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DESIGNING A PBL ENVIRONMENT USING THE 3C3R METHOD

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With the growing emphasis being placed upon situated learning theory, designs increasingly implement problem-based learning (PBL) in various educational contexts. However, some of the difficulties instructional designers face include interweaving elements such as breadth, depth, and situated knowledge in a contextualized learning task. This design case details how the 3C3R method was systematically employed to design a PBL learning environment that highlights the effects of environmental toxins on human fertility. We also discuss how a case library learning environment (CLLE) was implemented and designed to support the decision-making process. This design case examines the challenges involved, such as misunderstandings between the SMEs and instructional designer as we contextualized complex issues related to human biology. A discussion of how we designed for multiple solution paths is also included. Lastly, we discuss the challenges of interweaving the ill-structured problem with multiple narratives found in a case library.

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CONTEXT

This case details an instructional design project that aimed to redesign an undergraduate Biology module into a problem-based learning activity. The instructor (SME-instructor) wanted to enhance the application of critical thinking skills to the student's examination of the biological world around them. The SME-instructor commented that because her students were non-science majors, they might never have exposure to scientific concepts in an academically rigorous setting outside of her class. Furthermore, the SME-instructor found that students were unable to assimilate all of the varied scientific concepts and research that connected environmental pollutants with infertility in humans. The SME-instructor told the instructional designer that students would often fail to recognize how to apply their textbook readings during problem-solving activities in previous iterations of the course. In particular, she wanted students to draw connections across the curriculum so students could generate a global perspective of the environment.

A further challenge was that this class was offered in a hybrid format. The students would complete lecture material online via recordings from the instructor, and only meet for laboratory and discussion sections once every few weeks. Although the SME-instructor was pleased with the class discussions, much of the class conversations consisted of reflection and sharing ideas related to the biological concepts. She wanted to utilize the online format to promote collaborative higher order learning skills such as co-construction of knowledge and synthesizing peer perspectives. It was for this reason we believed that a problem-based learning (PBL) design would allow the students to meet the learning objectives identified by the SME-instructor.

DESIGN OVERVIEW

The design team consisted of three individuals: the instructional designer, SME-instructor (Biologist), and SME-practitioner. The PBL environment we created includes two primary components: an ill-structured problem (Figure 1) and a supporting case library (Figure 2).

Ill-Structured Problem to Solve

After going through the 3C3R process (detailed later), we created an ill-structured scenario related to human infertility (see Figure 1 below). The problem presented a married couple, Andre and Anna, who were trying to conceive. However, after nearly a year of trying, the couple became increasingly frustrated with the process and questioned whether they needed to see a physician.

The assigned ill-structured problem to solve is a scenario that details Andre and Anna's relationship, health, and lifestyle. On the surface, things appeared to be relatively normal. Embedded within the descriptions, however, were aspects of their lifestyle that posed potential problems to their fertility. For instance, students read how Andre regularly drank from an old plastic water bottle, faced exposure to Atrazine at work, and had been experiencing lower libido. Anna ingested BPA from canned foods and PCBs from fish, but failed to realize that these chemicals impacted her fertility. These and other descriptors serve as clues to the environmental toxins such as BPA, herbicides, and PCBs that potentially play a role in their inability to conceive.

Because research has shown that students have difficulty with the problem-solving process and self-directed learning (Morris et al., 2010), we wanted to embed just-in-time support for further inquiry. The case library strategy provided a collection of narratives that contained key elements germane to the Andre and Anna case. (Dasgupta & Kolodner, 2009; Jonassen, 2010). That is, each support case detailed how physicians solved problems similar to the fertility issue Andre and Anna were experiencing. For instance, in the case of "Helping Asha" (see Figure 2) the students read how Dr. Johnson interacted with Asha, a new mother from Kenya, who worked with Atrazine. The students then read how Asha had experienced miscarriages before birthing her son, who now appears to have genital deformation. In another case, "Kiana's Concerns," the student was able to read about how a doctor in Hawaii helped fertility patients identify the PCBs and other pollutants accumulating in the fish they consumed.

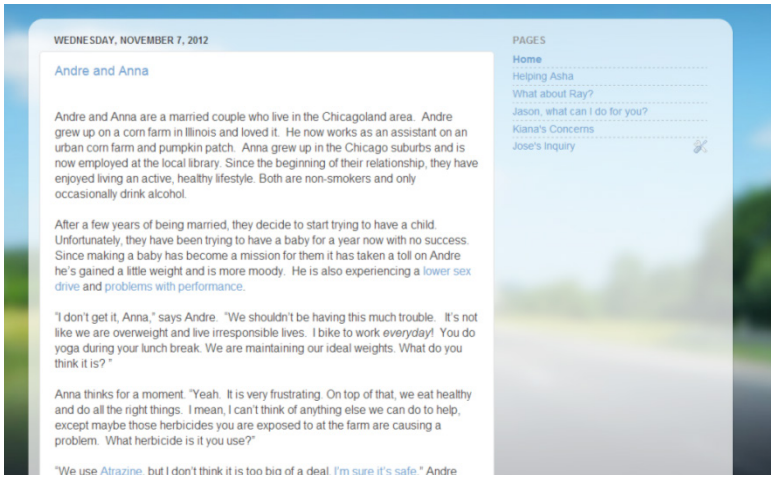

FIGURE 1. The home page of the case learning library, containing an ill-structured problem to solve.Instructional Supports

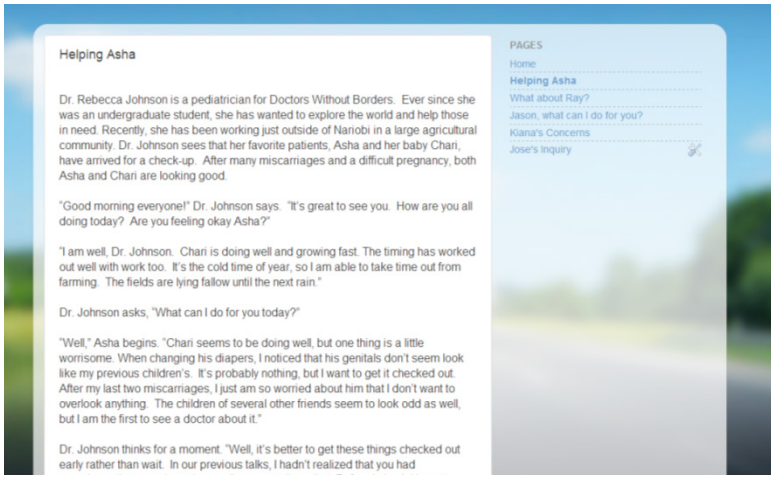

FIGURE 2. Individual case page.

