ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

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Paper ID #14714

Solution-based Learning (SBL): Using Systems Engineering Principles to Guide Capstone Projects in Technology

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Solution-based learning (SBL): Using systems engineering principles to guide capstone projects in technology

Abstract

In this paper, a new learning framework – solution-based learning (SBL) – is introduced. It offers a way of motivating students to continuously improve products or processes based on practical or aesthetic considerations. This learning framework keeps the focus on early and sustained success through all phases of a project. It leverages selected principles of Systems Engineering such as developing a discovery-oriented, multidisciplinary, life-cycle view of any given project. It also provides learners with the opportunity to deepen their critical/creative and process-oriented thinking skills. Developing a holistic and working understanding of the entire system, including the environment, the eventual users and the conditions of use, can result in more resilient designs, and more thoroughly tested solutions. Shifting the focus to developing early working solutions that are grounded in both learning theory and systems engineering allows students the opportunity to create a product that can be reviewed by both the designer and potential customer early, often, and potentially over its entire lifespan.

Introduction

In the global knowledge-based economy of the foreseeable future, members of the workforce will need to continually develop appropriate solutions for effectively managing increasingly complex systems and societal issues. This, in turn, will require professionals to update their technical, management, and thinking skills. There is thus a need for a framework that provides learners with an opportunity to develop a deeper understanding of their discipline, along with the ability to transfer this learning from academic settings to real-life situations. Project-based courses such as capstone experiences allow fertile ground for such learning to occur.

Capstone courses in technology typically aim to provide students with opportunities for designing and implementing solutions. Owing to their inherent multi-disciplinary nature, the projects developed in these courses are especially well suited to benefit from ideas rooted in Systems Engineering.

The International Council on Systems Engineering (INCOSE)[1] defines Systems Engineering as "an interdisciplinary approach and means to enable the realization of successful systems." The Systems Engineering Body of Knowledge (SEBoK), created by Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) project[2], notes that systems engineering includes the "full life cycle of successful systems, including problem formulation, solution development and operational sustainment and use." As noted in the SEBoK, a host of criteria such as continuous process improvement, considerations for tradeoffs, system integration, safety, recycling, etc., are needed while developing solutions for technical problems. In fact, Zhang and Probst[3] advocate the need for systems thinking across the curriculum for solving a variety of problems. These can help students realize that there is a "common thread cross-cutting" different fields of study.

Collective System design, proposed by Cochran and Kim[4] includes a process involving identification of customers and customer needs; determination of "system purpose" as part of the functional domain; and the "means to achieve purpose" in the physical domain. They emphasize the need to "separate the means" from the functional requirements and use a design matrix for identifying the relationships between the two domains, aiming at minimizing interactions. This can be very useful while developing solutions for complex systems with unclear objectives. As part of an engineering design process[5], a systematic methodology is needed for devising useful, safe, and efficient products or processes. Sugarman, Schneider, and Mykytka[6] provide ideas for deploying a systems engineering course using online technologies. The ideas regarding the functional/physical representations of systems, along with the use of online instructional tools, can be adapted for use in classes involving projects.

Additionally, project-based courses often require students to use critical- and creative thinking while solving problems. These skills are vital for success in the professional workforce. The US Bureau of Labor Statistics, which provides a comprehensive list of educational requirements for all occupations, ranks critical thinking among the top qualities by professionals in various disciplines. Hence, any training aimed at improving critical thinking and problem solving for students as part of their curriculum is also likely to improve opportunities for professional success in the future.

Providing students with opportunities for learning through immersion in projects while strengthening their thinking skills can be a challenge. As part of actively engaging students in the learning process, the "backward design process" pioneered by Wiggings & McTighe[7] may be used. It requires curriculum designers to first identify core competencies associated with the course and link evidence indicating its achievement. Course assessments and activities are designed for ensuring achievement of these competencies. In order to facilitate transfer of learning from the classroom to the workforce, Bransford, Brown, and Cocking[8] suggest that students initially be provided with opportunities for working on scaled-down versions of problems. These practical ideas can be used in the design of technology capstone projects.

