Chapter 4

Engaging Students Through Design Based Biotechnology Literacy

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Abstract

As the field of biotechnology expands, the need for greater education regarding biotechnological applications and innovations is imperative. Biotechnology is defined as "any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals, or to develop microorganism for specific purposes" (OTA, 1988/1991, FCCSET 1992/1993, Wells, 1994). With the goal of Science, Technology, Engineering, and Mathematics (STEM) education focusing on creating technologically literate citizens, it is important that schools and institutions create opportunities for students to explore how biotechnology has evolved throughout the years and the types of challenges biotechnology can help address. In integrating biotechnology literacy within the schools and universities, teacher preparation programs need to modify the way they teach their pre-service teacher by incorporating more instruction in the area of design based biotechnological literacy best practices. This chapter will discuss how the design based biotechnology literacy (DBBL) approach requires a change in an educator's pedagogical practice which leads to a deeper understanding of both content and practice for teacher and student alike.

***Keywords**:* Design Based Biotechnology Literacy, Design Based Learning, Technology Education, Biotechnology

Introduction

Biotechnology has a major impact on the world particularly the medical, agricultural, and educational fields. With the discovery of the double helix in the mid-1950s and the increased need for bioremediation, the field of biotechnology is constantly advancing and seems to play a significant role in our 21st century world. With new technologies emerging every year, it is imperative that the United States educational system creates technologically literate citizens that understand the scientific and technological concepts to make informed decisions. Economic growth and the improvement of America's standard of living is one of the major goals set forth from the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) Committee on Life Sciences and Health (1992). As with any area of study, definitions play a major role in accurately describing a given area. As for biotechnology, there was much confusion regarding its definition particularly in the areas of biology, health care and education. That being said, in the *Design Based Biotechnology Literacy Curriculum* (2017), biotechnology is defined as involving "any technique that uses living organisms (or parts of an organism) to make or modify products, to improve plants or animals, or to develop microorganism for a specific use" (Wells, 2019, p.53).

The field of biotechnology is constantly advancing and many educators have misconceptions that biotechnology needs to have expensive materials and equipment in order to successfully teach these concepts of biotechnology within a technology education classroom (Dunham, Wells, & White, 2002, p.7). In working towards educating individuals to ensure that they have the specific education and training needed to work in these biotechnology companies and industries, the International Technology Engineering Educators Association (ITEEA) has adopted the taxonometric structure developed in 1992 (Wells, 1994) for teaching biotechnology. This taxonomy organized biotechnology content into eight distinct knowledge areas: foundations of biotechnology, environment, agriculture, bioprocessing, genetic engineering, biochemistry, medicine, and bioethics (Dunham, et al., 2002, p.7-8). This research article will discuss the importance of incorporating methods of teaching and learning biotechnology within teacher prepatory programs, as well as ways of increasing student engagement in this area.

In order for biotechnology to be effectively taught in schools, pre-service teachers must be enrolled in teacher prepatory programs that teach them the science content as well as the technological content requisite to their understanding of the concepts. As more and more biotechnologies emerge, students in the 21st Century are required to develop their understanding and abilities to use these technologies throughout their everyday lives. Teachers must not only learn the pedagogical content and practice knowledge for teaching biotechnology literacy, but also experience first-hand the strategies that are most effective in teaching it.

