaders et al. 2007).

On the not-so-bright side, it has been observed that gestures may exhibit reduced efficacy in instances where children exhibit suboptimal proficiency in the subject matter under investigation (Wakefield and James 2015). Furthermore, the capacity to acquire knowledge from gestural cues, relative to other pedagogical methodologies, may be influenced by age-related factors and therefore may not be immutable or universally applicable (Novack and Goldin-Meadow 2015).

10.10.2 Gestures in Teaching

Adequate implementation of instructional gestures facilitates the instructor's ability to sustain student engagement, highlight critical points, and promote student enthusiasm. The use of gestures has demonstrated the potential to mitigate the extrinsic cognitive load associated with pedagogy, implying a more facile mode of instruction. Moreover, gestures function as supplementary mechanisms that reinforce verbal information conveyed through speech. Representative gestures assist students in coordinating different elements of an explanation, thereby enhancing their comprehension (Crowder 1996). These gestures orient students to specific aspects of visual representations that the lecturer may indicate, trace, or accentuate (Roth 2001), while also providing novel perspectives on the lecture content (Corts and Pollio 1999). Gesture aids are versatile and may take diverse forms, as determined by the instructor's ingenuity. For example, gestures may be used as a means of embodied cognition, in which body parts serve as proxies for the structure under consideration, or may trace or carve an imaginary hologram to bring to life the topic under study (Oh et al. 2011; Yohannan et al. 2022). Given that gestures are not bound by the constraints of linguistic systems or conventions, they enable the expression of ideas that may be challenging to convey verbally (Novack and Goldin-Meadow 2015). By means of their representational form, gestures permit the transmission of ideas. The imagistic and topological nature of gestures provides a supplementary mode of expression, thereby enhancing linguistic communication. Moreover, the versatility of gesture implementation facilitates its application in a wide range of instructional contexts and proves particularly advantageous in resource-restricted settings, where expensive teaching aids may not be practical.

The present study suggests that instructive nonverbal cues facilitate the comprehension of visual concepts, leading to an improved understanding of spatial anatomy. This phenomenon has been observed through an increased capacity to assimilate anatomical content (Stieff et al. 2016; Yohannan et al. 2022). This enhanced understanding may ultimately translate into a heightened proficiency in the practical applications of these concepts in the context of clinical examination, diagnostic imaging, and surgical and radiological interventions. These findings are corroborated by the results of similar investigations conducted in other Science, Technology, Engineering and Mathematics (STEM) fields, such as statistics (Newcombe 2017; Rueckert et al. 2017).

The act of observing the nonverbal movements of a learner may offer a lens through which their inner cognitions can be inferred. Inconsistencies between verbal and gestural expression could potentially signify a lack of comprehensive understanding (Goldin-Meadow 1997). Moreover, there is evidence to suggest that the facilitation of gesturing amongst pupils may encourage the emergence of implicit ideas (Broaders et al. 2007). Empirical data suggest that children who have undergone gestural instruction interventions exhibit increased spoken language proficiency and an elevation in their spontaneous interactive gestures (LeBarton et al. 2015). Furthermore, it has been established that children are more inclined to echo their instructor's words if they are accompanied by congruent gestures (Goldin-Meadow et al. 1999).

It is a truism that students must attend to both the nonverbal cues and verbal utterances to comprehend the information presented during a lecture. Notably, instructional gestures that are intended to depict an abstract concept may be perceived as iconic gestures, rather than as metaphoric representations of the same, due to their representative nature (e.g., when gestures signify conceptual entities such as electrons) (Roth and Welzel 2001). Additionally, the cognitive load appears to increase when the instructor's gestures are temporally or conceptually dissonant with their verbal counterparts (Roth 2001). To avoid confusion and optimize gesture use, instructors should be cognizant of these issues and take appropriate preventative measures.

10.11 "Static" and "Dynamic" Anatomy: Animating Anatomy with Gestures

As stated by the sixteenth century French Physician, Jean François Fernel (Sieck 2017), "Anatomy is to physiology as geography is to history; it describes the theater of events." Anatomy (the form) and Physiology (the function) are integral (Sieck 2017). Anatomy, which is concerned with the structure of the human body, is readily visualizable and provides a foundational framework for learners to comprehend the biological and clinical significance of bodily function. For instance, knowledge of the structure of a simple squamous epithelium, which rests on a basement membrane in the lung alveolar wall, enables a comprehensive understanding of the biological function of gas diffusion through the delicate 0.1 micron-thin tissue into the capillary blood. Furthermore, it allows for the appreciation of the clinical implications of diffuse alveolar damage in acute respiratory distress syndrome (ARDS), which can lead to acute respiratory distress syndrome and rapid hypoxemia (Cardinal-Fernández et al. 2017).

Comprehending the functional significance of certain phenomena necessitates the visualization of various dynamic events, thereby necessitating the utilization of physical working models (Joseph et al. 2006; Salinas-Alvarez et al. 2022) and animated visual aids in the form of videos, computer software, and PowerPoints (Habbal and Harris 1995; Carmichael and Pawlina 2000; Guttmann 2000). The volume of knowledge that such dynamic demonstrations offer in a learning environment is extensive. The statement made by McQuivey's Forrester study (McQuivey et al. 2008) highlights the role of animations, videos, and "moving pictures"—"a picture is worth a thousand words, one minute of video is worth 1.8 million!" (McQuivey et al. 2008; Forbes 2016). Their study further demonstrated that a webpage featuring a video is more likely to be ranked on the first page of Google searches (McQuivey et al. 2008; Forbes 2016).

The vast potential of hand movements and gestures used to convey dynamic content has led to their significant role in education. Cherdieu et al. conducted a study to explore the impact of gestural communication on student learning (Cherdieu et al. 2017). The researchers focused on forearm movements as a topic of interest (see Fig. 10.6).

Their study compared the performance of students who only observed the gestures to those who not only observed but also replicated the dynamic gestures. The findings showed that the group that imitated the gestures had significantly higher scores than the group that only observed them. Moreover, the group that replicated the gestures displayed greater levels of engagement, interactivity, and motivation in the learning process.

10.12 Using Gestures with Modern Teaching Aids in the Twenty-First Century

In the current era, the pedagogy of anatomical instruction preserves the fundamental tenets established during the seventeenth century (Leung et al. 2006; Ghosh 2017). Nonetheless, unprecedented advancements in science and technology during the preceding century have furnished anatomy educators with an array of modern amenities, prospects, a diverse set of instruments, and distinctive challenges, far beyond the conception of Andreas Vesalius or Henry Gray. The domain of anatomy education encompasses both technology-aided education, ranging from rudimentary to highly sophisticated visualization tools, and educational technology, which entails the amalgamation of concepts from diverse sources to impart the most efficacious

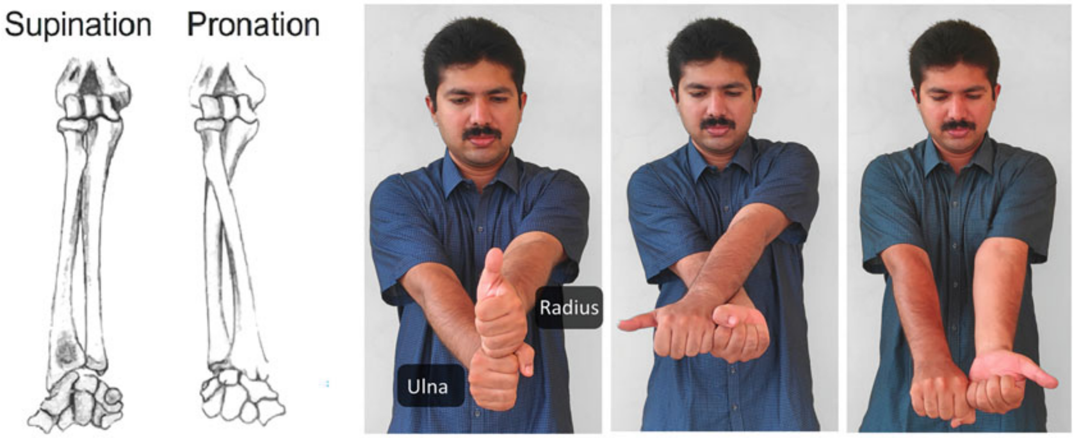

Fig. 10.6 The function of the radius and ulna during pronation and supination is explained. The model associates one of his limbs to the radius (thumb-up limb) and the other to the ulna. From left to right: in the neutral position, the radius is on the top, it then pivots over the ulna in pronation while staying almost parallel to it in supination. (Adapted from Cherdieu et al. (2017); This file is licensed for use under Creative Commons Attribution License (CC BY). Model in the image here is one of the authors)

learning experience to students (Hooper and Rieber 1995). Nevertheless, the advent of technology has not impeded the utility, clarity, and simplicity of conventional methods, such as the use of a blackboard and chalk, which have stood the test of time (Clavert et al. 2012).

The function of manual gestures renders them optimal, even when utilizing the latest visualization techniques. The interplay between gestures and technology has been investigated. In addition to their general application, technological advancements have paved the way for hand gesture-driven command and navigation of virtual space. Hochman et al. (2014) expounded upon hand gesture-based manipulation and control of the 3D virtual milieu for the purpose of surgical training. Their research comprised the creation of virtual reality-based temporal bone anatomy from CT temporal bone data. Gesture recognition and haptic feedback technologies synergistically combine to establish instructional settings, in which learners can manipulate structures, navigating and adapting environments in a semi-realistic manner, thereby enhancing anatomical and surgical training efficacy (Hutchins et al. 2006; Blum et al. 2012; Zhou et al. 2012).

10.13 Gestures and Online Education

The present study posits that online education represents a contemporary alternative to erstwhile correspondence courses (Harasim 2000). The advent of the internet and the World Wide Web has effectively eliminated geographical barriers and engendered novel opportunities for learning (Allen and Seaman 2011). Empirical evidence suggests that one in every three tertiary-level students partakes in at least one web-based course throughout their academic tenure (Bettinger and Loeb 2017). The unprecedented challenges posed by the COVID-19 pandemic to the educational domain has led to a paradigm shift in the perception, acceptability, and utilization of online education (Xie et al. 2020). Blended learning and flipped classroom pedagogies have redefined the way in which education is viewed within the post-pandemic era (Walker 2022).

The dissemination of educational content through video recordings of lectures has become ubiquitous worldwide. These recordings offer the opportunity to capture nonverbal cues such as facial expressions, eye movements, body language, and hand gestures. Yang et al. (2020)) assert that instructional gestures have a significant impact not only on the listener but also on the teacher, as they reflect cognitive processes and have a reciprocal relationship with the speaker's thoughts. Their two experiments demonstrated enhanced teaching performance and experience and recommended the use of gestures, particularly pointing gestures, during video lectures. The instructor's face, eye gaze, voice, and appearance are deemed crucial social and attentional cues for promoting learning (Stull et al. 2021; Pi et al. 2022). Recognizing and attending to a speaker's face, as well as processing key features such as the eyes, are biologically fundamental abilities that reflect social and evolutionary advantages (Kanwisher et al. 1997; Geary 2008). In the context of video lectures, pointing gestures have been shown to improve learning performance independently of directed gaze effects (Pi et al. 2019).