The capstone project at Eastern Kentucky University is a synthesis experience, wherein students are required to select a topic for independent research and implementation. This one-semester course provides students with an opportunity to design, develop, test, troubleshoot, and manage an integrated research- and laboratory-based project in an area of their interest. Students deploy their projects in homes, work places, or community settings. The course includes a considerable amount of experiential learning, requiring students to reflect on their design and developmental efforts throughout the semester. Projects which enhance safety, accessibility, or "greener" alternatives to existing devices often serve as potential projects. Each student selects a project from a broad program area such as electricity and electronics, computer systems, or networking. Project topics which bridge multiple program areas or include mechanical components are recommended. These projects allow students the opportunity for showcasing their knowledge, skills, and professional work practices.

Learning in the capstone course is directed so that it is solution based. Students start off by identifying the specific technical problem they intend to solve. They list both the project constraints and the assumptions they are making about it. Simple "back-of-the-napkin" sketches for quickly explaining the working of the project in non-technical terms are required. These initial activities focus on the core functionality provided by the project. They also note possible future extensions once the core functionality has been met. A multi-phase project core is strongly encouraged for each project, as this allows for early building and testing of prototypes. This, in turn, can provide key information about the viability of the project itself. It allows student to make progress on their core project goals without being sidetracked by mutually competing design considerations not vital to the project's success.

With the project consisting of a strong multi-level core and extensible phases, the completion of each phase denotes both a solution for the current one, as well as a launching pad for the next phase. It can also serve as a safety net – a pre-established return point to a previous level in case one is needed. The solution of each phase thus seeds subsequent phases of the project. Students first complete the core functionality and then continue working on optional extensions.

The systems engineering process does not shy away from introducing the tradeoffs that are inevitable while designing, prototyping, and improving systems. These include improvements in safety, costs, security, efficiency, speed, size, quality, user experience, upgrade functionality, modularity, durability, redundancies, ease-of-maintenance, re-configurability, multi-use capabilities, recyclability, reduced variability, and considerations for legal and ethical issues. Students are encouraged to provide diagrams of any sub-systems used in the design and linkages or feedback between these. Visual representation of the project allows students to maintain a hierarchical big-picture view of the system, along with the close-up view of specific sub-systems. Maintaining both these viewpoints simultaneously is useful in testing and troubleshooting project prototypes.

The positive, learning-focused, online-research, and solution-based approach used while developing their capstone project helps students develop innovative, personally customized extensions to existing products. Samples from recently completed Bachelor of Science (BS) and Associate of Applied Science (AAS) capstone projects using this learning framework include a custom electric guitar, an arcade machine theft monitoring system using Internet Protocol (IP) GeoLocation, a 3D CNC and printer, and a Raspberry Pi based cloud server. Completed student project presentations, video demonstrations, and brochures are displayed through a capstone web page.

Learning Paradigms and Solution-based Learning (SBL)

The leading role of lecture-based instruction has been challenged by the emergence of several learning paradigms over the past few decades. Problem-based learning (PBL) as defined by Barrows [9], includes a well formulated problem as the focus for stimulating student centered learning in small groups, using facilitators instead of teachers. It leads to the development of skills related to problem solving, stimulation of the cognitive process, and new knowledge as part of this process. It may be viewed as a specialized type of open Inquiry-based or Enquiry-based learning (EBL)[10] wherein the often rocky road to new knowledge is explored by investigating open questions, issues, scenarios, or problems; using models of thinking; researching ideas; designing experiments; performing observations; analyzing results; computing; using evidence; and providing explanations and communicating results. It is related to project based learning (also PBL), as summarized by Helle, Tynjälä, and Olkinuora[11], and involves projects spanning a considerable amount of time. It requires finding the solution of a problem resulting in an end product. The learning activities are motivated by a problem at the root of the project.

Davis and Arend[12], while discussing the experiential aspects of learning, state that it "is not isolated from experience but grows out of experience," along with the idea that such, "Learning is not fragmented but holistic." (Flake[13]). They emphasize the need for students to have goals as part of any experiential learning, stating that "having goals helps focus attention and energy." They note that setting up "student responsibilities" while working with community partners can have a positive impact on the learning process (Sylwester[14]). When engaged in experiential learning, students are, in effect, engaged in the creation of knowledge, skills, and work attitudes through experience. Typically, this is quite different from that which is learned in a classroom or laboratory. Personal interest, the motivation to succeed on a self-defined set of technical goals, is quite different from that preselected for the student. This "reflection-in-action", as defined by Schön[15], develops out of one's experiences, a knowing in ones very actions while performing technical or professional work.