Each case in the online library was designed to address specific problems, concerns, and problem-solving skills needed to resolve the problem Andre and Anna faced. This design, based on Schank's goal-based scenarios (Schank, Berman, & Macpherson, 1999; Schank, Fano, Bell, & Jona, 1993)1999; Schank, Fano, Bell, & Jona, 1993, p. 199, included similar narratives that helped the student solve the analogous problem. Schank notes that case library learning environment (CLLE) should not only make the cases available, but the design should link the cases to the ill-structured problem at specific junctures during the task. In the learning environment, the SME-instructor identified the best time to introduce a related case when reading Andre and Anna's problem. Therefore, when students read Anna's comment about encountering PCBs, we embedded a link within the learning environment that linked to Kiana's case about ingesting the same chemical (see Figure 3). Similarly, when Andre talked about his intake of water, the text on the homepage hyperlinked to a case where another character, Jason, had experienced decreased fertility as a result of ethinyl estradiol in the Illinois River. This served as a scaffold to the student's problem-solving process

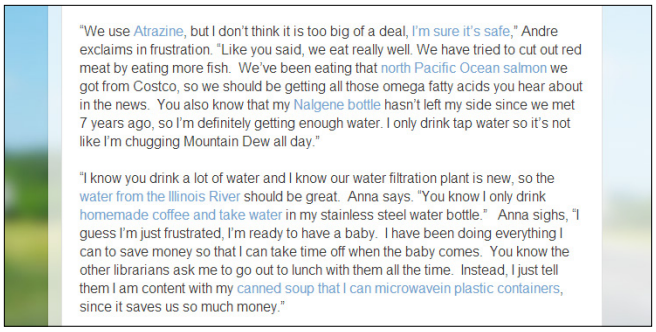

FIGURE 3. Embedded cases hyperlinked within the ill-structured problem.

by highlighting a variable the student might otherwise overlook.

DESIGN NARRATIVE

The design team for this learning environment consisted of 3 individuals: one instructional designer and two subject matter experts. One SME served as the instructor of the course, and the other SME worked for a sustainability company, where he focused on environmental remediation. We believed that the team members promoted interdisciplinary design perspectives by incorporating learning theory (instructional designer), complex biological concepts (SME-instructor), and practitioner experiences (SME-practitioner).

In many traditional learning settings, teachers and students agree on a clearly defined set of concepts that must be memorized for a later test (Brown, Collins, & Duguid, 1989). Problem-based learning, however, often interweaves these concepts throughout a contextualized, problem-solving experience. In past design projects, this shift in focus caused design tensions throughout the project. Occasionally, I (instructional designer) believed my PBL activities focused too much on the concepts at the expense of context. Other designs that I had created in the past were so specific that students had difficulty drawing out the overarching concepts and thus failed to apply the knowledge learned to analogous problems. The environments were further complicated because the PBL activities required designing for conceptual learning as well as problem-solving skills, such as self-directed learning and question generation (Hung, Jonassen, & Liu, 2008; Jonassen & Cho, 2011)

Hung (2006) argued that "without assurance of the quality of problem or intended aims being met, the effects of PBL are unpredictable and questionable" (p. 56). Rather than assuming the concepts were clearly evident to the students, I (as the instructional designer) set out to identify specific design strategies for designing PBL environments. The 3C3R (3C: content, context, and connection; 3R: researching, reasoning, and reflecting) model (Hung, 2006) is one strategy that was identified as a potential means to promote consistency and quality of learning using a systematic design process. The model focuses on two aspects of PBL design: core components and reasoning components (see Figure 4). The former includes an emphasis on the content, context, and connection (3C) of the design. These aspects set up the problem-solving activity while considering the relationship to previous knowledge. The reasoning aspects of the design promote researching, reasoning, and reflecting (3R). These aspects are important because cognitive processes and problem-solving skills are central components of a PBL system. The 3C3R strategy helped our team to consider conceptual learning and problem-solving skills in conjunction with information acquisition and retention throughout the project.

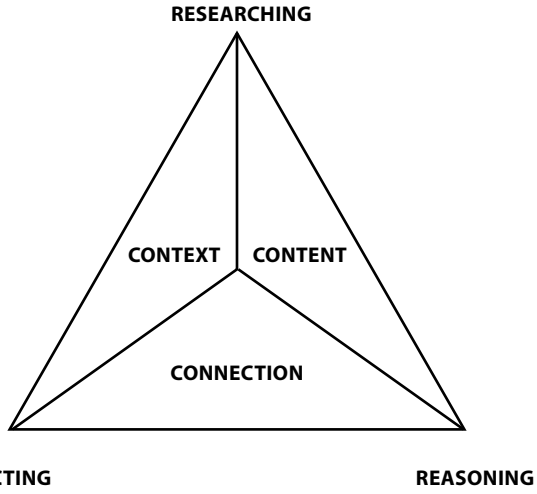

FIGURE 4. The 3C3R PBL design model (reproduced with permission from Hung, 2006).

Prior to the initial meeting with the SME-instructor, I (the instructional designer) reviewed the literature concerning the 3C3R method so it could be employed in our design. Based on the 3C3R literature (Hung, 2006), I constructed a semi-structured interview (see Table 1).

Meeting 1: Defining the Core

As I met with the SME-instructor, I began by asking her to focus on two overarching questions: (1) What are the students expected to learn and (2) Who cares about it? Answering the first issue was relatively easy to answer because the SME-instructor had taught the class multiple times and was familiar with the learning objectives concerning environmental toxins. The second question was slightly more difficult. The SME-instructor knew of the importance of environmental toxins, but we had discussions where she would reiterate the merits of learning these concepts. In a sense, she was trying to convince me that these were important. I had to clarify my statement by asking her what profession cared and applied this material every day to solve problems. I then told her that this would help to formulate the PBL activity and contextualize the problem. We discussed the appropriateness of

Content	1. What is the learning goal for students after completing this module? 2. What are some specific objectives? 3. What is the scope of the problem? 4. How many solutions can result from this type of problem?
Context	1. How is the problem we are assigning actually valid/authentic for the context? 2. How contextualized is this problem? Can the students easily see how these concepts can be applied to other similar types of problems? 3. In what way is this topic motivating to students? Why does this problem seem important to them?
Connection	1. Do the concepts build upon other concepts from earlier in the course? 2. Do the concepts and objectives overlap with other concepts from earlier in the course? 3. How does the problem allow students to test ideas in different contexts?
Researching	1. How do we explicitly articulate the overall goal of the problem? 2. What type of research is needed for this type of context and problem?
Reasoning	1. Is there a problem-solving protocol that we can implement or embed? 2. What information resources are we providing students? 3. How are we encouraging students to: 4. Analyze interrelated nature of the variables? 5. Link new knowledge with previous knowledge? 6. Think about causal relationships? 7. Generate and test hypothesis?
Reflecting	1. Does the problem require: 2. High information researching and high reasoning (complexity)? 3. High information researching and low reasoning (complexity)? 4. Low information researching and high reasoning (complexity)? 5. Low information researching and low reasoning (complexity)? 6. How do we allow the students to reflect on what they have learned in previous modules? How do we allow the students to reflect on what they have learned in the current PBL modules?