A salient point worthy of attention is that in numerous video lectures, the primary mode of presentation may be a screen recording of a PowerPoint presentation, either with or without the instructor's countenance captured through a web camera or another camera recording overlay. Alt (2021), at the University of Northern Colorado, investigating the impact of hand gestures on mathematical Euclidean transformations during synchronous lectures, has recommended that pedagogical experts should engage in specialized development workshops to cultivate intentional and precise gestural communication. Additionally, it has been proposed that video recording methods should be optimized to ensure that all student learners are afforded the opportunity to visually perceive all the gestures executed by the teacher. The scholars further contend that this approach would encourage the instructor to generate more calculated gestural communications, while simultaneously guiding students to meticulously observe the produced gestures. Extending this finding to the field of anatomy, which involves more distinct spatial concepts in contrast to the domain of Mathematics, careful deliberation of content creation for online education is imperative. As such, thoughtful adaptation of the learning environment to provide students with not only academic information but also visual access to the speaker's facial expressions, gestures, and hand movements may significantly impact student learning outcomes.

10.14 Optimizing Gestures in the Classroom Based on Visualization Principles and Cognitive Theory

The acquisition of knowledge by biomedical students is facilitated through the use of visual aids. Therefore, pedagogues are obliged to present visual content in an efficacious manner, based on the principles of visualization, which are grounded on the theories of cognitive load and multimedia processing. In this regard, the judicious employment of gestures during teaching can be optimized by adherence to these selfsame principles.

- Contiguity Principle: Stated simply, this means "Align words to graphics" (Clark and Mayer 2016). This principle comprises two interrelated components, namely spatial and temporal contiguity. Spatial contiguity dictates that visual elements should not be spatially separate but rather contiguous. This principle is of particular significance in the design of book illustrations, posters, and static models, as it mitigates the need for mental exertion required to search, match, and integrate separate visual components. When temporal contiguity is added to the equation, i.e., spatiotemporal contiguity, visual components must be both spatially and temporally proximate to optimize working memory capacity. Empirical evidence (Moreno and Mayer 1999) supports the notion that learning is enhanced when text and animations are closely aligned rather than separated. Thus, in dynamic learning environments, such as lectures or small group discussions that entail spatially-oriented gestures to comprehend a 2D figure, it is crucial to create gestures in close spatial and temporal proximity to the corresponding visual element.

- Modality Principle: It posits that when presenting multimedia materials, it is preferable to use spoken language in conjunction with visual aids, rather than relying solely on on-screen text. With respect to pedagogy, incorporating hand gestures while delivering a lecture aligns with the modality principle and confers pedagogical benefits.
- Segmented Principle: The act of partitioning a sizeable segment into smaller ones is advocated herein. This practice is particularly desirable in depicting sequences involving handwashing, medical interventions, surgical procedures, and dissection protocols. Hand gestures are well-suited for the purpose of fragmenting a large sequence into more manageable sub-sequences to effectively communicate spatial concepts. The relationship between anatomical structures can be readily elucidated by partitioning a sequence of gestures.
- Signaling Principle: The proposition posits that visualizations coupled with cues that serve to direct the attention of learners toward significant elements are more efficacious. Amongst these cues, pointing gestures are particularly effective. Moreover, the incorporation of verbal instructions, body language that conveys enthusiasm, and gaze cues can also serve as potent social indicators of importance (Valenzeno et al. 2003; Hale et al. 2017).

The aforementioned principles of visualization are employed in an instructional session (see Fig. 10.7). The utilization of segmentation and instructional techniques allows for the demonstration of the intricate relationship between the parotid salivary gland and the facial nerve.

The session commences with the depiction of an axial section of the parotid gland on a two-dimensional plane (board), as illustrated in Fig. 10.7a. The squiggly lines (representing the Lateral surface (L), Anteromedial surface (AM), and Posteromedial surface (PM)) delineate the wedge-shaped parotid gland. Due to the inherent limitations of the two-dimensional representation in demonstrating spatial anatomy, we introduce gestures as a means of bridging the dimensionality gap and conveying spatial information. In Fig. 10.7b, the right and left hands are utilized to represent the anteromedial and posteromedial surfaces of the parotid (in adherence to the contiguity principle). This approach is augmented by accompanying speech, following the modality principle. The right hand is subsequently moved to depict the lateral surface (Fig. 10.7c), thus outlining the parotid gland.

The next step involves introducing the facial nerve into the scene, with adherence to the segmentation principle in which the concept is broken down into shorter segments. The facial nerve (represented by the right thumb) enters the gland from the posteromedial surface (represented by the left hand) (Fig. 10.7d), branches within the substance of the parotid (as depicted by the right hand in Fig. 10.7e), and approaches the anteromedial surface (as illustrated in Fig. 10.7f, with the right-hand fingers representing facial nerve branches and the left hand representing the anteromedial surface). The facial nerve branches (right-hand fingers) then splay and exit through the anteromedial surface (left hand) (Fig. 10.7g). Finally, the spatial concept is reinforced by rotating the viewing perspective (as demonstrated in Fig. 10.7h), providing a view of the lateral surface of the parotid with the five fingers of the right hand representing the five branches of the facial nerve (as seen in Fig. 10.7g). The entire sequence is available in video format (https://youtu.be/Gdg9-pHpzVA) for future reference and is accessible on the first author's publicly accessible YouTube channel (https://www.youtube.com/@AirAnatomy_Doris).

The introduction of gestures into teaching has led to the incorporation of 3D, anatomically relevant, and clear representations of information. Gestures have the potential to facilitate engagement and interaction between teachers and learners. Additionally, learners may be prompted to engage with and manipulate the "holographic structure" of the parotid gland by "touching" its anteromedial surface or deeper lobe, thereby

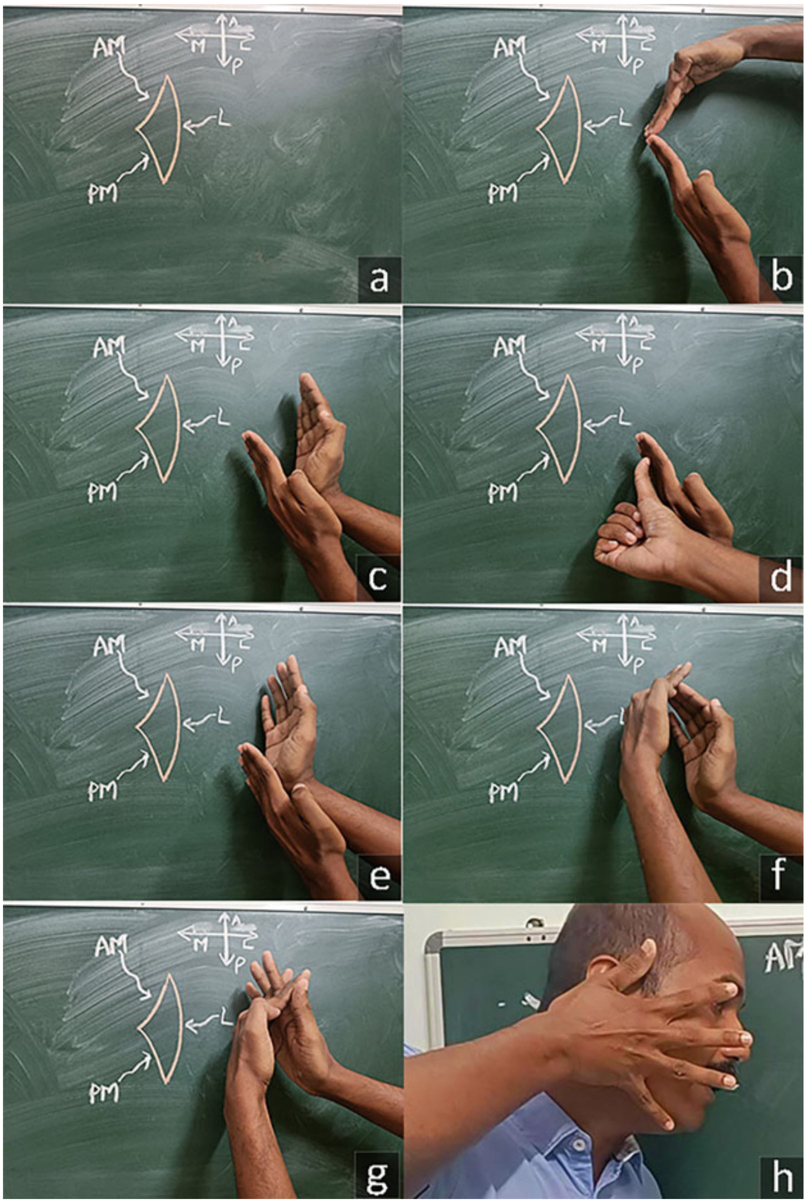

Fig. 10.7 A series of gestures to show the relation of the facial nerve to the parotid gland. (**a**) Drawing on a 2D plane (board) the axial section of the parotid gland. AM is Anteromedial, PM is Posteromedial, and L is lateral surface. A "compass" is shown to understand directions. (**b**) the right and left hands show the anteromedial and the posteromedial surfaces of the parotid. (**c**) The right hand is shifted to "touch" the lateral surface. (**d**) Facial nerve (right thumb) enters the gland from the posteromedial surface (left hand). (**e**) Facial nerve (right hand) branches inside the substance of the parotid. (**f**) Facial nerve approaches the anteromedial surface (right-hand fingers now represent facial nerve branches and left hand the anteromedial surface). (**g**) Facial nerve branches (right-hand fingers) now splay and exit the anteromedial surface (left hand). (**h**) Concept is finally reinforced by rotating the viewing perspective in Fig. 10.7h, where now we are viewing the lateral surface of the parotid, the five fingers of the right hand are the five branches of the facial nerve [same as in g]. Model in the image here is the first author

increasing their involvement, and facilitating the development of motor memory.

As described above, this exercise involves the sequential movement of the examiner's hands and requires the learners' attention and follow-up. However, if the exercise is properly followed, it can lead to improved spatial understanding of the relationship between the parotid gland and the facial nerve, which is a clinically and surgically relevant concept.

10.15 Limitations of the Use of Gesture

Notwithstanding its universal applicability, cross-cultural and regional usage, and pedagogical versatility that transcends linguistic barriers, employment of gestures in pedagogy is constrained by certain limitations.

One requisite when solely utilizing gestures is the necessity to maintain attentive focus and adhere to the sequence of gestures in order to comprehend the presented concept. Unfortunately, this approach carries a potential drawback of the learner becoming disoriented. The reason behind this predicament is that the absence of static visual stimuli precludes learners from observing the transformation of gesture-based content over time, which is critical in the gradual construction of a spatial construct. The dearth of actual static visual input can be remedied using complementary visual aids, such as images/diagrams (Streeck 2009), which can either be pre-prepared or produced live, or with the aid of models or 3D graphic solutions. By incorporating both gestures and visual content, instructional delivery can be significantly enhanced.

The video recording of gestures has been found to have limitations in capturing the subtle nuances of gestural expressions and the gaze of the teacher (Streeck 2009). Therefore, video recording and online teaching or blended learning modalities may not be optimal for teaching that relies on gesturing. However, it is noteworthy that the use of gaze guidance and cues in video lectures has been shown to increase social presence in students and to direct their visual attention toward appropriate learning content (Wang et al. 2019; Stull et al. 2021).