Scientific and Technological Literacy for All

Given the identified context organizers for technological systems are physical, informational, and biological (ITEA TfAAP, 2006, p.16), biotechnology was a content organizer included in the *Standards for Technological Literacy* (2000) within Standard 15 *Students will develop an understanding of and be able to select and use agricultural and related biotechnologies* (ITEEA, 2000, p.149-157). Biotechnology is also aligned to the crosscutting concepts of the Next Generation Science Standards within the Life Science and Engineering Design Disciplinary Core Ideas (DCIs) (Pruitt, 2015). The ability to be both scientifically and technologically literate stems from the ability to think critically, "design and develop products, systems, and environments to solve practical problems" (ITEA TfAAP, 2006, p.1). The standards listed above provided a framework that could be used to develop curricular materials (Wells, 2019) and programs that promote these competencies. If all citizens are not required to learn technological knowledge and pracitces, society will remain technologically ignorant and be poorly equipped for fully integrating in a 21st Century world (Pearson & Young, NAE/NRC, 2002, p.1-2). The goal of technology education is to create technologically literate citizens that "understand the nature of technology, appropriately use technological devices and processes, and participate in societies decisions on technological issues" (ITEEA TLfA, 2006, p.1). Citizens should be able to think critically to design and construct systems to solve real-world problems. Recent research has indicated that schools are not properly preparing graduates to make well-considered decisions or think critically about technology (Pearson &Young, 2002, p.2; ITEEA TLfA, 2006, p.1).

There are many definitions of technology, but ITEEA defines it as " the innovation, change, or modification of the natural environment in order to satisfy perceived human wants and needs" (ITEEA TfAAP, 2006, p.5). It is essential that technology education be made a requirement for graduation. When students are involved in technology education activities they engage in "cognitive and psychomotor activities that foster critical thinking, decision-making, and problem-solving related to the use, management, evaluation, and understanding of the designed world" (ITEEA TfAAP, 2006, p.9). Technology education should not be confused with educational/instructional technologies such a SMART boards and audio-visual equipment that is used to enhance instruction (ITEEA TLfA, 2006, p.9). In 1996, the International Technology Educators Association (ITEA) published the *Technology for All Americans: Rationale and Structure* for the study of technology, which discussed the Universals of Technology that all students should know. Then between 1996 and 2000, ITEA published the *Technology for All Americans Project* (TfAAP) as well as published the *Standards for Technological Literacy* (STL), which focused on the Universals of Technology, which include three areas: knowledge, process, and contexts.

Teaching Biotechnology

The most natural intersection to include the teaching of biotechnology content is through a technology education course. Through an Integrative STEM Education perspective, the biology and technology/engineering concepts can be easily taught in an integrative manner. Technology education focuses on solving real world problems using the technical knowledge to design and construct a product or solution, which is unlike scientific fields that focus on the natural laws and phenomena students observe in order to solve and carry out an investigation (Wells, 1994, p. 72). Thus, it would be beneficial to students if they could engage in a design challenge where they can use the scientific knowledge as well as tacit knowledge to understand the natural intersections between the science and the technology (Wells, 1994, p. 73). One example of integrating the biological processes with the technological processes would be the construction of a hydroponics/aquaponics system.

The Design Based Biotechnology Literacy (DBBL) approach engages students in implementing design based biotechnology challenges intended to further their understanding of science concepts, as well as improves the biology content knowledge of technology education teachers in order to better integrate the science with the technology/engineering (T/E) concepts. Science concepts are inherent within any technological/engineering design challenge, and when engaged in DBBL experiences students are intentionally immersed in biology content while improving their understanding of the connections between science and technology/engineering

(Peterman, Pan, Robertson, & Lee, 2014, p.45). In addition to student achievement, technology teachers can increase their scientific knowledge to better recognize the integration of science, technology, engineering and mathematics content within the lesson design.