TABLE 1. 3C3R Semi-Structured Interview Protocol adapted from Hung (2006).

some professions, such as an environmental lobbyist or a U.S. Food and Drug Administration (FDA) representative, but we settled on a physician because we believed it would be more familiar to the reader. That is, our students were knowledgeable about the work of physicians, but may be less clear about the work of governmental agencies or lobbyists. Once we had settled on the context, I asked her the 3C3R semi-structured interview questions I adapted from Hung (2006) (see Table 1). Below is a description of our meeting discussions.

3C: Content, Context, and Connection

Content: What is the learning goal for students after completing this module?

Asking this question at the outset helped to provide a general sense of our overall learning mission. The SME-instructor noted that a growing problem in our society relates to chemicals in food, but many people are unaware of contaminants in the food they consume. Specifically, studies have shown various negative effects on humans due to contaminants in food (Hoekstra et al., 2012). At this point, the SME-instructor asked: "How generic can we make it?" She had questions related to how complex the learning should be for "true" PBL activities. She further questioned whether students could be expected to answer problems that even some physicians may not be able to solve.

At this point, I explained to her the value of scaffolding and its use when designing PBL. Although we did not decide upon any particular scaffolds, it helped her to understand how the addition of scaffolds to the curriculum redesign would allow her to transition to a facilitation role throughout the problem-solving activity. I then explained that we could scaffold as needed based on her knowledge of the students learning patterns. After our initial discussion, we began to think of a general outline for the ill-structured problem. We

decided that we would pose a situation where a doctor needed to solve a problem for an infertile couple (Andre and Anna).

Content: What are some of the specific objectives?

Identification of the objectives helped to further demarcate the scope of the problem. Whereas the first question helped to outline a general problem, a focus on specific objectives caused us to examine the exact ways in which human biology may be impacted by pollutants. After looking at the syllabus, we focused on three objectives:

1. Students should be expected to identify toxins in the environment that pose a problem to the food supply.
2. Students should be able to identify the impact of toxins on male fertility and suggest strategies for removing the identified toxins.
3. Students should be able to identify the impact of toxins on female fertility and suggest strategies for removing the identified toxins.

Once again, we began to further develop the ill-structured problem. We decided that the ill-structured problem would ask the students to solve a problem for a couple, Andre and Anna, who are seeing a doctor to understand why their trying-to-conceive (TTC) attempts were not successful. The fertility related problems would center on their unintentional ingestion of chemicals found in foods.

Content: What is the scope of the problem?

Identification of the specific concepts students were expected to learn was much more complex during the design. At one point the SME-instructor asked: "How complex can we make the problem?" Specifically, we had difficulty with demarcating the scope of the ill-structured problem and how broad to make the activity. A complicated issue such as biological infertility can be related to many variables, such as environmental factors (toxins), hereditary factors (preexisting conditions), or a combination of the two. Each of these factors may impact the other and thus makes it hard to control variables when designing for PBL. For instance, something as simple as the age or ethnicity of the problem characters could play a role in how likely an individual is to become pregnant. Similarly, the work conditions or the food the characters ate might also impact the problem-solving trajectory of the student. Each of these contextual elements contained certain assumptions. In one example, I assumed that living in a rural area would imply Andre was healthier because of the lack of automobile pollution. However, the SME-instructor noted this common assumption was erroneous because research has shown fertility could still be impacted by agricultural toxins (Sallmén, Baird, Hoppin, Blair, & Sandler, 2006). As such, we had to question even the smallest of descriptions throughout the module design because it would impact the overall scope and complexity.

The specific module we designed focused on the effect of the following chemicals on fertility in humans: atrazine, PCB, BPA, and ethinyl estradiol. These pollutants were selected because they are fairly common in many foods that people consider safe or healthy, such as fish and canned foods. We also chose these toxins because recent studies have linked these chemicals to fertility issues in humans and other species (Balabanič, Rupnik, & Klemenčič, 2011). We wanted to address the issue of ethinyl estradiol appearing in rivers and drinking water because older sewage treatment plants have not removed pharmaceutical endocrine disrupting chemicals from the sewage effluent (Blazer et al., 2012). At this point, it was important to remind ourselves that we were only focusing on the ingestion of these chemicals through food and drinks. This was important for the PBL design because these xenoestrogens, which can negatively affect male and female fertility, can also be found in other objects. By limiting the scope to food sources, we were able to focus our efforts on building the context of the problem. From an instructional design standpoint, this allowed us to focus the support materials in the online library. This approach also helped to limit complexity and made it a manageable problem to solve within the allotted time (one week).

Content: How many solutions can result from this type of problem?

One of the hallmarks of PBL is its ability to promote multiple solution paths for the learners (Barrows, 1996; Ertmer, 2005). As such, it was important for us to design in such a way that students could compare a hypothesis and evidence to support their reasoning when solving for Andre and Anna. Our initial design allowed the student to problem-solve using multiple paths as they eliminated one or more toxins for the female, male, or both. More specifically, the students were allowed to suggest solutions, such as eliminating sources like plastic toxins or checking for the presence of polycystic ovaries in the characters.

Because I (the instructional designer) had little experience with the subject matter, I had difficulty understanding the scope of the problem and the required causal reasoning as we delved further into this aspect of the design. It was particularly helpful that the SME-instructor took it upon herself to draw a causal reasoning chart (see Figure 5). This allowed me to visualize the intersecting elements embedded within the problem. We could then begin to collaboratively discuss how to best support each element. It was later formalized into an artifact that we would frequently reference as we discussed the intersecting concepts in the course (see Figure 6). These artifacts also helped us to finalize all the potential solution paths the students could pursue.

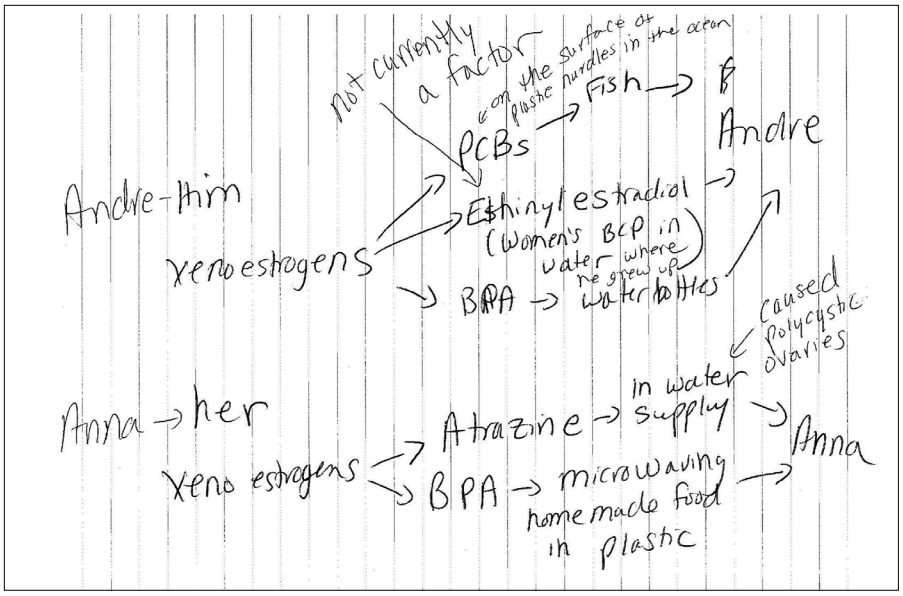

FIGURE 5. Causal reasoning chart drawn by the SME-instructor.