Furthermore, it is important to note that the effectiveness of hand gestures as a teaching tool may be best suited for small group teaching, and the number of students may need to be limited accordingly.

The occurrence of visual impairment among students has been shown to impede perception. Additionally, there may exist a subset of students who display a disinclination toward visual modalities, such as those involving gestures. It is incumbent upon educators to consider learner preferences, ensuring that student needs are met in a tailored and individualized manner.

10.16 Conclusion

Anatomy learning is a complex and challenging endeavor that is nonetheless rewarding, engaging, and pertinent. The contemporary anatomy instructor must transcend traditional pedagogical approaches and stimulate students' intellectual curiosity by combining novel and conventional teaching methods, as well as scientific and artistic perspectives. A potential means of enriching the teacher's arsenal of techniques, tools, and technologies is through the adoption of simple yet effective measures such as gestures and manual actions, which boast benefits such as affordability, efficacy, engagement, and interest. The efficacy of this instructional approach is supported by robust scientific evidence grounded in cognitive load theories, neuroscience, and empirically conducted educational experiments. By integrating gestures and manual movements with traditional teaching modalities such as chalkboard instruction, anatomical dissection, and cutting-edge visualization technologies, educators can leverage a versatile, convenient, and accessible toolset to optimize student learning outcomes.

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References

Alibali MW (2005) Gesture in spatial cognition: expressing, communicating, and thinking about spatial information. Spat Cogn Comput 5:307–331

Alibali MW, Heath DC, Myers HJ (2001) Effects of visibility between speaker and listener on gesture production: some gestures are meant to be seen. J Mem Lang 44:169–188

Allen IE, Seaman J (2011) Going the distance: online education in the United States, 2011. ERIC

Almoznino A, Pinas Y (2002) The Art of Hand Shadows. Dover Publications

Alt AC (2021) Online instructors' gestures for Euclidean transformations. University of Northern Colorado

Baratz G, Wilson-Delfosse AL, Singelyn BM, Allan KC, Rieth GE, Ratnaparkhi R, Jenks BP, Carlton C, Freeman BK, Wish-Baratz S (2019) Evaluating the Anatomage table compared to cadaveric dissection as a learning modality for gross anatomy. Med Sci Educ 29:499–506

Beaudoin-Ryan L, Goldin-Meadow S (2014) Teaching moral reasoning through gesture. Dev Sci 17(6): 984–990

Bettinger E, Loeb S (2017) Promises and pitfalls of online education. Evid Speaks Reports 2(15):1–4

Blum T, Kleeberger V, Bichlmeier C, Navab N (2012) Miracle: an augmented reality magic mirror system for anatomy education. p. 115–116. IEEE. [accessed]

Bosker HR, Peeters D (2021) Beat gestures influence which speech sounds you hear. Proc R Soc B 288: 20202419

Broaders SC, Cook SW, Mitchell Z, Goldin-Meadow S (2007) Making children gesture brings out implicit knowledge and leads to learning. J Exp Psychol Gen 136:539

Cambridge English Thesaurus (2022) Cambridge English Thesaurus. Cambridge University Press. https://dictionary.cambridge.org/dictionary/english/in-mind-s-eye [Accessed 28th November 2022]

Carbonneau KJ, Marley SC, Selig JP (2013) A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. J Educ Psychol 105:380

Cardinal-Fernández P, Lorente JA, Ballén-Barragán A, Matute-Bello G (2017) Acute respiratory distress syndrome and diffuse alveolar damage. New insights on a complex relationship. Ann Am Thorac Soc 14:844–850

Carels PE (1981) Pantomime in the foreign language classroom. Foreign Lang Ann 14:407–411

Carmichael SW, Pawlina W (2000) Animated PowerPoint as a tool to teach anatomy. Anat Record 261:83–88

Carroll C, Carroll R (2012) Mudras of India: a comprehensive guide to the hand gestures of yoga and Indian dance. Singing Dragon

CAST (2018) Universal design for learning guidelines version 2.2. http://udlguidelines.cast.org [accessed]

Chan LK (2010) Pulling my gut out—Simple tools for engaging students in gross anatomy lectures. Anat Sci Educ 3:148–150

Cherdieu M, Palombi O, Gerber S, Troccaz J, Rochet-Capellan A (2017) Make gestures to learn: reproducing gestures improves the learning of anatomical knowledge more than just seeing gestures. Front Psychol 8: 1689

Chytas D, Salmas M, Paraskevas G, Demesticha T, Kefaliakos A, Stavroulakis A, Noussios G (2022) Gestures-enhanced anatomy teaching: a literature review of an educational strategy with promising outcomes. Morphologie

Clark RC, Mayer RE (2016) e-Learning and the science of instruction: proven guidelines for consumers and designers of multimedia learning. Wiley

Clavert P, Bouchaïb J, Duparc F, Kahn JL (2012) A plea for the use of drawing in human anatomy teaching. Surg Radiol Anat 34:787–789

Cloud BA, Youdas JW, Hellyer NJ, Krause DA (2010) A functional model of the digital extensor mechanism: demonstrating biomechanics with hair bands. Anat Sci Educ 3:144–147

Clough S, Hilverman C (2018) Hand gestures and how they help children learn. Front Young Minds 7:14

Congdon EL, Kwon M-K, Levine SC (2018) Learning to measure through action and gesture: Children's prior knowledge matters. Cognition 180:182–190

Cook SW (2018) Enhancing learning with hand gestures: potential mechanisms. Psychology of learning and motivation. Elsevier, p 107–133

Corts DP, Pollio HR (1999) Spontaneous production of figurative language and gesture in college lectures. Metaphor Symb 14:81–100

Cosman JD, Vecera SP (2010) Attention affects visual perceptual processing near the hand. Psychol Sci 21: 1254–1258

Crowder EM (1996) Gestures at work in sense-making science talk. J Learn Sci 5:173–208

Dempsey AMK, Lone M, Nolan YM, Hunt E (2021) Universal design for learning in anatomy education of healthcare students: a scoping review. Anat Sci Educ

Dempsey AMK, Hunt E, Lone M, Nolan YM (2022) Awareness of Universal Design for Learning among anatomy educators in higher level institutions in the Republic of Ireland and United Kingdom. Clin Anat

Dick AS, Goldin-Meadow S, Solodkin A, Small SL (2012) Gesture in the developing brain. Dev Sci 15:165–180

Dwyer FM (1972) A guide for improving visualized instruction

Elizondo-Omaña RE, Guzmán-López S, De Los Angeles García-Rodríguez M (2005) Dissection as a teaching tool: past, present, and future. Anat Record Part B New Anat 285:11–15

Forbes (2016) Is your company giving video the love it deserves? https://www.forbes.com/sites/kateharrison/2016/03/31/is-your-company-giving-video-the-love-it-deserves/?sh=344d3198464d [accessed]

Galati A, Weisberg SM, Newcombe NS, Avraamides MN (2018) When gestures show us the way: co-thought gestures selectively facilitate navigation and spatial memory. Spat Cognit Comput 18:1–30

Geary DC (2008) An evolutionarily informed education science. Educ Psychol 43:179–195

Ghosh SK (2017) Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. Anat Sci Educ 10:286–299

Ginns P, King V (2021) Pointing and tracing enhance computer-based learning. Educ Technol Res Dev 69: 1387–1403

Ginns P, Kydd A (2019) Learning human physiology by pointing and tracing: a cognitive load approach. Advances in cognitive load theory. Routledge, p 119–129

Goldin-Meadow S (1997) When gestures and words speak differently. Curr Dir Psychol Sci 6:138–143

Goldin-Meadow S, Kim S, Singer M (1999) What the teacher's hands tell the student's mind about math. J Educ Psychol 91:720

Goldman SR (2003) Learning in complex domains: when and why do multiple representations help? Learn Instr 13:239–244

Guttmann GD (2000) Animating functional anatomy for the web. Anat Record 261:57–63

Habbal OA, Harris PF (1995) Teaching of human anatomy: a role for computer animation. J Audiov Media Med 18:69–73

Hale AJ, Freed J, Ricotta D, Farris G, Smith CC (2017) Twelve tips for effective body language for medical educators. Med Teach 39:914–919

Harasim L (2000) Shift happens: online education as a new paradigm in learning. Internet High Educ 3:41–61

Hochman JB, Unger B, Kraut J, Pisa J, Hombach-Klonisch S (2014) Gesture-controlled interactive three dimensional anatomy: a novel teaching tool in head and neck surgery. J Otolaryngol Head Neck Surg 43:1–6

Hooper S, Rieber LP (1995) Teaching with technology. Teach Theory Practice 2013:154–170

Hostetter AB, Alibali MW, Kita S (2007) I see it in my hands' eye: representational gestures reflect conceptual demands. Lang Cognit Proc 22:313–336

Hu F-T, Ginns P, Bobis J (2015) Getting the point: tracing worked examples enhances learning. Learn Instr 35: 85–93

Hulme C, Monk A, Ives S (1987) Some experimental studies of multi-sensory teaching: the effects of manual tracing on children's paired-associate learning. Br J Dev Psychol 5:299–307

Hutchins MA, Stevenson DR, Gunn C, Krumpholz A, Adriaansen T, Pyman B, O'Leary S (2006) Communication in a networked haptic virtual environment for temporal bone surgery training. Virt Real 9:97–107

James KH, Swain SN (2011) Only self-generated actions create sensori-motor systems in the developing brain. Dev Sci 14:673–678

Joseph B, Rebello G, Mayya S (2006) The use of a working model for teaching functional and applied surgical anatomy of the subtalar joint. Foot Ankle Int 27:286–292

Kalenine S, Pinet L, Gentaz E (2011) The visual and visuo-haptic exploration of geometrical shapes increases their recognition in preschoolers. Int J Behav Dev 35:18–26

Kanwisher N, McDermott J, Chun MM (1997) The fusiform face area: a module in human extrastriate cortex specialized for face perception. J Neurosci 17:4302–4311

Keenan ID, ben Awadh A (2019) Integrating 3D visualisation technologies in undergraduate anatomy education. Biomed Visual:39–53

Kita S (2009) Cross-cultural variation of speech-accompanying gesture: a review. Lang Cognit Proc 24:145–167

Kita S, Alibali MW, Chu M (2017) How do gestures influence thinking and speaking? The gesture-for-conceptualization hypothesis. Psychol Rev 124:245

Krakauer JW, Shadmehr R (2006) Consolidation of motor memory. Trends Neurosci 29:58–64

Kuo KH, Leo JM (2019) Optical versus virtual microscope for medical education: a systematic review. Anat Sci Educ 12:678–685

Kurt E, Yurdakul SE, Ataç A (2013) An overview of the technologies used for anatomy education in terms of medical history. Proc Soc Behav Sci 103:109–115

Lacombe N, Dias T, Petitpierre G (2022) Can gestures give us access to thought? A systematic literature review on the role of co-thought and co-speech gestures in children with intellectual disabilities. J Nonverbal Behav:1–18

Laski EV, Jor'dan JR, Daoust C, Murray AK (2015) What makes mathematics manipulatives effective? Lessons from cognitive science and Montessori education. SAGE Open 5:2158244015589588

Lavelli M, Majorano M (2016) Spontaneous gesture production and lexical abilities in children with specific language impairment in a naming task. J Speech Lang Hear Res 59:784–796