Literature Review

Student Achievement

When biotechnology is integrated at a young age, students are able to increase their background knowledge as they cognitively develop and make better interdisciplinary connections. "From research in education, it has been found that if previously learned knowledge is tapped and built upon, it is likely that children will acquire a more coherent and thorough understanding of these processes than if they are taught them as isolated abstractions" (ITEA, 2006, p.20). Bigler and Hanegan (2011, p.253) concluded that hands-on learning could also increase student's motivation and confidence. Teachers know that students become more engaged in their learning when they are participating in a hands-on activity and that this engagement promotes deeper knowledge acquisition (Dunham, et al., 2002, p.8). Biotechnology is a field of science, which requires hands-on learning in order to fully learn and understand the content (Bigler & Hanegan, 2011, p.246). When students are able to participate in hands-on activities it increases their ability for knowledge transfer and gives them meaningful learning opportunities to apply their knowledge to real scenarios. Hands-on learning can be defined as an "educational experience that actively involves people in manipulating objects to gain knowledge or understanding" (Bigler & Hanegan, 2011, p.246). Bigler and Hanegan compared traditional learning environments to an inquiry based hands-on classroom instructional approach and they determined a statistically significant increase in student content knowledge of ($p=0.0481$) which was concluded that hands-on learning "is at the heart of science learning" (p. 246). Not only was less time needed to spend on this topic in only 13 days compared to the traditional learning sequence of 20 school days, students had increased motivation and confidence in the biotechnology content (Bigler & Hanegan, 2011, p.253).

As students engage in DBBL, it is essential educators have appropriate assessments that can evaluate the students' skills and understanding rather than tests that only focus on vocabulary words (Bigler & Hanegan, 2011). In a research study that focused on student attitudes and content knowledge of Genetically Modified Organisms (GMOs), it was concluded that student attitudes changed from argumentation to engagement in critical thinking while working through a digital module what was based on peer collaboration and critique (Noroozi & Mulder, 2017, p.35). Those students attained a 2.85 knowledge gain from 9.37 in their pre-test to 12.22 in their post-test (Noroozi & Mulder, 2017, p.34-35). When students engage in biotechnology project-based learning opportunities, it stimulates excitement, knowledge and confidence in the given subject matter and the students are able to effectively troubleshoot and apply their acquired knowledge to real-world situations (Movahedzadeh, Patwell, Rieker, & Gonzalez, 2012, p.7). "Project-Based Learning is a method in which students engage in intellectually challenging tasks that drive inquiry questions through gaining content knowledge and academic skills to solve complex problems and informatively defend their solution and outcomes" (Movahedzadeh, et al., 2012, p.7). In project-based learning, the teacher acts more like a mentor and facilitator rather than the source of direct instruction to the students. They allow the students to take ownership of their own learning and work collaboratively with their peers to generate questions that help them research what items need to be understood in order to proceed in the activity (Movahedzadeh, et al., 2012, p.5). In addition, students should be aware of how the field of biotechnology can be used to advance scientific knowledge (Borgerding, Sadler, & Koroly, 2013, p. 143).

Whether it is project based learning or problem based learning, they are both critically important for engaging students in the biotechnological content as well as increase their achievement and understanding. Israel, Pearson, Tapia, Wherfel and Reese (2015), shares that a problem solving framework also increases struggling learners, including students with disabilities and those living in poverty (Israel, et al., 2015, p.1). By using these instructional approaches in one's technology education class, diverse learners will be able to expand their horizons and improve their problem solving skills. In one's own observations as an elementary and middle school teacher, one can deduce that students with special needs and high poverty socioeconomic status (SES) benefit greatly from these technology education biotechnology classes as noted from having one's students participate in a Technology Student Association competition in the field of medical and biotechnologies and winning 1st place in their state division (Papadopoulos, 2017). Hanegan and Bigler (2009) indicate that learning is not a passive activity. The National Science Education Standards "call for students to be actively engaged in solving problems that allow them to realize applications beyond the scope of the classroom" (p.248). Hands-on learning is an essential teaching element that promotes scientific literacy and citizens who are scientifically literate not only knowing the science content, but also are able to do science (Bigler & Hanegan, 2011, p.246).