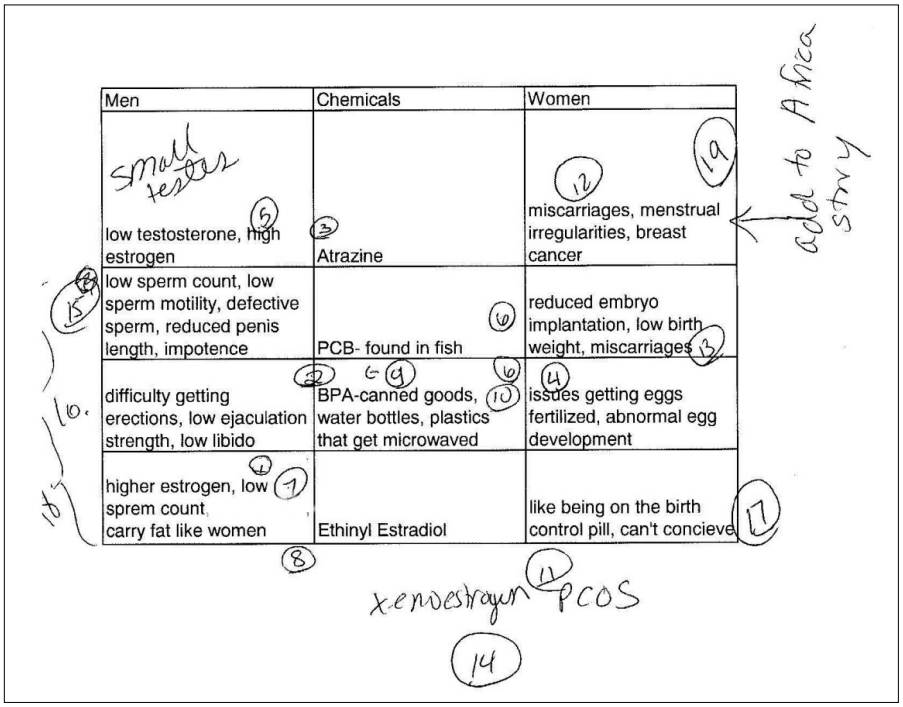

FIGURE 6. Concept intersection chart based on SME-instructor sketch.

Context: How is the problem we are assigning actually valid/ authentic for the context?

By allowing the students to take on the role of physicians, we were afforded some flexibility in the design as we progressed in the first meeting. Research has shown physicians see a myriad of issues in settings where variables are not always obvious (Jonassen, 2011). Moreover, environmentally-related fertility problems have become more prevalent within the field of medicine, and thus served as valid context for which to build the PBL activity (Woodruff, Carlson, Schwartz, & Giudice, 2008). This is why we felt justified in using a physician's role for the PBL activity.

Context: How contextualized is this problem? Can the students easily see how these concepts can be applied to other similar types of problems?

We reasoned that contextualizing the PBL module from a physician's perspective would support analogical transfer to other concepts. Because physicians often deal with "everyday people," we designed the backstories of Andre and Anna to promote analogical reasoning. For instance, we could have one character from an urban population and another from a small town. Since the students were solving a problem that dealt with various toxins for both men and women (PCB, BPA, etc) that could be found in a variety of sources (cans, toys, fish, etc), we believed that the students would be able to see how these issues could be applied to a range of contexts beyond just the characters.

Context: In what way is this topic motivating to students? Why does this problem seem important to them?

We reasoned that this design would promote motivation in the students for several reasons. First, by taking on the role of a physician, students were asked to assume the role of respected decision-maker and profession. Second, students were given autonomy to problem-solve and discover a cause that promoted civic responsibility. Additionally, the issue of toxins and their relationship to infertility is gaining increased interest as more attention is paid to the rising issues of overpopulation, birth rates, and the impact upon human biology. Lastly, the PBL activity was situated in a problem the students would most likely encounter, directly or indirectly, at some point in their future.

Connection: Do the concepts build upon other concepts from earlier in the course?

The course, entitled Biology in the World Today, was designed by the SME-instructor to make the biology concepts relevant to the students' lives. Earlier in the course, students

learned about molecules, the human body and the effects of certain chemicals on specific bio-molecular pathways. In earlier weeks, students had been asked to study the effects of endocrine disrupting chemicals (EDCs) such as xenoestrogens, as well as Pharmaceutical and Personal Care Products (PPCPs).

Connection: Do the concept objectives overlap with other concepts from earlier in the course?

We designed the PBL activity to intentionally both overlap and enhance concepts that were learned earlier in the course. Before completing the PBL design, students had covered EDCs and PPCPs via lecture with the instructor. The students also learned about other chemicals, such as artificial food coloring, MSG and preservatives in prior sections of the course.

Connection: How does the problem allow students to test ideas in different contexts?

Because many of these ideas were previously discussed to varying degrees earlier in the semester, it allowed the students to draw connections between the effects of EDCs and PPCPs to fertility and hormone related cancers, such as breast cancer and testicular cancer. These linkages further reinforced specific concepts of human biology.

3R: Researching, Reasoning, and Reflecting

Researching: How do we explicitly articulate the overall goal of the problem?

This question posed some significant design problems. Because it was important to not limit student creativity during problem-solving, we did not want to pose a goal that caused students to narrow their focus and overlook the wide array of variables that could impact human fertility. Alternatively, we thought a lack of explicit directions potentially overwhelmed the students' cognitive load. This design tension caused us to balance the open-ended nature of PBL and the potentially overwhelming task of solving ill-structured problems. Based on the recommendations by Hung (2006), we decided to pose questions at the end of the learning environment to direct research efforts (see Figure 7). The questions were designed to be concise, yet open to interpretation and multiple solution paths per the recommendations of PBL.

Researching: What type of research is needed for this type of context and problem?

We decided that students needed to study a variety of research in order to resolve the problem. First, students needed to investigate what types of toxins were prevalent in today's society. As such, the students needed to identify important characteristics of the ill-structured problem (e.g. location, symptoms) and parlay these into research questions. Learners also needed to investigate how toxins such as xenoestrogens impacted the human body. Lastly, learners were required to research how the EDCs or PPCPs impacted the bodies of men and women differently, and thereby identify what role each toxin plays in human fertility issues.

Reasoning: Is there a problem-solving protocol that we can implement or embed?