LeBarton ES, Goldin-Meadow S, Raudenbush S (2015) Experimentally induced increases in early gesture lead to increases in spoken vocabulary. J Cogn Dev 16: 199–220

Leung K-k, Lu K-S, Huang T-S, Hsieh B-S (2006) Anatomy instruction in medical schools: connecting the past and the future. Adv Health Sci Educ 11:209–215

Li J, Nie L, Li Z, Lin L, Tang L, Ouyang J (2012) Maximizing modern distribution of complex anatomical spatial information: 3D reconstruction and rapid prototype production of anatomical corrosion casts of human specimens. Anat Sci Educ 5:330–339

Macken L, Ginns P (2014) Pointing and tracing gestures may enhance anatomy and physiology learning. Med Teach 36:596–601

Matsumoto D, Hwang HC (2013) Cultural similarities and differences in emblematic gestures. J Nonverbal Behav 37:1–27

McLachlan JC, Patten D (2006) Anatomy teaching: ghosts of the past, present and future. Med Educ 40:243–253

McNeill D (1992) Hand and mind: what gestures reveal about thought. University of Chicago Press. 416 p

McQuivey JL, De Lussanet M, Wilkos D (2008) How video will take over the world. Forrester Research, Cambridge, MA

Montessori M (1912) The Montessori method. Robert Bentley

Moore KL, Dalley AF (2018) Clinically oriented anatomy. Wolters Kluwer India

Moreno R, Mayer RE (1999) Cognitive principles of multimedia learning: The role of modality and contiguity. J Educ Psychol 91:358

Mori S, Tretter JT, Spicer DE, Bolender DL, Anderson RH (2019) What is the real cardiac anatomy? Clin Anat 32 (3):288–309. https://onlinelibrary.wiley.com/doi/full/10.1002/ca.23340

Newcombe N (2017) Harnessing spatial thinking to support stem learning

Novack M, Goldin-Meadow S (2015) Learning from gesture: How our hands change our minds. Educ Psychol Rev 27:405–412

Novack MA, Goldin-Meadow S (2017) Gesture as representational action: a paper about function. Psychon Bull Rev 24:652–665

Oh CS, Kim JY, Choe YH (2009) Learning of cross-sectional anatomy using clay models. Anat Sci Educ 2:156–159

Oh CS, Won HS, Kim KJ, Jang DS (2011) "Digit anatomy": a new technique for learning anatomy using motor memory. Anat Sci Educ 4:132–141

Paas F, Sweller J (2012) An evolutionary upgrade of cognitive load theory: using the human motor system and collaboration to support the learning of complex cognitive tasks. Educ Psychol Rev 24:27–45

Paas F, van Merriënboer JJG (2020) Cognitive-load theory: methods to manage working memory load in the learning of complex tasks. Curr Dir Psychol Sci 29: 394–398

Patra A, Asghar A, Chaudhary P, Ravi KS (2022) Integration of innovative educational technologies in anatomy teaching: new normal in anatomy education. Surg Radiol Anat 44:25–32

Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, Richardson C (1995) A redrawn Vandenberg and Kuse mental rotations test-different versions and factors that affect performance. Brain Cogn 28:39–58

Pi Z, Zhang Y, Zhu F, Xu K, Yang J, Hu W (2019) Instructors' pointing gestures improve learning regardless of their use of directed gaze in video lectures. Comput Educ 128:345–352

Pi Z, Deng L, Wang X, Guo P, Xu T, Zhou Y (2022) The influences of a virtual instructor's voice and appearance on learning from video lectures. J Comput Assist Learn

Ravi KS (2020) Dead body management in times of Covid-19 and its potential impact on the availability of cadavers for medical education in India. Anat Sci Educ 13:316

Reed CL, Grubb JD, Steele C (2006) Hands up: attentional prioritization of space near the hand. J Exp Psychol Hum Percept Perform 32:166

Rimé B, Schiaratura L (1991) Gesture and speech

Rose ML, Mok Z, Sekine K (2017) Communicative effectiveness of pantomime gesture in people with aphasia. Int J Lang Commun Disord 52:227–237

Rosse C, Gaddum-Rosse P, Hollinshead WH (1997) Hollinshead's textbook of anatomy. Lippincott-Raven Publishers

Roth W-M (2001) Gestures: their role in teaching and learning. Rev Educ Res 71:365–392

Roth WM, Welzel M (2001) From activity to gestures and scientific language. J Res Sci Teach 38:103–136

Rueckert L, Church RB, Avila A, Trejo T (2017) Gesture enhances learning of a complex statistical concept. Cogn Res Princ Implicat 2:1–6

Salinas-Alvarez Y, Garza-Gutiérrez A, Quiroga-Garza A, Elizondo-Omaña RE, Gutierrez-De-La-O J, Guzman-Lopez S (2022) 3D printed schematic model for extraocular muscles teaching. FASEB J 36

Sieck GC (2017) Physiology in perspective: structure and function—anatomy and physiology are integral. Physiology 32:264–265

Skinder-Meredith AE (2010) Innovative activities for teaching anatomy of speech production. Anat Sci Educ 3:234–243

Skulmowski A, Pradel S, Kühnert T, Brunnett G, Rey GD (2016) Embodied learning using a tangible user interface: the effects of haptic perception and selective pointing on a spatial learning task. Comput Educ 92: 64–75

Smith CF, Martinez-Álvarez C, McHanwell S (2014) The context of learning anatomy: does it make a difference? J Anat 224:270–278

Somera dos Santos F, Osako MK, Perdoná GSC, Alves MG, Sales KU (2021) Virtual microscopy as a learning tool in Brazilian medical education. Anat Sci Educ 14: 408–416

Stefanini S, Recchia M, Caselli MC (2008) The relationship between spontaneous gesture production and spoken lexical ability in children with Down syndrome in a naming task. Gesture 8:197–218

Stevanoni E, Salmon K (2005) Giving memory a hand: instructing children to gesture enhances their event recall. J Nonverbal Behav 29:217–233

Stieff M, Lira ME, Scopelitis SA (2016) Gesture supports spatial thinking in STEM. Cogn Instr 34:80–99

Streeck J (2009) Gesturecraft: The manu-facture of meaning. John Benjamins Publishing

Stull AT, Hegarty M, Mayer RE (2009) Getting a handle on learning anatomy with interactive three-dimensional graphics. J Educ Psychol 101:803

Stull AT, Fiorella L, Mayer RE (2021) The case for embodied instruction: The instructor as a source of

attentional and social cues in video lectures. J Educ Psychol 113:1441
Sweller J, Ayres P, Kalyuga S (2011) Cognitive load theory. Springer, New York
The Economist (2021) The pandemic has caused a shortage of cadavers. https://www.economist.com/britain/2021/05/06/the-pandemic-has-caused-a-shortage-of-cadavers [accessed]
The Guardian (2023) 'Culture is hard to break': Kenya's medical schools face a shortage of cadavers. https://www.theguardian.com/global-development/2023/jan/24/kenya-medical-schools-shortage-of-cadavers [accessed 28th January 2023 2023]
Triepels CPR, Smeets CFA, Notten KJB, Kruitwagen RFPM, Futterer JJ, Vergeldt TFM, Van Kuijk SMJ (2020) Does three-dimensional anatomy improve student understanding? Clin Anat 33:25–33
Trostle Brand S, Favazza AE, Dalton EM (2012) Universal design for learning: a blueprint for success for all learners. Kappa Delta Pi Record 48:134–139
Valenzeno L, Alibali MW, Klatzky R (2003) Teachers' gestures facilitate students' learning: a lesson in symmetry. Contemp Educ Psychol 28:187–204
Vandenberg SG, Kuse AR (1978) Mental rotations, a group test of three-dimensional spatial visualization. Percept Mot Skills 47:599–604
Wakefield EM, James KH (2015) Effects of learning with gesture on children's understanding of a new language concept. Dev Psychol 51:1105
Walker KW (2022) A silver lining for pandemic-weary libraries: how blended and flipped instructional programs have improved upon pre-pandemic norms. J Acad Librariansh 48:102595
Wang H, Pi Z, Hu W (2019) The instructor's gaze guidance in video lectures improves learning. J Comput Assist Learn 35:42–50
Wang B, Ginns P, Mockler N (2022) Sequencing tracing with imagination. Educ Psychol Rev 34:421–449
Xie X, Siau K, Nah FF-H (2020) COVID-19 pandemic-online education in the new normal and the next normal. J Inform Technol Case Appl Res 22:175–187
Yang J, Zhu F, Guo P, Pi Z (2020) Instructors' gestures enhance their teaching experience and performance while recording video lectures. J Comput Assist Learn 36:189–198
Yohannan DG, Oommen AM, Umesan KG, Raveendran VL, Sreedhar LSL, Anish TSN, Hortsch M, Krishnapillai R (2019) Overcoming barriers in a traditional medical education system by the stepwise, evidence-based introduction of a modern learning technology. Med Sci Educ 29:803–817
Yohannan DG, Oommen AM, Amogh BJ, Raju NK, Suresh RO, Nair SJ (2022) "Air anatomy"—teaching complex spatial anatomy using simple hand gestures. Anat Sci Educ 15:552–565
Zhou M, Tse S, Derevianko A, Jones DB, Schwaitzberg SD, Cao CGL (2012) Effect of haptic feedback in laparoscopic surgery skill acquisition. Surg Endosc 26:1128–1134

Corporeal Pedagogy: Visualizing Anatomy Through Art, Archaeology, and Medicine

11

Olivia Turner and Sally Waite

Abstract

This chapter outlines the educational methodology, *Corporeal Pedagogy* established by Dr. Olivia Turner and Dr. Sally Waite, which uses the Shefton Collection of Greek Art and Archaeology for interdisciplinary teaching and learning. This methodology considers the relationship between objects, art, and medicine to better understand how we visualize and imagine the visceral body. It aims to create a form of learning and teaching that addresses and challenges certain conventional modes of Western education, particularly within a European university setting, and to instead facilitate embodied and haptic learning and production of knowledge. *Corporeal Pedagogy* explores ancient and contemporary notions of the body and embodiment, and how our perception of anatomy changes during experiences of transition, illness, and disease. The participating students used object handling, creative practice, meditation, and selected readings to investigate what it means to learn through the body. Within a university setting, the workshops illustrate the transformative role objects can play in education to facilitate radical forms of teaching and learning in the field of medical humanities.

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Keywords

Anatomical votives · Art · Archaeology · Medical humanities · Pedagogy · Shefton Collection

11.1 Introduction

Corporeal Pedagogy (Turner 2022) is an interdisciplinary teaching methodology, which considers the relationship between artifacts, art, and medicine to enable better understandings of how we visualize and imagine the visceral body. *Corporeal Pedagogy* manifested as a series of experimental workshops called *The Way My Body Feels*, designed for university students across the subject areas of fine art, archaeology, and medical sciences. These workshops explored how we could create new pedagogical methodologies for teaching and learning, while investigating their value within our university setting. The workshop series used artifacts from the Shefton Collection of Greek Art and Archaeology as a focus to stimulate learning around ancient objects and the body, cultivating innovative and collaborative teaching between the arts, humanities, and medical sciences.