Egan[16] notes that the teacher needs to able to provide a safe setting for students to tell their experiential stories. This allows students to step back and view the experience more objectively. They can understand it better in terms of perceptions and feelings and can be helped to challenge ways of thinking or acting that may be counter-productive for completing the project. Empathetic communication between the student and faculty is important for uncovering areas that the student may be overlooking, even while realizing that some "reluctance and resistance" is normal. This, Egan states, will be helpful in more effectively identifying or managing situations and for creating opportunities for improvement.

Solution-based Learning (SBL)

In learning which is solution based, the focus is on successively enlarging the scope of solutions for a given system, situation, or scenario. It is an iterative process fundamentally explorative and expansive in its outlook. It seeks to build on the successes or solutions available or developed in each phase, continually improving various facets of a system including its operations, features, functionality, or form. It ties in with the interests and motivations of both the designer seeking to improve the system and of the existing or potentially new stakeholder. The overriding requirement in this type of learning is to develop solutions early and often, and to refine and expand existing solutions with each successive iteration.

The shift in focus from the problem to the solution is more than semantic. It is fundamental and substantive. It encourages a positive outlook and continuous improvement focus while developing a practical project that serves an increasingly useful purpose for an ever expanding group of stakeholders.

Solution-based learning promotes a mindset for viewing every situation as an area potentially ripe for improvement. It suggests that there is room for progress in most systems, products, or processes. It is a way of saying, the glass is half-full, rather than half-empty. As part of the process, students investigate what is working and how can it be improved, learning about various critical and creative thinking strategies [17-23] such as reverse plus-minus-interesting, state-elaborate-exemplify-illustrate, reverse brainstorming, rich pictures, and fishbone diagrams.

It should be noted that while a solution implies the existence of a problem, issue, or concern, the mere existence of a problem does not imply a solution is achievable or that it even exists. This type of learning provides students with a pro-active, solution-based mindset – one that is frequently needed in the workplace.

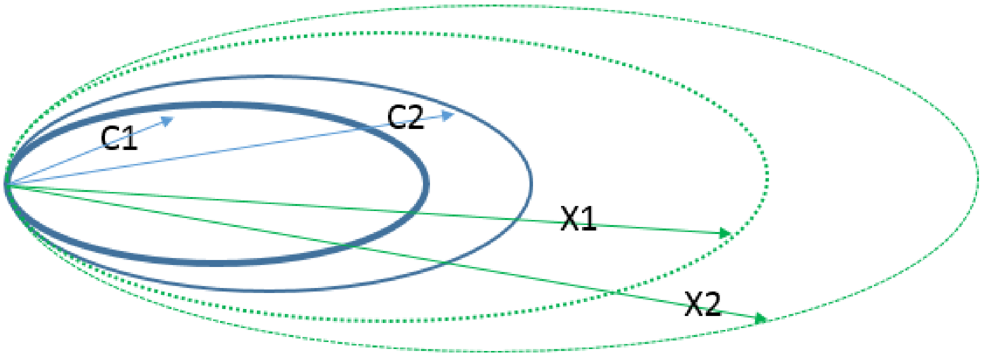
Characteristics of SBL

(1) Focus on early and sustained success as evidenced by working solutions through all phases of a project.

(2) Development of both a holistic view and a working understanding of the entire system, including the context in which it is set, its environment, various stakeholders, and the conditions signifying success.
(3) Application of critical/creative and process-oriented thinking skills, along with the domain-specific knowledge while developing solutions.
(4) Actions informed by research taking into consideration human factors.
(5) Development of an iterative solution-oriented mindset.

What SBL is.
Solution-based learning incorporates elements of problem- and project-based learning, enquiry-based and experiential learning. While it uses projects involving the creation of tangible products, the focus remains on the process of creating and improving solutions in all situations. It is multidisciplinary in nature and informed by advances in cognitive science. This solution-oriented mindset is intended to extend out of the classroom into the workforce where it can be used to develop effective solutions for tackling complex issues. The ownership, customization, and personalization of solutions is crucial for meeting the needs of stakeholders. This enlarging scope of solutions is not directly addressed by other types of learning paradigms.