Although we discussed various protocols such as the Jonassen (1997) problem-solving model or other more specific scientific argumentation scripts (Baker, Andriessen, Lund, Van Amelsvoort, & Quignard, 2007; Clark, Sampson, Weinberger, & Erkens, 2007) we thought a protocol derived from the scientific process would be better for this learning environment. The scientific process is more fundamental to the domain in which the ill-structured problem is situated (physician). This would then further contextualize the

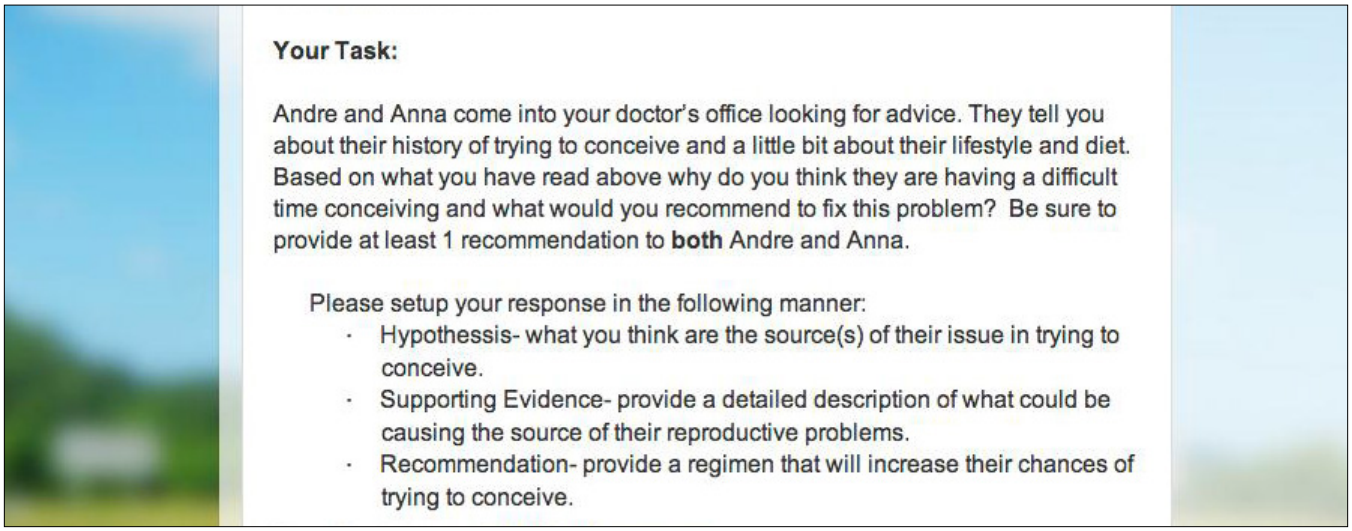

FIGURE 7. Embedded scientific process at the conclusion of the case.

problem and prepare the learner for the type of reasoning expected in practice.

Reasoning: What information resources are we providing students?

This question was arguably the most difficult to answer. Previous studies have shown that students have difficulty with the information seeking process needed to solve ill-structured problems (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012; Sockalingam & Schmidt, 2011). Specifically, students in the research cited felt overwhelmed and confused as they searched information resources. Thus, we needed to provide resources that effectively directed student efforts while also allowing for individual meaning making.

We considered various forms of scaffolding (e.g. question prompts, scripts) to embed within the design. Although these were beneficial, these failed to model how physicians might encounter the ill-structured problems, reason through evidence, engage in causal reasoning, hypothesize, and come to a resolution. Because of these limitations, case library learning environments (CLLEs) seemed like the best scaffold. Case-based reasoning theory (Schank, 1999) states that as participants reason in practice, they store these experiences in memory as a story (or "case"). Embedded within the case exists a contextual index that describes the context and makes the case accessible from memory. These cases are later retrieved from memory based on the index and reused to solve new problems (Aamodt & Plaza, 1996). If a new experience presents itself as being deviant, an individual's memory is revised to include the new case, and is then retained for later use (Dasgupta & Kolodner, 2009). In education, a collection of experiences can be combined to create a CLLE and then be employed as a means to provide contextualized knowledge to novices. These CLLEs supplement case-based reasoning cognitive processes and are utilized to deliver the problem-solving experiences that novices lack (Jonassen, 2011). The pedagogical benefits of this method stem from engaging meaning making and seeing how multiple individuals solve problems. As such, we believed a CLLE would best support the "Reasoning" component of 3C3R for our design.

Reasoning: How are we encouraging students to: (a) Analyze interrelated nature of the variables? (b) Link new knowledge with previous knowledge? (c) Think about causal relationships? (d) Generate and test a hypothesis?

Using a case library allowed us to answer this aspect of the reasoning process. The modeling aspect of case libraries (Kim & Hannafin, 2008) was especially important because students had little experience with solving ill-structured problems within the medical profession. Cases, by their nature, are narratives that detail how ill-structured problems are solved by practitioners (Hernandez-Serrano & Jonassen, 2003). We could therefore design cases such that the protagonist of each case worked through one or more of these reasoning components. We could then add the narrative elements for a particular problem-solving component that we felt the students might lack.

Reflecting: Does the problem require: (a) High information researching and high reasoning (complexity)? (b) High information researching and low reasoning (complexity)? (c) Low information researching and high reasoning (complexity)? (d) Low information researching and low reasoning (complexity)?

After our discussion, we decided to categorize the activity as "High information researching and high reasoning" for various reasons. First, the objectives we identified in the Core discussion required students to research how toxins were prevalent throughout their environment. Second, the task asked students to research the variety of ways these chemicals could be ingested by humans (e.g canned goods, plastics, water pollution, and fish). In terms of reasoning, the students would then be required to identify how these sources of toxins impacted different gender reproductive system and fertility in specific ways. This required combining multiple variables and significant causal reasoning.

Reflecting: How do we allow the students to reflect on what they have learned in previous modules? How do we allow the students to reflect on what they have learned in the current PBL modules?

We decided this particular question could be facilitated by the instructor. Through in-class discussion, the SME-instructor linked the case-based contexts back to the experiences of students by discussing examples of family members, friends and former students that had suffered from exposure to EDCs and PPCPs leading to cancers and fertility issues.

DESIGNING THE LEARNING ENVIRONMENT

Once we had outlined the groundwork of the learning environment, we decided to design the problem-based learning activity. At the outset, we once again asked ourselves "How complex do we make this activity?. We found ourselves having to first question the order of the design process. Designing the ill-structured problem first would help to set the groundwork for what needed to be included in the case library. However, we questioned whether we would inadvertently overlook a topic (e.g., BPA, PCc) or learning objective that we had identified in our Core component discussion. Alternatively, beginning with the case library would help us to ensure each concept was included (e.g., BPA, PCc), but we worried that it would be very hard to tie five disparate stories back to supporting a single problem. After much debate, we went ahead and designed the ill-structured problem first to promote a cohesive learning environment. This also aligned

CHARACTER	CHARACTER DESCRIPTION	TOXINS
Andre	**AGE:** 28 years old **LIFESTYLE:** Healthy lifestyle and healthy weight. Non-smoker, occasional drinker **OCCUPATION:** Urban farm worker **EXERCISE:** Soccer	**XENOESTROGENS:** fish (PCB), drinking water (estrogen), Water bottle (BPA)
Anna	**AGE:** 26 years old **LIFESTYLE:** Healthy lifestyle and healthy weight. Non-smoker, occasional drinker **OCCUPATION:** Librarian. **EXERCISE:** Pilates and Yoga	**BPA SOURCE:** microwaves homemade meals in thinking she's healthy, but actually being exposed to high levels of BPAs **XENOESTROGENS:** atrazine

TABLE 2. Character Descriptions of Andre and Anna.

with the CLLE design literature that notes that cases are used as a support to problem-solving.