Teacher Pedagogical Content Knowledge

Some of the major reasons that biotechnology is not taught in schools is that there are many teachers who lack the pedagogical content knowledge required to teach biotechnology. "Pedagogical knowledge refers to the specialized knowledge of teachers for creating effective teaching and learning environments for all students" (Guerriero, 2017, p.2; Shulman, 1986). "With a clear definition of biotechnology in place, its position within the Technology Education (TE) curriculum is more evident, and instructors will more easily find points of inclusion they recognize and can attempt to incorporate" (Wells, 1995, p.12). As teachers teach science to their students, it is imperative that they provide multiple perspectives which allow students to make their own opinions and conclusions about what is presented (Goodrum, Rennie, & Hackling., 2001; Hilton, Nichols, & Kanasa, 2011). Where technology education courses are not offered, Bigler and Hanegan suggested that biotechnology education using hands-on teaching methods should be considered by secondary biology teachers (Bigler & Hanegan, 2011, p.246). If more hands-on learning can occur within both the science and technology classrooms, students will be able to understand and transfer knowledge between the classes.

Teacher preparation programs will also need to be changed to include this effective way of teaching in order to produce effective educators in teaching biotechnology. As stated by Shulman (1986) and Grossman (1990), teachers acquire their knowledge from many sources that affect their teaching such as in-service workshops, webinars, professional development opportunities such as lectures and conferences just to name a few. Biotechnology, like the other content areas of technology education, is naturally interdisciplinary and lends itself to a blended approach of behavioral, cognitive, and constructivist principles in the design of instruction (Dunham, et al., 2002, p.68). Just as there is biotechnology pedagogical content knowledge, there is also technological pedagogical content knowledge (TPACK) which focuses on design based or inquiry based learning experiences deriving from a constructivist nature (Chai, 2013, p.44). When technology teachers engage in creating TPACK lessons, they are able to change their epistemological approaches to include “design literacy, flexibility, and creativity” in their lessons (Chai, 2013, p.46). As noted previously, the model depicting the universals of technology includes knowledge, process, and contexts (ITEA TfAAP, 2000). Biotechnology provides for a multidisciplinary and multiple instructional approach to technology education because it allows for the integration of other content areas and 21st century skills (Petrina, 2008; Dunham, et al., 2002, p.69). Middleton (2005) indicated that there are three representations of knowledge which include visual, verbal and tacit, all of which are used within a technology education classroom while conducting an engineering design challenge. When investigating teacher content knowledge and pedagogical content knowledge, Friedrichsen, Abell, Pareja, Brown, Lankford, & Volkmann (2009) indicated three areas of teacher subject-matter knowledge to include the teachers’ own K-12 learning experiences, the type of teacher education and professional development they had as well as their own teaching experiences that formed their beliefs and knowledge base (Friedrichsen, et al., 2009). There are many ways to investigate teacher pedagogical content knowledge (PCK). The first can be through a university course and the second can be through a preservice education program (Kleickmann, et al., 2013, p.93). “In the 1980s, Shulman identified research on the content specific characteristics of teachers and of instruction as the ‘missing paradigm’ of research on learning and instruction” (Shulman, 1986, 1987 as cited in Kleickmann, et al., 2013, p.90).

“Teacher beliefs have been studied to understand teaching practices (Pajares, 1992) since beliefs influence behaviors” Ajzen & Maddenm, 1986 (as cited in Kim, Kim, Lee, Spector, & DeMeester, 2013, p.77). In a mixed methods study conducted by Kim, et al., (2013), the significant findings included that the “epistemological beliefs about *the structure of knowledge* was significantly correlated with teacher conceptions on *learning process* ($r = .444$) and *teacher role* ($r = .447$)” as well as “teacher conceptions on *class discussions* was significantly correlated with *lesson design* ($r = .692$) and *levels of technology use* ($r = .882$)” (Kim, et al., 2013, p.81). The Pearson correlation coefficient r indicates a positive correlation to all the variables. The correlations regarding teacher beliefs and their teaching practices are consistent with other researchers in the field such as Nespor (1987), Kagan (1992), and Pajares (1992). Teacher beliefs also changed with increased professional development focused on biotechnology content knowledge that promoted the strategies for teaching it (Borgerding, et al., 2013, p. 146).