The visceral body refers to our perception of the bodily interior through methods of seeing, sensing, and speaking. In medical language, visceral is used to describe the anatomical location of the internal organs in the main cavities of the

L. Shapiro (ed.), *Graphic Medicine, Humanizing Healthcare and Novel Approaches in Anatomical Education*, Biomedical Visualization 3, https://doi.org/10.1007/978-3-031-39035-7_11

body. In the humanities, "visceral" refers to the metaphorical capturing of sensations in the bodily interior, defined as being "felt in or as if in the internal organs of the body" (Merriam-Webster 2022). Within the clinical encounter between a doctor and a patient, the patient often uses subjective visceral descriptions to explain their physical or psychological complaint. Drawing on this subjective visceral language to describe one's representation and understanding of illness and disease can also be termed *lived experience*.

The term "visceral" embodies a tension through the juxtaposition of objective knowledge and subjective experience. When presented with standardized anatomical representations, how does the imagined bodily interior influence our understanding of our own body, and how does our understanding of the body influence our imagined body? Our imagined bodily interior is shaped by subjective corporeal sensation. In other words, it is an internalized vision and an extension of the body's proprioceptive sense. Proprioception is the body's internal sense of itself and its conscious sensations, relating to our overall somatosensation (Proske et al. 2012). This sensorial "sight" encapsulates the corporeal experience of every person's body, and not solely the expertise of medical professionals. Therefore, we argue that acknowledging the subjective, "imagined visceral inside," in addition to objective anatomical knowledge is key to gaining a deeper corporeal understanding, which in turn opens avenues for interdisciplinary teaching.

The history of medicine is contextually important in understanding how our contemporary knowledge of the body has been shaped by the past. Medical practices and ideologies in ancient Greece have been foundational for contemporary Western medicine (Ackerknecht 1982; Temkin 1991; Nutton 1997; Jotterand 2005). As such, *Corporeal Pedagogy* uses objects from antiquity that are associated with illness, disease, and healing practices, in workshops for higher education teaching settings. At the heart of *The Way My Body Feels* was an anatomical votive artifact from the Shefton Collection of Greek Art and Archaeology.

Today, medical training, education, and research visualize the inside of the body through surgery, dissection, and imaging techniques. These are methods that see the body from the outside in, whereas anatomical votives visualize and make sense of the body, physically and psychologically, from the inside out. Little critical attention had been paid to anatomical votives, within previous archaeological scholarship, until the international research group titled, The Votives Project (2016), pioneered by Jessica Hughes and Emma Jayne Graham, which brought focused attention and study to these artifacts. This *Corporeal Pedagogy* project contributed to this growing body of research through a public exhibition and short film (Turner and Waite 2022). However, the relationship between contemporary art, anatomical votives, and the visceral body in medicine remains largely unexplored. *Corporeal Pedagogy* was devised as a methodology to explore these ideas of the imagined and real visceral body in medicine. It considers alternative ways of imagining, visualizing, and experiencing the visceral body, and how these can change through circumstances of transition, illness, and disease.

11.2 The Shefton Collection of Greek Art and Archaeology

The workshop series *The Way My Body Feels* centered on a terracotta anatomical votive offering (inventory number 421) (Fig. 11.1), representing a uterus, from the Shefton Collection of Greek and Etruscan Archaeology. The Shefton Collection was founded by Professor Brian B. Shefton (1919–2012), a leading classical archaeologist who spent most of his career at Newcastle University. Shefton established an internationally significant collection of Greek and Etruscan artifacts which are now located in the Great North Museum, Newcastle upon Tyne which is in the North East of England. The collection was initiated in the 1950s to support teaching and research within the university and now numbers almost one thousand objects, with the final acquisition being made shortly before the

Fig. 11.1 (**a**–**d**). Terracotta (clay) votive, Shefton Collection of Greek and Etruscan Archaeology, 421, fourth century BCE? Manufactured in Italy | Photograph by Andrew Parkin © Newcastle University/Great North Museum: Hancock

collection's move to the Great North Museum in 2009. The collection has been little researched and is largely unpublished (Shefton 1970; Spawforth and Parkin 2016; Boardman and Parkin 2018). The uterus is part of the Shefton Study Collection and is usually kept in storage in the Great North Museum. Although, in more recent years, the uterus has been used in teaching for classics and archaeology, prior to the project it had not been on public display since its arrival in Newcastle.

The terracotta uterus is an enigmatic object and is part of a wider academic debate over the categorization of certain internal anatomical votives and the contemporary medical lens through which they are viewed. Our documentation for this object is tantalizingly limited. Manufactured in Italy, the uterus is intact, although there is a small amount of damage in some areas revealing a buff, gritty clay. It is 14 cm long, 7 cm wide, and 8 cm in height and has a flat base which enables it to rest in position. The uterus consists of a central "spine" transected by four ridges; one end is oval and the other forms into a sealed opening. There are traces of a pinkish paint over much of the surface. A 3D scan, undertaken in conjunction with this project at the Newcastle Material Culture Analytical Suite, (Fig. 11.2) revealed that despite its weight the uterus is hollow; a fact which is surely significant given the function of the votive as a container organ (see below). This also suggests the votive was made in a mold which would be consistent with the manufacturing technique for the majority of extant votive uteri (Lesk 2002). The uterus has been dated to the fourth century BCE although the stylistic dating of anatomical votives is difficult since the forms persist for centuries.

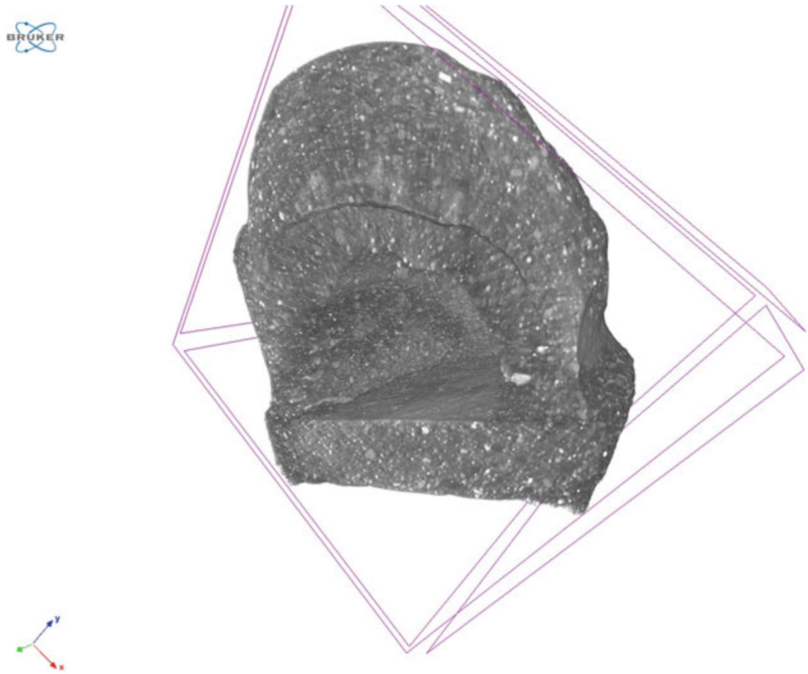

Fig. 11.2 3D scan of Shefton Collection's terracotta votive | Newcastle Material Culture Analytical Suite

Furthermore, additional contextual information for dating is most often absent (Lesk 2002).

11.2.1 Anatomical Votives

The dedication of anatomical body parts to gods or goddesses was a common practice in the ancient Greek, Etruscan, and Roman worlds and these survive in clay, marble, and metal. In fact, the practice of dedicating a body part to a divine entity is both transhistorical and transcultural (Weinryb 2016a). The offering is generally understood to represent the transaction between the dedicant and the god—either in petition or in thanks for healing. The votive is therefore a material remnant of the relationship between the human and the divine and as such it serves to "embody the hopes, dreams and anxieties" of the dedicants (Weinryb 2016b) and, through bodily visualization, contain them. The capacity of the imagination for investing visions and feelings in the votive object is important, as it is a mediator and marker of encounters with pain, disease, and transition. Illness and bodily transformation (as in pregnancy) leads to a heightened awareness of bodily sensation (Hughes 2017) and engenders a specific attention from the individual to examine their visceral body through feelings, touch, and gesture.

In mainland Greece, in the late fifth and fourth centuries BCE, there was widespread dedication of votive body parts. These are especially associated with the healing god Asklepios in Corinth and Athens (Hughes 2008). Whereas in mainland Greece anatomical offerings represented the exterior bounded body with very few exceptions (van Straten 1981), in Etrusco-Italic contexts (fourth to first centuries BCE) interior body parts were also dedicated to a number of deities including Demeter, Hera, and Aphrodite, in their Etruscan manifestations as Vei, Uni, and Turan and Diana and Juno in Roman contexts (Lesk 2002). These offerings took the form of specific abdominal organs, or a collective representation of these visceral organs made of terracotta. The uterus is the most common anatomical offering; thousands of examples survive from antiquity and no doubt refer to issues of fertility as well as disease. The votive uteri are clearly "inexpensive commodities" (MacIntosh Turfa 1994) presumably purchased from a varied selection, at the sanctuary prior to dedication. Most are, like the Shefton example, around 10–20 cm in length and characterized by a main body, often structured with ridging and ribbing and a mouth (cervix) which can be both open and sealed (Baggieri 1998; Flemming 2017). It is noteworthy that there is a great variety in the representation of these uteri. Many surviving uteri have no known find-spot, while others have been found in great quantities within sanctuary sites where, even at a single location, uteri are marked by their formal divergence (Flemming 2017). This is particularly true in southern Etruria where at the sanctuary of Gravisca there were 63 types of uteri while at the sanctuary of Fontanile di Legnisina there were 48 new variations—out of a total of around 300 uteri at each site (Flemming 2017). Presumably dedicants chose a variation which reflected their need, responding to their perception of their body, and Alexandra Lesk (2002) suggests these may have been further personalized by the addition of paint.

11.2.2 Anatomical Authenticity

Votives representing internal bodily organs inevitably prompt questions about their anatomical authenticity, and we may wonder about the extent of their makers' bodily knowledge. When looking at the votive uteri, the dominating question is, how much does this look like a *real* womb? The accuracy of anatomical votive uteri in relation to human anatomy has been much debated in the scholarship, not surprisingly given their formal diversity. Indeed, the characteristic ridges which feature on many votive uteri are perhaps more closely associated with internal vaginal rugae (Weinryb 2016c). While the dissection of human bodies was not commonplace in antiquity: there is no evidence of human dissection and studies of the cadaver, other than in third BCE Alexandria (King, 2017), it is however possible that prolapses or postmortem Cesarean sections afforded some understanding of the uterus alongside medical writings (Flemming 2017; Weinryb 2016c). Animal sacrifice and dismemberment likewise provided knowledge of the internal organs to a general audience (Hughes 2016).

While some point out the similarities between the uterus and the votive representation (MacIntosh Turfa 1994), others question the identification of these votives as uteri. King (2017) suggests the diversity of votive uteri shapes could be indicative of "generic 'container' organs" and that the ridged edges capture the tight pressure of the abdomen, or the pointed bulges represent sharpness of pain. Rebecca Flemming (2017) calls for an acknowledgment of the value of a "focused indeterminacy" surrounding these formally diverse wombs, as well as votive practice of internal organs more broadly. The indeterminacy of these votive uteri could signify the personal variance of living with illness and pain. This leads us to consider the role of imagination and creative conceptions of the visceral body. The anatomical definition of these votive uteri can be considered superfluous. By allowing the votives' anatomical categorization to be unfixed, it enables objects to be amorphous and flexible, depending on dedicants' needs, bringing forth the imagined potential of the votive. For example, a stomachache or abdominal pain encapsulates many visceral organs, and it is often difficult to discern the location of pain and discomfort (Graham 2016).