Designing the Ill-Structured Problem to Solve

At this point, we focused on the following overarching problem: recent research is showing that individuals are having a harder time getting pregnant due to environmental toxins in their food source (Woodruff et al., 2008). As noted earlier, our main characters in the ill-structured problem were Andre and Anna, who had been unsuccessfully trying to conceive a child. Although we had identified them as a married couple, we had yet to outline the specific characteristics that would serve as cues to the problem-solving process. As we discussed their characteristics, we noticed that we had difficult time controlling the variables of the ill-structured problem throughout the design. For instance, describing their city as large or small implies the characters might encounter different toxins. We discussed similar problems related to age and workplace. After much discussion, we decided to use character descriptions of Andre and Anna in the design as a way to control variables and delineate the scope of the problem. For example, the relatively young ages of the characters helped to limit age as an infertility factor. Setting their professions as a librarian and urban farmer allowed us to narrow their exposure to certain chemicals and control for those variables. This helped us to further establish the parameters of the design.

Based on the 3C3R semi-structured interview described above, we outlined the following characteristics for Andre and Anna (see Table 2).

Because I (the instructional designer) had experience with constructing narratives for PBL, we decided that I would initially lay out a general framework for the ill-structured problem. I used the Comment feature of Microsoft Word to communicate to the SME-instructor where I had implemented some of our learning objectives and how I controlled for variables (see Figure 8); for instance, in the introduction where we introduced "Anna" as having a healthy lifestyle. The comment feature showed the SME-instructor how I had controlled for weight as a factor. Later, I used the comment

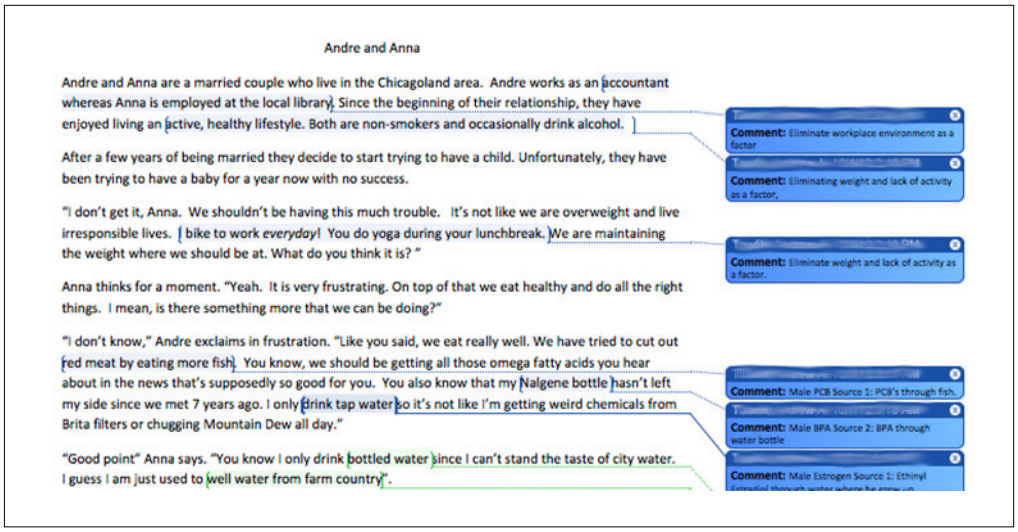

FIGURE 8. Developing Andre and Anna's story collaboratively through the use of commenting in Microsoft Word.

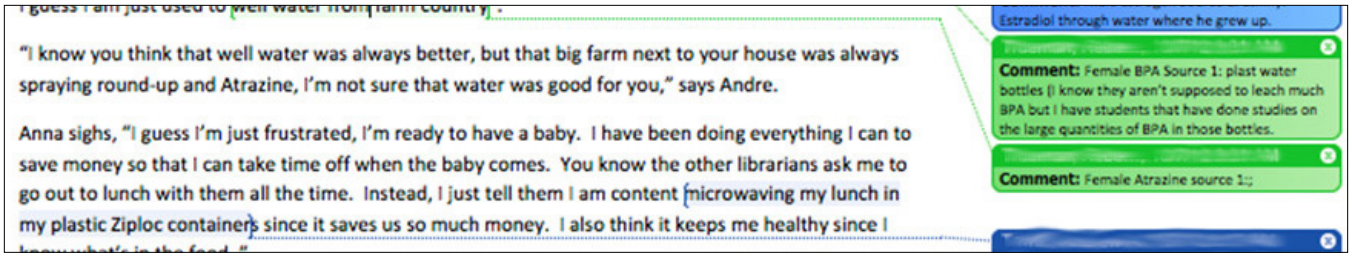

FIGURE 9. Artifact of the first draft showing two designers manipulation of the text of the scenario. Instructional designer comments in blue, SME in green.

feature to show how Andre's statement "We have tried to cut out red meat by eating more fish" was a way to introduce their ingestion of PCB's through seafood.

In many ways, this aspect of the design was similar to a "wireframe" approach that webmasters employ when constructing new sites. This approached worked well because it helped to set the general narrative elements that would create an interesting and motivating problem to solve, yet allowed for the SME-instructor to add scientific concepts or amend erroneous statements at the beginning of the process. It also helped to initially set the variables within the ill-structured problems. The SME-instructor said this iterative approach helped her to further conceptualize the goals of a PBL activity.

After the first draft, the SME-instructor then made larger modifications to the narrative as she added specific environmental toxins that can act as endocrine disruptors. In one example, she noted how using well water as a variable could introduce the presence of Atrazine to the scenario (see Figure 9). After going back and forth, the SME-instructor and the instructional designer finalized the ill-structured problem.

Designing the Case Library

SME-Instructor First Draft

Because the case library introduced many of the scientific concepts, we suggested the SME-instructor develop an outline and first draft. This was important for multiple reasons. The SME-instructor knew what concepts to include and which toxins were pervasive in the environment. Having the SME-instructor complete the outline of the first draft would therefore help to ensure that these important concepts were not overlooked. We believed this would reduce the possibility of massive rework that would be required if these concepts were left out, which would have been more likely if the instructional designer outlined the first draft.

Handoff to Instructional Designer

Although this helped to set the stage, it revealed some misconceptions about the case-based reasoning process that the instructional designer had failed to discuss with the SME-instructor. For instance, the first versions of the case related to Atrazine and ground water relied heavily on the scientific elements, but lacked some narrative and contextual elements:

Rebecca, a frog scientist, has been examining decreases in frog populations around the world. She has found that frogs are particularly susceptible to certain hormones in the environment. These hormones, xenoestrogens, have the ability to mimic real hormones within the frogs. She has found the following toxins to be mimics of estrogen: Ethinyl estradiol, DDT, PCBs, BPA, PDBE and atrazine. In looking at the frogs in these environments, she has noticed strange secondary sex characteristics and other anomalies. For example, when she has dissected male frogs, she has found that they have many sets of testes and ovaries. These mutations are clearly not normal. Rebecca has noticed that the areas where frog populations were lowest also coincided with areas that use Atrazine as a herbicide on farmers' fields. Rebecca has now contacted Dr. Matt Lorez, an expert in the effects of Atrazine on organisms.