Implications

The DBBL approach engages students in implementing design based biotechnology challenges that further their understanding in science concepts as well as improves technology education teachers’ biology content knowledge to better integrate the science with the T/E concepts. This being said, it is important to increase the biology content knowledge of technology education teachers because they can better understand how the technological processes are used to teach the biological processes that drive the DBBL lessons, activities and projects. Thus, by preparing pre-service teachers with substantial science courses, particularly biology courses, they are more likely to know how to connect the biological concepts and effectively teach them alongside the technology ones. Throughout one’s literature review, it is evident that there are many publications that indicate that DBBL is a successful approach to increase student achievement as well as teacher competencies in biotechnology (Casanoves, González, Salvadó, Haro, & Novo, 2015; Dunham, et al., 2002; Fulmer, 2013; Wells, 1992. 1995, 2016, 2017). In addition, it is evident through the literature that at times it is necessary for front-loading content to guide students through a 'need-to-know basis' in order to make connections to the STEM content (Dunham, et al., 2002).

Implications for Teaching Biotechnology

There are many implications for teaching biotechnology. Federal investment needs to be organized as well as training and career development in using various instrumentation and biotechnological resources (FCCSET, 1992, p.69-80). The *Standards for Technological Literacy* as well as the *Next Generation Science Standards* have also included biotechnology within their required standards that educational systems must adhere to in order to be compliant with the national demands (ITEEA STL, 2000; Pruitt, 2013). In regards to curricular materials and resources, it is evident from the literature that teachers are limited with various resources available to them (Fonseca, Costa, Lencastre, & Tavares, 2012). Fonseca, et.al. discussed how there are many implications to teaching biotechnology in K-12 education, however the most cited in these articles involved the inadequate content training for teachers, the lack of resources, time, experience and qualifications. Some other areas that teachers perceive challenges are through "material limitations to conceptual, motivational and attitudinal constraints" that deter teachers from teaching biotechnological topics (Fonseca, et al., 2012, p.369).

Lack of Teacher Content Knowledge and Confidence in Biotechnology

The issue of teacher confidence and pedagogical content knowledge in biotechnology was a major implication to this field and the researchers tried to investigate the cause for this issue, which was rooted in teacher preparation programs and professional development workshops. Bigler and Hanegan (2011, p.247) stated that the lack of confidence in knowing how to use biotechnology equipment as well as the lack of content knowledge students possess indicate major implications for this field. Another cause cited is that many educators are not trained in using biotechnology equipment and never had the opportunity to engage in research experiences before graduating with their teaching certificates. It is also essential that the biology teacher is an expert in the field as well as has confidence with biotechnology so that they can teach the knowledge with confidence to prevent students from losing interest or revert back to traditional ways of learning through lecture (Bigler & Hanegan, 2011, p.254). Once the content is mastered, Shulman's "signature pedagogies" (2005, p.52) can begin to develop for the field of biotechnology. Some issues discussed included the difficulty of the content knowledge and access to courses that teach this content for teachers to be comfortable to teach it. Teachers need to have good teacher knowledge in order to be able to teach it, just as Shulman (1987) stated that "pedagogical reasoning" is necessary for understanding (Moreland, Jones, & Cowie, 2006, p.145). This concept is further supported by Harlen and James (1997) stating that "Good teacher knowledge of subject content has been found to have a positive effect on decision-making related to changing pedagogical strategies for creating better learning opportunities" (as cited in Moreland, et al., 2006, p.144).