While developing solutions, it is important to designate key or core functionality upfront. This serves as a way to clearly identify success at each phase of the project. The enlarging range of functionality provided by a project can then readily be tracked visually. Once the core functionality has been achieved, optional extensions may be included in the design and implementation. This is shown in Figure 1.



C: Core functionality provided by project (C1, C2, ...)
X: Extension functionality (X1, X2, ...)

Figure 1: Expanding scope of solutions provided by the learning framework

What SBL is not.
While solution-based learning is being developed at Eastern Kentucky University for use in technology-based projects, its scope is by no means limited to only technological systems. Indeed, it can be used in any realm of human activity. It seeks to involve participants in projects over an extended period of time for developing an expanding set of solutions to an issue of personal interest. SBL does not make judgements about the ultimate use of the solution, and in that sense is not limited to benign products or processes.

At the onset of the project, it is advisable to have clear understanding of what initially constitutes success, as would be evidenced by meeting a core set of features. Without this it would not be possible to conclude if a project has been successfully completed. Since solutions are the goal, the final product at the end of each successful iteration serves as the initial state for the next one.

Learning that is solution based is very sensitive to the context within which it is set. It is unlikely to result in a better understanding of the system unless it is used judiciously. The learning benefits involved in solving a specific predetermined problem will result in widely varying degrees of learning for different students. In order for a student to truly benefit through the solutions they discover and develop for themselves, the problem being solved must be customized based on their prior knowledge, skill, work experience, and personal motivation. For example, with regard to the core functionality for a given capstone project, this definition is likely to be quite different for a student who is just learning a new technology from one with prior experience or training in the area. Accordingly, for significant learning gains to be achieved for each student, care is needed while defining the scope of the project – the core and extension phases – on an individual basis. Solution-based learning also assumes sufficient content knowledge and skill level, along with authorization to make suitable changes leading to improvement.

Implementing Solution-based Learning in a Technology Capstone Course

A capstone course at Eastern Kentucky University is being used as a testbed for developing various solution-based learning strategies and tactics. This project and research oriented course as noted in the undergraduate catalog involves "design, implementation, analysis, and troubleshooting of networking, computers and electronics technology related systems, and managing a technical project."

Developing a sense of personal ownership regarding the individual capstone project has been an overarching goal for the capstone course, alongside other student outcomes. This allows students to develop professional traits, including feeling responsible for more than what they are being held accountable for as part of the capstone project. They are invited to continuously broaden and deepen the scope of the project after its core functionality has been met, making it a "labor of love," a project which has the potential to continue long after the course is completed. This allows students to regard the project as an advanced hobbyist activity, inviting them to be immersed for countless hours while trying to tinker, improve performance, and fix issues as these arise.

The process of selecting a capstone project that spans multiple areas such as electricity and electronics, computer systems, and networking can be a challenge. As a means to jump start the process, students are asked to identify improvements they may choose to make in existing commercially designed and developed products. Rather than reinvent the wheel as part of their capstone, students initially explore technological products and prior projects that are of personal interest. They work with projects they are interested in expanding on, customizing, or otherwise improving. The Internet abounds with the information needed for creating thrilling technological products. These can subsequently be adapted and personalized as part of the capstone. Students must gain competencies in identifying valid sources of information online, blending ideas from different sources, noting specific adaptations needed, accurately citing technical sources, and creating a well-researched product that serves a specific stakeholder's need. Building, in part, on the work of others, they form a growing community of learners, with the understanding that their work, when publicized on the Internet could serve as the starting point for a project elsewhere. Quoting William Hull, artist Lee J. Ames, states, “If we taught children to speak, they'd never learn.” He advises mimicry as a “prerequisite to creativity. It's wonderfully effective to imitate, copy, or trace what others have done in order to develop one's own tools,” and then continue the process by developing something original.

Since project budgets are often limited, researching low-cost solutions to existing commercially available system products on the market is often a priority. A critical part of the design is improving any existing designs and customizing it to meet present and future needs of a customer. Frequently the final customer is the student his/herself, or a family member, or a community partner. Once students see that any commercially available product can be improved, they are liberated from the assumption that the first design they choose to develop and implement needs to be perfect. Additionally, as part of the design process, students are required to identify the intended audience for the product, along with the most surprising, intriguing, or interesting thing about it. This allows students to simultaneously consider personal and outside perspectives while evaluating professionally designed products as may be available through websites such as Skymall (http://www.skymall.com/), Hammacher Schlemmer (http://www.hammacher.com), WhateverWork (http://www.whateverworks.com/) catalogs, or AsSeenOnTV (http://www.asseenontv.com/) infomercials.