Because we planned to use the case library to both inform the students about the concepts and model the problem-solving process, I suggested to the SME-instructor that we edit the case. For instance, we met to discuss how the case lacked contextual and narrative elements such as where Rebecca was located, how the problem was identified, where the toxins were located, what problem the protagonist is trying to solve, assumptions, decision-making process, and outcomes. These were all important to the design if the student was to make meaning from the narrative.

The initial draft also highlighted that I (the instructional designer) failed to inform the SME-instructor about the true definition of case libraries. Case-based reasoning (CBR) uses a collection of narratives to solve similar problems. Because our problem asked students to resolve human fertility issues, some would argue a scientist seeing abnormalities in frogs would not be considered a valid application of CBR. We discussed how we needed to redesign the cases so that the concepts and contexts were aligned across the ill-structured problem and case library.

Handoff to SME-Practitioner

The SME-instructor also struggled with being creative. At this point we brought in a practitioner (SME-practitioner) to work closely with the SME-instructor in the development of the cases. While the SME-instructor had performed research that explored the linkages between anthropogenic and natural processes in terrestrial and aquatic ecosystems, she had difficulty transforming scientific jargon into terms that were uncomplicated to novices. The SME-practitioner's main job focused on facilitating collaboration between scientists and other stakeholders such as, politicians, citizens and construction companies, so he utilized his experience as the chief technology officer of an environmental sustainability company to mold the narratives.

Working as a team, the two SMEs and the instructional designer came together to make final edits to the cases. Our changes largely centered on the following elements: contextual introduction, presentation of problems, problem-solving modeling, conceptual description, and resolution/outcome. We drastically revised the case so that Dr. Johnson was a physician for Doctors Without Borders and was in the process of helping a patient, Asha, understand some of the problems she is noticing with her 9 month-old son's reproductive organs. Below is a final version of a case using the following structural elements: contextual introduction, presentation of the problem, problem-solving modeling, conceptual description, and resolution/outcome. (Note: headers were not displayed within the learning environment).

Contextual Introduction:

Dr. Rebecca Johnson is a pediatrician for Doctors Without Borders. Ever since she was an undergraduate student, she has wanted to explore the world and help those in need. Recently, she has been working just outside of Nariobi in a large agricultural community. Dr. Johnson sees that her favorite patients, Asha and her baby Chari, have arrived for a check-up. After many miscarriages and a difficult pregnancy, both Asha and Chari are looking good.

"Good morning everyone!" Dr. Johnson says. "It's great to see you. How are you all doing today? Are you feeling okay Asha?"

"I am well, Dr. Johnson. Chari is doing well and growing fast. The timing has worked out well with work too. It's the cold time of year, so I am able to take time out from farming. The fields are lying fallow until the next rain."

Presentation of the Problem:

Dr. Johnson asks, "What can I do for you today?"

"Well," Asha begins. "Chari seems to be doing well, but one thing is a little worrisome. When changing his diapers, I noticed that his genitals don't seem look like my previous children's. It's probably nothing, but I want to get it checked out. After my last two miscarriages, I just am so worried about him that I don't want to overlook anything. The children of several other friends seem to look odd as well, but I am the first to see a doctor about it."

Dr. Johnson thinks for a moment. "Well, it's better to get these things checked out early rather than wait. In our previous talks, I hadn't realized that you had experienced some miscarriages. I'm sorry to hear that. Before I check him out, please tell me a little bit about why you think there is a problem."

"Thank you for your kind words, Dr. Johnson. I think the main issue is that his testes seem very small compared with my other sons."

Problem-solving modeling (questioning, variable identification, and reasoning needed for effective problem-solving):

After Dr. Johnson takes a look, a concerned look covers her face. "I'm afraid you are right. This does seem to be an issue. However, you are not alone. I have been seeing this with many other children in the area. It could be that some environmental factors affected your pregnancy. You mentioned that you work on a farm. Tell me a bit about that."

"It's not too bad actually. I don't have to pull weeds since we spray Atrazine to kill them. I just spend time walking around spraying the herbicide. It's nice for the most part because I love being outside. I am sure the exercise was good when I was pregnant too."

Asha is distraught because she wants to have more children, so she asks, "What can I do to make sure my future babies don't have these problems?"

The doctor urges Asha to stop using Atrazine and other Xenoestrogens on her farm immediately, and suggests moving toward organic weed control. Dr. Johnson will continue to monitor Asha's hormone levels and will help her decide when she is healthy enough to try to conceive again.

(continued on next page)

Conceptual Description (primary index of the case)

"Your use of Atrazine worries me," Dr. Johnson says. "Many people don't know this, but Atrazine is a dangerous herbicide and could have caused complications during your pregnancy. Atrazine is a known Xenoestrogen and it can convert testosterone into estrogen by activating an enzyme pathway called Aromatase. By doing so, it actually enhances estrogen and decreases testosterone, which is not a good thing for a little boy. These abnormal hormone levels caused by Atrazine exposure might have been passed to your son via your blood when he was still inside you. A biologist friend of mine who works at the local University has collected many frogs from around here that have several sets of testes and ovaries. She thinks the mutations come from Atrazine exposure. Your previous miscarriages, the symptoms displayed by your son and the state of the frog population could be explained by exposure to the Atrazine you use at work."

Resolution/Outcome:

Asha immediately starts to cry. "This is terrible. I had no idea that this would happen. What can I do?"

"Let me do a physical exam first", says Dr. Johnson. After the physical exam Dr. Johnson confirms that the boy does have two testes, which is good.

Dr. Johnson then explains the best course of action to solve this problem. "The first thing you can do is to make sure Chari is no longer exposed to Atrazine. Why don't we do some tests to examine his testosterone levels now, and again in a month. We will know by the results whether his body is responding. If he needs a little help, we can consider using testosterone gels and creams to try and bring his testosterone levels up, but that would have to wait until he is much older. There are also aromatase inhibitors. They are basically drugs that will stop his body from converting testosterone into estrogen that we can try. This will probably take a long time to correct and the damage may be permanent. Once he goes through puberty I would recommend testing his sperm quality."

This process was indicative of many of the cases we designed. The edits also help to elucidate a design framework we employed to construct the subsequent cases.