Teacher confidence was also a major factor because if the teacher was not an expert in the content that they taught, various topics within the curriculum may not be taught to the students or produce more student misconceptions due to their lack of knowledge in that area (Bigler & Hanegan, 2011, p.247). Teachers and administrators must recognize that this content and hands-on learning approach is worthy and valuable and that students are able to transfer their knowledge between activities and disciplines (Bigler & Hanegan, 2011, p.248-249). Even though it might be more difficult to teach in this kind of inquiry design based approach, it yields better outcomes (Dunham, et al., 2002). Biotechnology infused in Technology Education makes a more natural environment for teaching and learning, which Dunham, Wells and White (2002) supported in stating that "biotechnology activities, given the interdisciplinary nature of the topic, provide a rich setting for student engagement in problem solving, investigation, and discovery – a hallmark of the cognitive orientation" (p. 7).

Design Based Learning Models

Throughout the literature review search about design based learnings strategies, one found many models that could be used to teach biotechnology. "The MISTRE group's definition of a model as 'a representation of an idea, object, event, process, or system" (France, 2000, p.1028). Within each of the listed models (Gilbert & Boulter, 1998; Archer, 1992; Roberts, 1992; DFEE, 1995; MISTRE group, 1997; Grosslight, Unger, Jay, & Smith, 1991), it was evident that there were three levels of thinking in regards to models Levels 1-3 referenced in *Biotechnology teaching models: what is their role in technology education?* (France, 2000, p.1029). Educators need to create activities that provide concrete representations of reality for evaluation (France, 2000, p.1035). Educators can provide formative assessments or summative assessments using the students' Interactive Engineering Journals/Notebooks to gauge student improvement throughout the Engineering Design Process (Wells, 2019; Peterman, et al., 2014, p.46). By using models to teach 'larger than life' concepts, students need to learn how to appreciate models and how they can use them to approach intellectual problems (France, 2000, p.1037).

Lack of Teacher Preparation in Biotechnology

There is also a lack in biotechnology instruction, which an NSF study indicated that biotech was "non-existent" in schools (Hanegan & Bigler, 2009). The goal of teaching biotechnology is similar to what is required from technology education which is being technologically literate citizens through "enabling citizens to perform routine tasks to requiring that they are able to make responsible, informed decisions that affect individuals, our society, and the environment" (Scott, Washer, & Wright, 2006, p.43). Some educators shy away from teaching biotechnology because they may feel ill prepared or unsure about the content knowledge required teaching it (Fonseca, et al., 2012, p.372). By including biotechnology in the K-12 setting, bioethics becomes a major discussion as to how society views the use of biotechnologies and what the cultural beliefs and impacts these technologies may have on humans, the environment and our economy (FCCSET, 1992, p.65).

NGSS Implications & Training

The *Next Generation Science Standards* (NGSS) that were implemented in 2013 have changed the way science is being taught in the K-12 setting and with this new focus on inquiry and engineering design integration. Bybee (2011) indicated that one of the greatest challenges in implementing NGSS is the shift from teacher centered direct instruction to student-centered inquiry using the science and engineering practices. As referenced in Petermen, et al., (2014), the future of public education looks very optimistic with the implementation of the *Next Generation Science Standards* (NGSS), that provides natural intersections of science content with the technology/engineering practices (Petermen, et. al., 2014, p.47). School districts are looking to provide their educators with more NGSS professional development so that they feel comfortable teaching the new way of teaching science.

Implications for the Field of Technology Education

With the new push towards implementing more science within technology/engineering practices, the NGSS is trying to mesh science classes and technology classes in an integrative way of teaching students content to make connections that are more explicit to real-world applications. In discussing these new changes with other technology education teachers, some TE educators are concerned that their signature pedagogies will be taken over from the science educators and potentially lose their jobs or activities that they currently already teach (Microbial Fuel Cells, Water Rockets, Bridges, etc.). Borgerding, et al., (2013) conducted a research investigation to "investigate teachers' awareness, informational, personal, management, consequences, collaboration, and refocusing concerns about biotechnology teaching by employing a qualitative design that allowed for the emergence of teachers' ideas" (Borgerding, et al., 2013, p.133). In teaching biotechnology, it may be required that some phases in the lesson design would be best carried out in a science laboratory while others would benefit from being in a technology education lab/classroom (Borgerding, et al., 2013, p.140).