Students create a top-level block diagram or illustration showing the functionality their prototype will provide. This functional diagram hides the specific implementation details. The initial sketches, meant to easily convey the key ideas to a lay person, have proved to be very helpful to the students themselves. A sample initial block diagram for a complete electric guitar build completed as part of capstone project is shown in Figure 2, along with a quick response (QR) code linking to the project online.

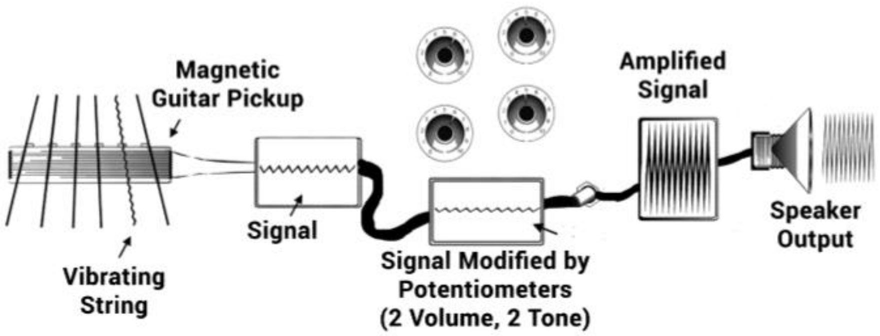


Figure 2: Sketch of functionality provided by Charles Judd’s capstone project titled *Ocean Water: A custom electric guitar build*

As part of the design process, students also consider why the project is important to the final user and potentially to other users as well. This often allows for an expanded set of constraints and assumptions to emerge early in the design phase. A tentative project schedule, including key milestones and sub-tasks within each, is developed. Overlaps between different segments of the project are identified for potential bottlenecks. Students delineate how the design is tested for compliance with its specifications. The free open-source project planning software Tom’s Planner[24] is frequently used for developing a project schedule. Early prototyping of the project is encouraged since success in developing prototypes that meet the core criteria can serve as a strong motivator through all phases of the project.

A multi-phase prototype development and testing model is strongly recommended for making steady progress towards the project. Rather than attempt to design and develop a fully-featured system, students are advised to sequence its development appropriately, so that success at each stage provides momentum and valuable information for improving the next phase of the prototype. Initially they focus on developing the core functionality associated with the project and in subsequent phases include improvements related to safety, efficiency, size, usability, environmental factors. They review test run results, focus on improving the solutions which are already working, and research fixes for technical issues. In subsequent prototyping stages they tweak performance and add functionality that further improves operation. Students document the process of improving designs in this iterative manner. A minimum 2-phase prototype for achieving core functionality of the project is required. The focus on early and sustained success associated with the project is aimed at allowing students to visualize and implement design changes as part of prototyping process.

Once individual project topics are identified and preliminary research on projects completed students form mid-term groups. Each group creates an integrated presentation including a short instructional demonstration video related to the general theme of the group. The same guidelines are used for evaluating the group mid-term and the final individual capstone presentation with integrated video. It is meant to familiarize students with the key deliverables for their individual project.

Development of the group how-to video follows the general principles of Digital Storytelling[25] which includes, "point of view, a dramatic question, emotional content, the gift of your voice, the power of soundtrack, economy, and pacing." As part of the video development process student groups are required to address the following five prompts:

- What is the specific purpose of the video?
- Why is it important to the publishers of the video and should be for the audience?
- Preparation (parts, tools, time, costs, safety, disclaimers, etc.) work needed?
- How to complete the series of tasks involved?
- Wrap-up summarizing what was done, noting key points, safety features, and credits.

Instructor and peer feedback of the mid-term presentation is provided to student groups. Each student is required to note at least one thing which stood out about their fellow student's presentation and video, as well as at least one way in which it could be enhanced further. This allows students to build on their successes as well as on areas that require improvement. A visual rubric, shown in Figure 3, adapted from Chandra and Steinbach[26], is used for evaluating the group mid-term and individual final presentation with integrated video. This, along with detailed in-class feedback, allows students to improve their presentation skills further.