11.2.3 Disease

There has been a desire to connect variations in the physical form of votive uteri to specific illnesses and disease (MacIntosh Turfa 1994) Anomalies, such as additional appendages and protuberances are pathologized and identified as congenital abnormalities, endometriosis, or the presence of abscesses, fibroids, or tumors (MacIntosh Turfa 1994). This approach of retrospective diagnosis, prioritized by medical history, is problematic (Graham 2016; Hughes 2017); as Flemming (2017) asserts votives are not just about the realities of the human body. Jessica Hughes (2008) moves beyond traditional readings which see the votives as representative of the malfunctioning body part alone suggesting rather that the bodily fragmentation of votives "gave visual form and social meaning to the otherwise intensely personal experience of illness." Hughes (2008) proposes that this fragmentation of the body into its constituent parts is a metaphor for illness and pain and that healing comes through the dismantling and reassembly of the body. The fragmentary nature of votives also provides the potential for an imagined conception of what a body *is* and *how* we perceive our bodily insides. This allows for more complex representations of the sick and diseased body: its relationship between fragment and soma, and dismemberment and reintegration of the body. Votives visualize and imagine the body's interior from the perspective of illness and disease, which could be considered to portray a more accurate, complex representation of a person's experience in illness and disease (Draycott and Graham 2017; Hughes 2017).

11.2.4 Reproductive Health

Uteri as votives are associated with fertility and reproduction as well as disease. They could represent a request or thanks for conception, a healthy pregnancy, or the successful delivery of a child (Hughes 2016; MacIntosh Turfa 1994). This would be consistent with the fact that many are found in sanctuaries associated with motherhood and fertility goddesses in combination with votive breasts and swaddled babies (Baggieri 1998; Oberhelman 2014). Here, the votive perhaps prioritizes the physical and social transition from bride to wife and mother rather than the movement from sickness to health (Graham 2017; Hughes 2017). A number of votive uteri contain one or two clay pellets which move freely within them. These add a further sensory dimension to the uteri which would make a sound when rattled, a feature which could have been significant for the ritual of dedication (Henquet 2018). In the Hippocratic corpus pain experienced is likened to "something like spheres pass[ing] by in the *gaster*" (*Places in Man* 47.344-346). As King (2017) points out the "*gaster* is a vague container, sometimes digestive, sometimes gynaecological." Perhaps these pellets were intended to represent bodily sensation (King 2017) rather than to signify the presence of eggs or the development of "intrauterine life" as is generally implied (Baggieri 1998).

The swollen form of some votive uteri is equated with pregnancy, and the rib-like impressions observed on the Shefton votive (Fig. 11.3) are thought by some to indicate the potential of the uterus for expansion (Flemming 2017) or instead to represent the rigid muscles of eclampsia, or the muscular contractions of the second stage of labor (MacIntosh Turfa 1986/1994), although this is at odds with the passive womb of the medical texts (Flemming 2017; King 2017). However, these striations could be considered as a material representation of physical pain (King 2017). They may also relate to the belief that the womb wandered within the body with the ridges acting as a kind of tether for the womb (Flemming 2017). In the Hippocratic corpus (fifth/fourth centuries BCE) the "wandering womb" is linked with female disease and pregnancy is perceived as a way to anchor the womb (*Nature of Women* 8.314–316). Likewise, menarche was believed to have induced a kind of madness in virgins—the cure for which was to marry and become pregnant to release the flow of menstrual blood (*Peri Parthenion* 8.466–470; *On Diseases of Women* 2.126; King 1993). The adjective *hysterikos* (from the womb) can be linked with more recent conceptions of "hysteria" (Walker 2020). The physician Aretaeus, writing in the second century CE asserts: "the womb in the female is altogether like one animal within another" (2.11)—both are wild and uncontrollable. The idea of the "wandering womb" as a cause of hysteria endured for centuries in later European thought; madness was incontrovertibly linked with biological essentialist perceptions of women (Showalter 1987). As Elinor Cleghorn (2021) comments: "unwell women were suffering because almost any illness they had could be explained away by the nebulous medical myth of 'hysteria.'" The womb was thought to have a psychosomatic hold over women.

Fig. 11.3 Participant holding the Shefton Collection votive | Photography by Janina Sabaliauskaite

11.3 The Way My Body Feels

Corporeal Pedagogy is a form of learning and teaching that addresses and challenges conventional modes of Western higher education and perception, which focus on the cerebral and visual (Sellers-Young 1998) and instead facilitates alternative embodied learning and productions of knowledge that use senses such as touch, sound, interoception, and proprioception. Through the workshop series *The Way My Body Feels*, participants were prompted to experience their visceral body—the real and imagined bodily interior, defined as both "real anatomy," shaped by both objective medical knowledge and "imagined anatomy," which is shaped by subjective corporeal sensation. In our workshop the votive womb, which encapsulates both definitions and perceptions of the visceral body, was used as a focal point to stimulate learning around ancient objects and the body and a mediating object through which to explore the visceral body.

The Way My Body Feels was devised as a one full day workshop and in total we facilitated five individual sessions, each with a different cohort. During *The Way My Body Feels,* we explored what it means to learn, through the body, the implications of corporeal pedagogical practice in an academic institution, and the opportunities it provides for interdisciplinary collaboration. We did this through object handling, object making, performance, reading, and meditation. The workshop series involved staff and students across undergraduate and postgraduate studies in the disciplines of fine art, archaeology, and clinical psychology (Fig. 11.4). This removed disciplinary and hierarchical knowledge structures experienced within higher education to enrich the learning environment and experience.

11.3.1 Object Handling

The workshop began with extended object handling to familiarize the participants with the Shefton votive uterus. The object is extremely tactile—it fits within the palm of the hands and the fingers fit perfectly into the ridge-like structures on the top of the uterus (Fig. 11.5). As we passed the votive around, we asked each participant to make one observation about it. These observations tended to focus on the material state of the object—color, shape, size, weight, and its construction and design. Through this activity the students gained a deeper understanding of the object and the analytic skills associated with investigating an object through sensory engagement. Furthermore, the materiality

Fig. 11.4 Students sitting in a circle for object handling and reflections | Photography by Janina Sabaliauskaite

of the votive is key to understanding the experience of the ritual (Graham 2020).

We then began to discuss the context and function of the uterus. In the handling session someone often commented on the flat base of the uterus which suggests it was designed to stand. Through a short visualization exercise, we encouraged the participants to imagine the display of votives within a sanctuary. Votives were displayed in temples and sanctuaries as "a public commemoration of a divine favor" remaining long after the dedicant had departed (Flemming 2017). As Hughes (2008) points out, the display would have been arresting and the impact on the viewer of the time seeing them in the darkened temple would have been profound. Life-size terracotta anatomical votives from Corinth suggest strategies of display; some votives have suspension holes and we can imagine that they would have hung from the rafters and walls of buildings, while others could have been displayed on shelves. In Etrusco-Italic contexts, as in Greek contexts, votives were leaned against the wall while others, like the Shefton uterus, would have been placed on shelves, altars, the floor and beside the cult statue, or even in its hands (Flemming 2017; Graham and Draycott 2017; Hughes 2008). Occasionally they were placed by the dedicant in primary pits dug for the purpose of receiving the offerings (Oberhelman 2014). The original placement of votives within a sanctuary is difficult to determine archaeologically as Hughes (2016) points out the dedications could well have been moved around by priests or caretakers or even by other dedicants. Offerings would also have been periodically removed and buried in secondary pits to make way for new dedications (Lesk 2002; Petsalis-Diomidis 2016). As Alexia Petsalis-Diomidis (2016) asserts, the meaning of the votive was determined in part by its position within shifting groupings of votives.

While using replicas of anatomical votives alongside the votive uterus, we encouraged the workshop participants to collaboratively arrange the objects. It was interesting to observe the

Fig. 11.5 Participant handling the Shefton Collection votive | Photography by Janina Sabaliauskaite

different approaches students applied to this exercise. Some groups arranged the votives according to their position within an imagined body. Others arranged them symmetrically, and/or by the way their forms fitted together as shown in Fig. 11.6 where the uteri are mirrored either side of the arm to fit within the curve of the wrist. Some students felt profound discomfort in moving a votive someone else had already placed. This negotiatory forging of a social body served as a metaphor for our pedagogical methodology. Through their display the combination of the disparate elements, of multiple anatomical bodies, is incorporated into a collective whole to create a communal body: "a reconfiguration of the totality of pilgrims" (Petsalis-Diomidis 2016) and a representation of the combined religious community (Graham 2017). The physical body and the social body are combined through the communally manufactured monumental body.

We completed this part of the workshop with the uterus being passed around the circle of participants one more time and by inviting the participants to give an emotional response to the object and identify the connection they felt with it. There was quite a dramatic shift in the atmosphere of the workshop at this point, and some students gave very moving accounts of their connection to their own bodies in health and disease. As the votive is handled the terracotta warms to the touch: the uterus is enclosed within the hands as the fetus is enclosed by the uterus. Indeed, the transformation of the clay within the kiln echoes the transformation embodied through conception, pregnancy, and birth. The handling echoes the original dedicant's holding of the votive prior to dedication and we noted that participants often cradle the womb as their bodily experience becomes part of the object's continued biography (Fig. 11.7). Through handling, it is possible to access what Ittai Weinryb (2016b) terms "the materialization of sentiment": the emotions which are contained within the votive and forge a link between past and present.

11.3.2 Meditation

Anatomical votives highlight the connection between physical and emotional feelings during transition and illness, and therefore the importance in making provision for both psychological and physiological understandings of the body. To build on this as a concept and method, two meditation practitioner-academics were invited to participate in the workshop: Mr. Michael Atkinson from the Faculty of Medical Sciences and Dr. Jessica Komes from the School of Psychology. This part of the workshop was devised as a way for students to "tune into" their body, through body scan meditation, as a source of knowledge and creativity. Through breathing, movement, and mindfulness techniques, this engendered self-observation in the students as they lay quietly and experienced their body's breath-cycles. The body scan meditation brought focused attention in the participants to their present-moment sensations and to anatomical

Fig. 11.6 Participant arranging the authentic and replica anatomical votives | Photography by Janina Sabaliauskaite

awareness. Philomena Behmer (2019) affirms how through meditation, "observation of the breath and body can lead to the most advanced level of self-observation." This not only emphasized the experiential qualities of the teaching and learning process, but also through the regulation of breath, both the students and staff were able to relax together and feel physically and emotionally comfortable within a "safe space."