Elementary Teacher Implications

In regards to learning and teaching engineering to elementary, limited literature and resources are available to teachers and this poses a major concern. The lack of resources continues to be a major issue for elementary school teachers in finding engineering literature and resources they can use to teach engineering design with in their classrooms (Wendell, 2014, p.30). Teachers also restrict their search for information to only a few websites or textbooks and since the field of biotechnology is constantly advancing, much of the information becomes obsolete (Fonseca, et al., 2012, p.374). Fortunately, there are some biotechnology curriculum guides that offer lessons and activities that elementary teachers can use to integrate more biotechnology content within their daily lessons. One curriculum guide is the *Design Based Biotechnology Literacy Teaching Guide* (Wells, 2019) that was established to provide educators with a means to connect theory and practice within an integrative design-based approach, specifically in biotechnology. In addition, the implementation of the *Next Generation Science Standards* has required performance expectations for each grade level that provide students with the opportunity to focus on design as a means of integrating engineering within the lessons. Without extra time in the school day set aside for engineering, new elementary teachers will look for engineering experiences that align with the rest of their curriculum and can accomplish objectives in other content to areas. Teacher education programs need to provide models for connecting engineering not only to science, but also to reading and writing. In order to decrease the amount of information gathering, elementary teachers can use children's literature to integrate engineering design problems within their classroom activities (Wendell, 2014, p.45).

With more exposure to the science and engineering practices mentioned in the NGSS, elementary teachers may find cross-curricular connections that they can use to embrace the learning and teaching of engineering within their classrooms. The biggest challenge would be changing teacher attitudes towards teaching biotechnology and their willingness to learn and grow (Hilton, Nichols, & Kanasa, 2011, p.461). Classroom management in regards to materials and supervision can also become a limiting implication for teaching more design based biotechical lessons within the classroom. Some practical applications to elementary grades would be the use of team jobs where each member is responsible for a specific task such as being the research analyst, design manager, materials specialist and quality control agent (Dunham, et.al, 2002, p.75). The authors looked at the learning theory of technology education and examined behavioral, cognitive, and constructivist philosophies related to teaching biotechnology. Biotechnology education combines a behavioral, cognitive and constructivist approach and provides students with meaningful learning opportunities where they can collaborate and reflect on their possible solutions. Piaget (1966) stated, “The internal cognitive structure of the student is changed as a result of interacting with the environment and being exposed to an increasing number of experiences” (Durham, et al., 2002, p.71). With the growing field of biotechnology, one can be optimistic that this content will be better integrated within the primary and secondary grades as well as taught in teacher preparation programs. Biotechnology can greatly influence student learning and motivation to successfully become scientifically and technologically literate citizens. “Learning to teach engineering design will need to fit into other content and methods courses and therefore approaches that integrate engineering design with as many academic disciplines as possible will be attractive not only to pre-service teachers but also to teacher educators” (Wendell, 2014, p.30). In addition to the engineering design process, Wells (2016) introduced the P.I.R.P.O.S.A.L Model, which is also an iterative set of phases a student would go through to design and construct a product or solution (Wells, 2016).

Conclusions

As a result of literature, research, and observations it has been determined that DBBL approaches truly engage students in implementing design based biotechnology challenges that further their understanding of science concepts as well as improves technology education teachers’ biology content knowledge to better integrate the science with the T/E concepts. “Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it” (Bigler & Hanegan, 2011, p.248). This being said, education in the United States is moving towards a more integrative approach for learning through integrative STEM education and DBBL along with the *Next Generation Science Standards* and *Standards for Technological Literacy* will improve our citizens content knowledge, which in turn will create technologically literate citizens that can be fully integrated within this 21st Century world.

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