Bringing the Design Together

In a previous case library design (Tawfik, Jonassen, & Keene, 2012), I was concerned that the design I implemented did not support the ill-structured problem to the degree I wanted. Specifically, I was worried the student might lose sight as to how the cases support the ill-structured problem to solve because cases can be so contextual and specific. As the SMEs and I went through the problem, it became apparent that these cases often lost sight of the ill-structured problem we were trying to support. That is, the symptoms we articulated in the Conceptual Descriptions of the case framework were not necessarily described anywhere in the ill-structured problem (Andre and Anna) we were asking the students to solve. We then went through each case and asked the following questions:

1. In what way does the case relate back and help inform a solution to the Andre and Anna problem?
2. Where are the variables presented in the ill-structured problem?

Our questions found the case did not appropriately support the problem students were being asked to solve. For instance in the case entitled "Jason, what can I do for you?" the student read how exposure to ethinyl estriadol in the water caused the male to experience increased moodiness and gain weight. However, the initial problem to solve does not have Andre experience these symptoms.

> **VERSION 1:** *After a few years of being married Andre and Anna decide to start trying to have a child. Unfortunately, they have been trying to have a baby for a year now with no success.*

After we asked the two questions above, we realized that we had never presented moodiness as a characteristic of Andre. This would reduce the possibility to identify ethinyl estriadol as a variable in Andre. As such, we decided to revise the ill-structured problem to show how more ethinyl estriadol symptoms were apparent in Andre.

> **VERSION 2:** *After a few years of being married, Andre and Anna decide to start trying to have a child. Unfortunately, they have been trying to have a baby for a year now with no success. Since making a baby has become a mission for them it has taken a toll on Andre. Anna has noted he's gained a little weight and is becoming increasingly moody. He is also experiencing a lower sex drive and problems with performance.*

Prior to implementation we found similar instances where we had to failed to align the case library with the ill-structured problem. To address this, the SME-instructor constructed an artifact that would help us visualize how the ill-structured problem, case library, and concepts aligned (see Figure 10). In the center of the image, we see how various toxins are evident in the case and for whom. We then drew how each case aligned back to the problem to solve. Although this process added considerable time and revisions to the instructional design process, it helped to ensure that each case appropriately supported the researching aspects of the 3C3R process.

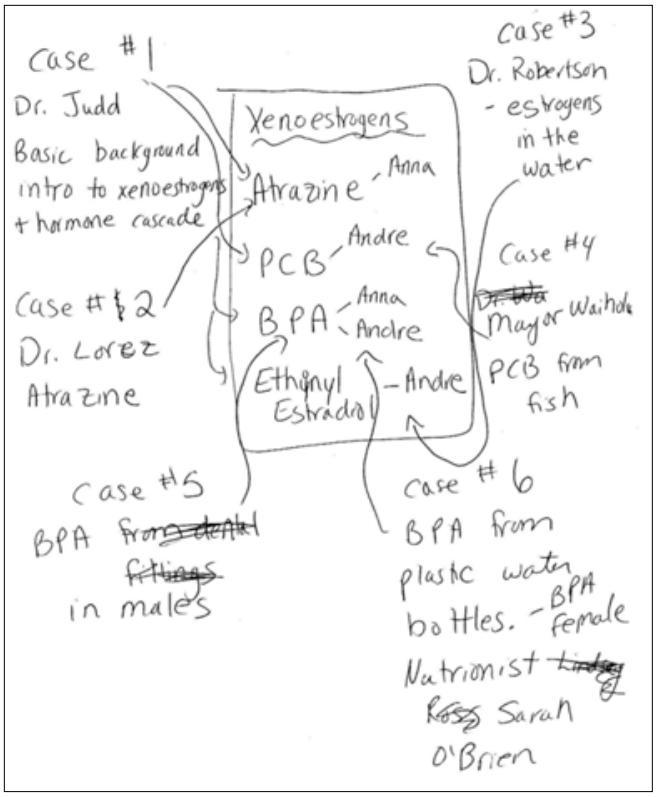

FIGURE 10. Sketch visualizing the alignment of the Andre and Anna story with the support cases.

STAKEHOLDER ASSESSMENT

After completing this activity, every student the SME-instructor spoke with was interested in learning more about environmental toxins. However, the SME-instructor noted that it was incredibly difficult to get the students to buy-in to this new way of learning, initially. The SME-instructor observed that she had to constantly remind the students to complete the activity. Despite very clear instructions, many of the students had the following questions: How do I do this? Do I answer the problem with the headings you provided? Do I email you my response? Do you want this in APA format? Do I need to have a reference list? In the future, the SME-Instructor would like to embed text boxes with pre-established headings (hypothesis, supporting evidence, recommendation) into the website as an additional scaffold. Creating such forms may provide the best approach for further PBL implementations.

In our case, the 3C3R method was highly effective when used to design a real-world PBL instrument. The SME-instructor noted that this project supported the students' ability to learn the target Biological concepts. The SME-instructor also noted that students were engaged more with the material and expressed curiosity to learn more about xenoestrogens, EDCs and PPCPs in the environment than they had with previous instruction methods. In essence, the instructor saw an increased awareness about the chemicals that students unwittingly exposed themselves to on a daily basis. In fact, some of her students informed her that they were going to seriously reevaluate the food they eat, as well as the food consumed by friends and family. Prior to the PBL project, few had realized the amount of BPA they consume from eating something as simple as canned soup. From the SME-instructor perspective, the case library accomplished what few activities do when teaching science to non-science majors—it stimulated genuine interest in the application of science. The SME-instructor was particularly excited about the possibilities of using case libraries in other areas of the course, provided they can make the project intriguing to students.

DISCUSSION

Positives

We believe that there were multiple positives as a result of this instructional design. As noted earlier, it is very hard to interweave concepts with context when designing for effective PBL. We believe that we were able to apply the 3C3R process to design a PBL environment that was comprehensive in terms of what the student was learning and how their problem-solving was supported.

In terms of supporting problem-solving, we believe the case library resolved some of the issues identified in a previous design case (Tawfik et al., 2012). Specifically, we were able to align a single ill-structured problem with multiple variables to several supporting cases. This iterative process identified potentially problematic areas that could easily have been overlooked had we not ensured that the problem and cases were connected. We avoided confusion about how complex to make the PBL activity, resolved ambiguity about how to apply the CBR theory, and ensured each case was able to relate back to the ill-structured problem the learner was expected to solve. This process also helped us to construct an outline we could employ when designing each narrative in the case library: contextual introduction, presentation of problem, problem-solving modeling, conceptual description, and resolution/outcome. This helped to promote the quality and consistency of the learning experience despite the different contexts of the narratives.

Opportunities for Improvement

Despite the successes, there are potential changes we would implement in the redesign as we reflect upon our experience. One option is to include additional outside individuals at different stages of the design process. In particular, we could have conducted checks for the final cases with physicians to ensure accuracy. In our case, we translated scientific concepts into a narrative, but it is possible that we may not have accurately represented the complexity of the

problem-solving processes that physicians encounter within their domain.

Another option is to place more of an emphasis on the visual elements of the case. It was important to use technology so we could strategically hyperlink certain aspects of the ill-structured problem with a particular case. However, the cases were largely text-based descriptions of problem-solving in context. The inclusion of images or multimedia presentations placed within the design may have provided a more engaging or aesthetically appealing learning environment for the students.

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