Fig. 11.7 Participant holding the Shefton Collection votive | Photography by Janina Sabaliauskaite

The meditation facilitated the embodied and experiential pedagogy, explicitly contrasting the students' typical higher education learning, which normally suppresses and ignores corporeality in favor of visual and cerebral methods (Stinson 1995). As one participating student commented, "meditation brings learning back to the self—to our own bodies, to encourage a level of empathy and of physical relations." It enabled students to let go of any preconceptions or inhibitions that they might have brought with them to the workshop, especially as they were out of their disciplinary and methodological comfort zone. From the student feedback, this melding of interdisciplinarity and meditation was crucial "to really get the full content." It was also a valuable exercise in setting the tone and atmosphere of the workshop to be as inclusive, relaxed, and welcoming as possible.

11.3.3 "Scores"

The students then moved onto working collaboratively to devise a series of "scores," which are performance-based instructions. The term "score" stems from musical composition; such that the music can be read and played by anyone. The *Event Score* was a key method used by the experimental 1960s art group Fluxus, founded by George Maciunas and included notable figures such as John Cage, Yoko Ono, and Joseph Beuys. The *Event Score* was created by George Brecht as a simple performance technique framed as "minimalistic performances or, occasionally, as imaginary and impossible experiments with everyday situations" (Higgins 2002). It allowed the artist to instruct a performer on the parameters that the piece of work could be realized at any time.

During the workshop, producing the "scores" was a process of democratizing an experience and about performing an instruction together as a group. This considered ideas of embodiment and making, as an individual as well as a social body. Examples of the *Event Scores* created include:

1. Hold at a distance.
2. Say thank you to one of your body parts.
3. Share a connection that you are grateful for.
4. Select and clasp part of your body you do not normally notice, see how you can entwine your fingers around it (Fig. 11.8).

The founding notion of an *Event Score* was underpinned by an experiential framework and characterized by "the dissolution of boundaries dear to Western epistemology, including the traditional distinction between subject and object" (Higgins 2002). The *Event Score* is based on creating a shared experience whereby the artists "place their living bodies between the material and mental worlds" (Stiles 1993).

Amanda William's *Event Score*-based exhibition, *Embodied Sensations* (2021) sought to create shared understandings of physical and emotional experiences through collective sensations and embodiment as a participatory practice. While her work was in response to the sudden restrictions placed on daily life due to the COVID-19 pandemic, the notion of "embodied sensations" and creative practice still has relevance beyond discussions on the pandemic. Williams (2019) commenting on *Embodied Sensations* says: "It feels like people may be in tune with the prospect of having to have their body do something they're not used to having it do, or being told to do something and having to follow instructions. It's something everybody has suddenly had to contend with this year. I think it's important too that . . . we really bring it back to the art and the making of art as a way to find our collective way through this." Williams' comments regarding collective embodiment, art making, and bodily awareness are also important questions present in *The Way My Body Feels.* As such, the use of scores is about forming a community by using language in a way that is accessible and open to interpretation. The engendered bodily awareness and forming of a collective, social body dissolves the metaphorical physical and emotional corporeal boundaries. Therefore, it is not only *The Way My Body Feels* but also the way *our* bodies feel and how we visualize our anatomy *together*.

11.3.4 Creating with Clay

In the last stage of the workshop, the students worked with clay as a way to materially manifest their imagined visualizations of their visceral bodies. Terracotta earthenware clay was used as a specific material reference to the Shefton votive uterus. Costumes were created (Fig. 11.9) to both protect the students' clothes from the damp clay and to reflect the color of the clay by using white and orange-dyed fabric. The fabric became an integral material on which to retain a recording of the marks made from the clay throughout the day. Each participant was invited to lie down, close their eyes, and given a palm-sized lump of clay. Drawing on the body scan meditation and its focus on "tuning in" to the body, the students were asked to bring awareness to bodily sensations and to try and capture them in their lump of clay, using their hands. This could be

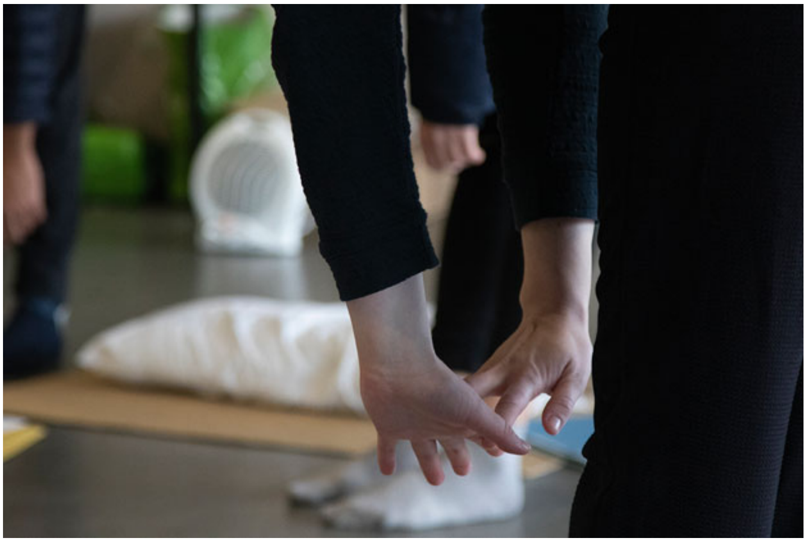

Fig. 11.8 Participants performing the score | Photography by Janina Sabaliauskaite

through pinching, shaping, and squeezing their lump of clay. The emphasis was placed on tactility and embodied experiences, as opposed to visual art making.

As the participants lay horizontal on their back with their lump of clay (Fig. 11.10), they were invited to listen to a series of texts: Anne Boyer's *The Undying: A Meditation on Modern Illness* (2019), Sinéad Gleeson's *Constellations: Reflections From Life* (2019), Elinor Cleghorn's *Unwell Women* (2021), and Olivia Turner's *A votive made for you* (2022). This served to enrich their corporeal experience by linking textual reference material to visual representations and theory. The texts, which spanned themes of votive offerings, clay, the medicalized body and gender, prompted participants to question how and why our bodies feel the way they feel, and how this might change in circumstances of medicalization and illness. The readings offered an important contextualization, which recognized that one cannot visualize and understand the visceral body in a holistic sense, without acknowledging its history. As Anne Boyer

Fig. 11.9 Participant making a costume | Photography by Janina Sabaliauskaite

Fig. 11.10 Participant lying horizontal with their eyes closed during readings, while manipulating lumps of clay | Photography by Janina Sabaliauskaite

(2019) underlines, "the history of illness is not the history of medicine—it is the history of the world—and the history of having a body could well be the history of what is done to most of us in the interest of the few." This highlights the importance of situating anatomical teaching and learning within a wider interdisciplinary field of medical humanities.

As the participants opened their eyes and looked at what they had created, they were invited to reflect on their experience. The students were often surprised by what form their lump of clay now took, commenting on the visual and haptic resemblance the object had in reference to the feelings and sensations they were trying to express. However, they did comment that they would not have shaped the clay in this way had the exercise been based solely on sight. This embodied and experiential making was critical in decentering the students' reliance on visual and cerebral conventions, and instead opened them up to conceptual and methodological spontaneity, "unfixedness" and fragmentation. The way that their clay object finally looked was not of importance. Instead, it was the *process of making* and connecting embodiment with the anatomical votives.

Each piece of shaped clay created by the students was then used as the basis for a collaborative activity. Working in pairs, the students created their own imagined clay organ by creatively and collectively visualizing their visceral bodies (Fig. 11.11). This process of externalizing one's own perception of their own anatomy mirrors the experience of creating and dedicating an anatomical votive. The votive becomes a metaphorical mediator between subjectivity and objectivity. This raised the topic of the healing process within literal and metaphorical corporeal fragmentation. By externalizing one's own anatomy through the manipulation of a malleable lump of clay—being able to handle, look at and shape it—can provide moments of healing by allowing for an alternative experience and perception of the visceral body. Sensations and feelings can be made more physically tangible for the individual and one can show and share with others, one's experiences that are otherwise intensely private and incommunicable.

As Elaine Scarry (1985) states, "physical pain has no voice," and when it does eventually find a voice, it is usually an inadequate medium of expression for an experience that cannot be fully grasped by the use of words. This is further entrenched within medicine and more specifically within the lived experiences of an individual in clinical interactions, which use standardized, objective language to describe the patient's body, thereby removing their subjectivity, agency, and autonomy (Shildrick 1997). As a

Fig. 11.11 Participants working in pairs and with terracotta clay to create their imagined anatomical votive | Photography by Janina Sabaliauskaite

result, "whatever pain achieves, it achieves in part through its unsharability, and it ensures this unsharability through its resistance to language" (Scarry 1985). This essential unsharability and shattering of language not only applies to pain but also encapsulates most intensely personal bodily feelings and experiences (Scarry 1985). Therefore, *The Way My Body Feels* uses different materials and means of expression to share interior states. The students used sensation to inform and create visual, subjective representations of their imagined visceral anatomy. This alternative somatosensorial method of expression brings awareness and understanding to the subjective, amorphous, and varied visualizations of anatomy.

In the final workshop activity, working in small groups, one student volunteered to lie down with their eyes closed and was invited to voice literal and metaphorical descriptions of their bodily interior. While they did this, the other students worked together to create small clay sculptures or "votives" in direct response to the verbal descriptions, which were often of pain or pressure in certain locations of the body (Fig. 11.12). As Hughes (2017) notes, "the process of healing is explicitly connected with the physical dismantling and reassembly of a fragmented body." The process of the workshop up until this point had been about focusing on fragmented areas, locations, and organs, as opposed to considering the somatic whole. Therefore, the concluding section of *The Way My Body Feels* highlighted the transformative process of corporeal fragmentation and its subsequent reintegration through a material and object-based manifestation (Figs. 11.13 and 11.14).

Hughes (2017) goes on to say, "The individual votive body part can thus be seen to play a functional role in the healing process, not (only) through processes of sympathetic magic or substitution, as has previously been suggested, but because the bodily fragmentation that it

Fig. 11.12 Participant lying down as another student places small clay sculptures onto their body | Photography by Janina Sabaliauskaite

symbolizes sets the whole process of healing in motion." By coming together and sharing their individual, subjective corporeal experiences, both during the ancient votive dedication and our present-day workshop, this fragmentation and solidarity serve as a metaphor for the process of healing. Within *The Way My Body* Feels, this final activity led to the forming of a social and collective body and brought together all the different experiences throughout the day.

11.4 Evaluation

The importance of the Shefton uterus was confirmed by post-workshop student evaluations, where the artifact was seen to act "as a witness to our shared experience" with "a gravitas. . .that made everything we did weighted and symbolic" and "offering a direct route to more intense and valuable dialogue." The votive acted as an "anchor to the past" and "handling the votive was a very powerful and unique experience . . . it made me feel emotionally connected to the past." Our approach, which blended creative, critical, and social pedagogies, placed an emphasis on haptic learning, recognizing the value of hands-on and creative learning for student engagement and development by encouraging active, sensory, and deep learning.

The volume of students applying to participate in our workshops far exceeded the number of places, clearly demonstrating the desire for this mode of experiential and experimental learning. Participating students affirmed the importance and necessity of this learning experience, highlighting the benefits of interdisciplinarity and embodied learning. The *Corporeal Pedagogy* project stimulated knowledge production between art, archaeology, and the medical sciences, and the students commented on the value of interdisciplinarity as a means of gaining

Fig. 11.13 Participant lying down with lots of small clay sculptures placed onto their body | Photography by Janina Sabaliauskaite

"a deeper understanding through varied ways of knowing." The project developed pioneering, practice-led interdisciplinary research and innovated methodologies applicable to both teaching, learning and research within and across disciplines. Most importantly, the workshops offered a diverse learning experience and was designed to foster both academic and personal development through active engagement in an inclusive and collaborative environment. Community building was key to creating "a sense of openness and vulnerability in a safe space" to facilitate a communal mode of learning which allowed students to experience embodied learning. For one student the workshop demonstrated "the importance of embodied knowledge" through "sensory learning," prompting them to "reconsider education as a whole" as a result of this "holistic, imaginative and immersive experience." This process was facilitated by the shared experience of handling and creating "scores" alongside the meditation which enabled students "to experience and participate" in the workshop more fully.

Fig. 11.14 Participant lying down with lots of small clay sculptures placed onto their body | Photography by Janina Sabaliauskaite

11.5 Conclusion

The focus on votive uteri and their importance in terms of how the past informs present ideologies, practices, and experiences in medicine is of critical pertinence particularly as the majority of the workshop participants self-identified as women or non-binary. As commented by Brandy Schillace, editor-in-chief for the *British Medical Journal: Medical Humanities*, "This is timely. I'm here in the United States, and as everybody knows, the Supreme Court has just overturned Roe versus Wade, meaning that a lot of autonomy [people] have had over their own uteruses has been lost. . . the fact that the focus piece of your [project] is a votive uterus has perhaps even greater meaning for me now than it did prior" (2022). The significance of *Corporeal Pedagogy* and *The Way My Body Feels* not only has positive implications for anatomical teaching and learning environments, but also for issues relating to social justice, bodily autonomy for the medicalized body, and gender studies. Elinor Cleghorn in her book *Unwell Women* (2021), used as part of the workshop readings, writes, "The lives of unwell women depend on medicine learning to listen." Therefore, *Corporeal Pedagogy* and *The Way My Body Feels* provide spaces to listen, not only to our bodies but also to each other, history, and archaeological collections.

References

Ackerknecht EH (1982) A short history of medicine. The Johns Hopkins University Press, Baltimore

Aretaeus On the causes and symptoms of acute and chronic diseases: Adams, F. (ed. and trans.) 1972. Available from http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.01.0254%3Atext%3DSA%3Abook%3D2%3Achapter%3D11

Baggieri G (1998) Etruscan Wombs. Lancet 352(9130): 790

Behmer PM (2019) Moving to learn: a meditative yoga approach to teaching and learning anatomy and physiology in multiple contexts. New directions for adult and continuing education, Issue 161: Meditation and Mindfulness in Adult Education, 67–77. Available at: https://onlinelibrary.wiley.com/doi/epdf/10.1002/ace.20312 (Accessed: 5 January 2023)

Boardman J, Parkin A (2018) Shefton, Brian Benjamin, 1919–2012. Biographical Memoirs of Fellows of the British Academy XV11:51–61

Boyer A (2019) The undying: a meditation on modern illness. UK: Penguin Books

Cleghorn E (2021) Unwell women: a journey through medicine and myth in a man-made world. Weidenfeld & Nicolson, London

Draycott J, Graham E-J (eds) (2017) Bodies of evidence. Ancient anatomical votives past, present and future. Routledge, London

Flemming R (2017) Wombs for the Gods. In: Draycott J, Graham E-J (eds) Bodies of evidence: ancient anatomical Votives: past, present and future. Routledge, London, pp 112–130

Gleeson S (2019) Constellations: reflections from life. Pan Macmillan, London

Graham E-J (2016) Votive visions of the body. The Votives Project. Available at: https://thevotivesproject.org/2016/11/13/votive-visions-of-the-body/ (Accessed: 7 December 2022)

Graham E-J (2017) Partible humans and permeable gods. Anatomical votives and personhood in the sanctuaries of Central Italy. In: Draycott J, Graham E-J (eds) Bodies of evidence: ancient anatomical votives: past, present and future. Routledge, London, pp 45–57

Graham E-J (2020) Hand in hand: rethinking anatomical votives as material things. In: Gasparini V et al (eds) Lived religion in the ancient Mediterranean world: approaching religious transformations from archaeology, history and classics. De Gruyter, Berlin, pp 209–235

Graham E-J, Draycott J (2017) Introduction: debating the anatomical votive. In: Draycott J, Graham E-J (eds) Bodies of evidence: ancient anatomical votives: past, present and future. Routledge, London, pp 1–19

Graham E-J, Hughes J (2016) The Votives Project. Available at: https://thevotivesproject.org/2016/03/11/welcome-to-the-votives-project/. (Accessed: 1 December 2022)

Henquet K (2018) Shake it till you make it: could votives have been used as rattles? Available at: The Votives Project. https://thevotivesproject.org/2018/06/25/rattles/ (Accessed: 7 December 2022)

Higgins H (2002) Fluxus experience. University of California Press, Berkeley

Hippocrates Places in Man, Potter, P. (ed. and trans.) 1995. Hippocrates, Volume VIII (Loeb Classical Library 482). Cambridge, MA/London: Harvard University Press

Hippocrates Peri Parthenion, Potter, P. (ed. and trans.) 2010. Hippocrates, Volume IX (Loeb Classical Library 509). Cambridge, MA/London: Harvard University Press

Hippocrates Nature of Women: Potter P (ed. and trans.) (2012) Hippocrates, Volume X: Generation, Nature of the Child, Diseases 4, Nature of Women and Barrenness (Loeb Classical Library 520). Cambridge, MA/-London: Harvard University Press

Hippocrates On Diseases of Women: Potter P (ed. and trans.) (2018) Hippocrates, Volume XI: Diseases of Women 1–2 (Loeb Classical Library 538). Cambridge, MA/London: Harvard University Press

Hughes J (2008) Fragmentation as metaphor in the classical healing sanctuary. Soc Hist Med 21(2):217–236

Hughes J (2016) Fractured narratives: writing the biography of a votive offering. In: Weinryb I (ed) Ex voto: votive giving across cultures. Bard Graduate Center, New York, pp 23–48

Hughes J (2017) Votive body parts in Greek and Roman religion. Cambridge University Press, Cambridge

Jotterand F (2005) The Hippocratic Oath and contemporary medicine: dialectic between past ideals and present reality? J Med Philos 30(1):107–128

King H (1993) Bound to bleed: Artemis and Greek women. In: Cameron A, Kuhrt A (eds) Images of women in antiquity. Routledge, London, pp 109–127

King H (2017) When is a womb not a womb? The Votives Project. Available at: https://thevotivesproject.org/2017/02/17/when-is-a-womb-not-a-womb/. (Accessed: 7 December 2022)

Lesk A (2002) The anatomical votive terracotta phenomenon in Central Italy: complexities of the Corinthian connection. In: Muskett G et al (eds) SOMA 2001 symposium on mediterranean archaeology. Archaeopress, Oxford, pp 193–202

MacIntosh Turfa J (1986) Anatomical votive terracottas from etruscan and italic sanctuaries. In: Swaddling J (ed) Italian Iron Age Artefacts: in the British Museum: Papers of the Sixth British Museum Classical Colloquium. British Museum Publications, London, pp 205–213

MacIntosh Turfa J (1994) Anatomical Votives and Italian medical traditions. In: De Puma RD, Small JP (eds) Murlo and the Etruscans: art and society in ancient Etruria. University of Wisconsin Press, Madison, pp 224–240

Merriam-Webster (2022) [Online] Available at: https://www.merriam-webster.com/dictionary/visceral#h1 (Accessed: 16 December 2022)

Nutton V (1997) Hippocratic morality and modern medicine. In: Flashar H et al (eds) Médecine et morale dans l'Antiquité. Fondation Hardt, Geneva, pp 30–63

Oberhelman SM (2014) Anatomical Votive reliefs as evidence for specialization at healing sanctuaries in the ancient mediterranean world. Athens J Health 1(1): 47–62

Petsalis-Diomidis A (2016) Between the body and the divine: healing Votives from classical and hellenistic

Greece. In: Weinryb I (ed) Ex Voto: Votive giving across cultures. Bard Graduate Center, New York, pp 49–75

Proske U et al (2012) The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. Physiol Rev 92(4), 1651–1697. Available at: https://journals.physiology.org/doi/full/10.1152/physrev.00048.2011 (Accessed: 5 January 2023)

Scarry E (1985) The body in pain: the making and unmaking of the world. Oxford University Press, Oxford

Schillace B (2022) Body talk: "Corporeal Pedagogies" with Dr Sally Waite and Dr Olivia Turner. Br Med J Med Human Blog, 18 August. Available at: https://blogs.bmj.com/medical-humanities/2022/08/18/body-talk-corporeal-pedagogies-with-dr-sally-waite-and-dr-olivia-turner/. (Accessed: 30 January 2023)

Sellers-Young B (1998) Somatic processes: convergence of theory and practice. Theatr Top 8(2):173–187

Shefton BB (1970) The Greek Museum, University of Newcastle upon Tyne. Archaeological Reports for 1969–70, 16, 52–62

Shildrick M (1997) Leaky bodies and boundaries: feminism, postmodernism and (bio)ethics. Routledge, London

Showalter E (1987) The Female Malady. Women, madness and english culture 1830–1980. Virago, London

Spawforth A, Parkin A (2016) Introduction. In: Boardman J, Parkin A, Waite S (eds) On the fascination of objects: Greek and Etruscan Art in the Shefton Collection. Oxbow, London, pp 1–7

Stiles K (1993) Between water and stone, fluxus performance: a metaphysics of acts. In: Armstrong E, Rothfuss J (eds) In the spirit of fluxus. Walker Art Centre, Minneapolis, MN

Stinson SW (1995) Body of knowledge. Educational Theory 45(1):43–54

van Straten FT (1981) Gifts for the gods. In: Versnel HS (ed) Faith, hope and worship: aspects of religious mentality in the ancient world. Brill, Leiden, pp 65–151

Temkin O (1991) Hippocrates in a World of Pagans and Christians. The Johns Hopkins University Press, Baltimore

Turner O (2022) Between Doctor, Patient and Cadaver: the slippages of the visceral body in medicine. Unpublished PhD thesis. Newcastle University

Turner O, Waite S (2022) The way my body feels. The Votives Project. Available at: https://thevotivesproject.org/2022/09/01/the-way-my-body-feels/ (Accessed: 1 September 2022)

Walker AL (2020) Bride of Hades to Bride of Christ. The virgin and the otherworldly bridegroom in ancient Greece and Early Christian Rome. Routledge, London

Weinryb I (2016a) Ex voto: votive giving across cultures. Bard Graduate Center, New York

Weinryb I (2016b) Introduction: ex voto as material culture. In: Weinryb I (ed) Ex voto: votive giving across cultures. Bard Graduate Center, New York, pp 1–22

Weinryb I (2016c) Procreative giving: votive wombs and the study of ex-votos. In: Weinryb I (ed) Ex voto: votive giving across cultures. Bard Graduate Center, New York, pp 276–298

Williams A (2019) A conversation with Amanda Williams about *Embodied Sensations*. Interviewed by Ana Janevski, Michelle Kuo, Alethea Rockwell for *MoMA Magazine*., 19 April, Available at: https://www.moma.org/magazine/articles/540 (Accessed 11 January 2023)