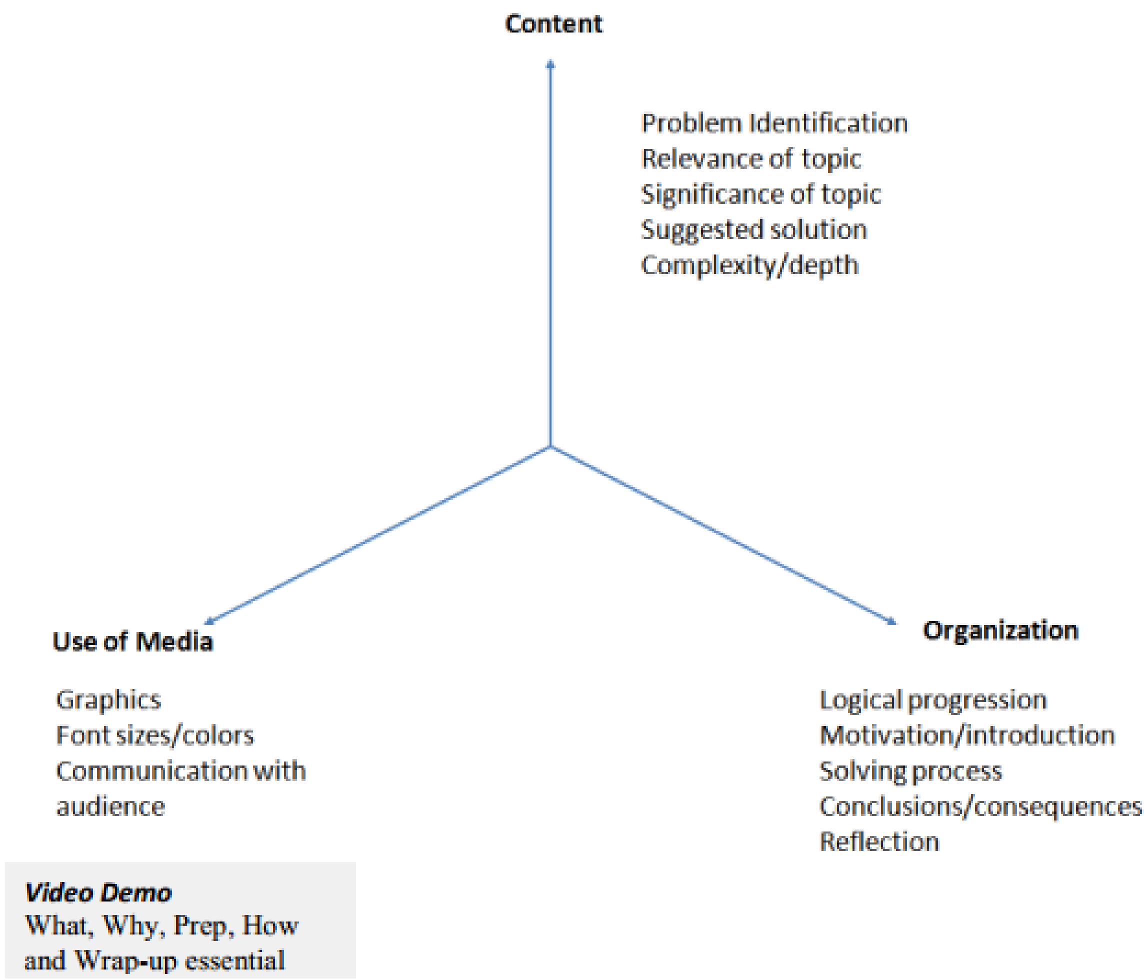


Figure 3: Visual rubric used to evaluate student mid-term and final project

Being based primarily in the electronics/computer systems domain, students in the capstone course are familiar with various troubleshooting methods. The Computing Technology Industry Association (CompTIA), which develops vendor-neutral professional certifications linked with various Information Technology (IT) areas, recommends a seven-step process[27] for tackling computer/network related issues. Here, it has been adapted for the capstone process as follows, with different project phases added in parenthesis, linking it with the Engineering is Elementary (EiE)[28] design process:

(1) Problem identification and information gathering: What, who, where, when, why, constrains, assumptions (“Ask” phase)
(2) Formulate a theory to establish probable cause(s) of the problem (“Imagine” phase)
(3) Identify suitable ways of testing the theory, and if not confirmed generate a new one (“Imagine” phase)
(4) Develop a plan of action, along with identifying potential consequences (“Plan” phase)
(5) Implement the plan (“Implement” or Prototype phase)
(6) Verify that the solution is working, with no unintended adverse consequences, and update as needed (“Improve” phase which may link back to the Ask, Imagine, or Plan phases)
(7) Document solution to inform/train users [suggest adding a “Tell” phase for sharing results following self- or group-reflection]

Additionally, the methodology for analyzing thinking proposed by Paul and Elder[29] is used at the foundational level of the capstone course, specifically with regard to the students' final product report and presentation guidelines. These eight "Elements of Thought" are: question at issue (problem), assumptions, purpose, point of view, concepts, implications, information, interpretations or inferences. Drawing on these for strengthening the students' critical thinking skills the key elements of the capstone report and presentation include (elements of thought included in parenthesis):

(1) Problem statement with assumptions and constraints clearly identified (Question at Issue, and Assumptions).
(2) Elaborating on the reason this problem is of importance to oneself and the larger community, along with noting prior scholarly work that has been performed in this area (Purpose, and Point of View).
(3) Design portion which includes the functional and physical domain representations. It also includes the parts, tools, equipment, budget, and process plans including testing procedures (Concepts, and Implications).
(4) Implementation and testing: A multi-phase prototyping process is to be used, highlighting progress at each stage, and documenting how technical issues were resolved. In the initial phase, focus attention on achieving the core functionality and, later, map it to the physical components. As part of the design process, also note specific ideas for improvement (such as speed, size, security, usability, aesthetics, safety, energy usage, environmental impact) which could be used in the latter phases of project. Annotated photos and results from each phase of the prototyping process are needed. Testing is integral to the process and information about the procedures used to determine whether it conforms to the specifications. Provide a flow chart showing the sequence of steps needed (Information).
(5) Conclusions regarding the status of the project, including comparisons with similar commercially available systems. Possible extensions of the project for making it commercially viable (Interpretation and Inference).

Students are also required to cite sources in a designated format. An Appendices section is recommended including a How-To document that steps a novice user through the functioning project. Emphasis on continuous improvement is further emphasized with the submission of a draft project and presentation. Feedback from faculty is used to update the documents.

In order to familiarize students with various critical/creative thinking strategies, a free, online training resource, qepCafe[17], customized for electronic/computer technology, is being used. It includes various intellectual development theories and examples of practice which can be adapted for use in various settings. It encourages engaging with content at both a broader and a deeper level for solving problems effectively and for creating a supportive environment where this kind of learning can occur.

Students are encouraged to keep improving on existing solutions, adding "good to have" features, along with the essential core functionality. Part of the initial planning process requires planning for future growth and new functionality as time and other resources permit. It builds on the "Model for Improvement"[30-31] suggested as part of the Plan-Do-Study-Act cycle by closely questioning what one is trying to accomplish, raising questions about the changes that can be made which will result in improvement, and identifying whether a change is really an improvement.

These ideas are readily adapted in the solution-based learning framework, allowing students to design and build prototypes for testing theories early in the semester. Students learn by “failing forward” as part of the early prototyping process, learning from what did not go as planned and from the solutions that did work as intended. Solution-based learning benefits from the feedback mechanism used in closed-loop systems for regulating output. The interdependence of various sub-systems requires carefully phased experimentation for improving integration and overall performance. Tinkering – a limited amount of unstructured inquisitiveness – is encouraged, alongside a structured method of designing safe and effective systems.

The technology capstone course itself incorporates a continuous cycle of improvement based on the needs of various stakeholders. These stakeholders include curriculum committee and industrial advisory committees, potential employers of program graduates, accreditation organizations, and the students themselves. Over the past few years various updates have been added to the capstone course including the requirement for an integrated project video; development of a capstone website with Quick Response (QR) two-dimensional barcode associated with each student project, links to project titles, abstracts, and resumes; weekly online logs about the progress being made; migration to an online project portfolio; and a project brochure or flyer. The project flyer or brochure summarizes and advertises the work accomplished by the capstone project. Figures 4-6 provide samples of completed student capstone projects. Release of work using Creative Commons[32] licensing is encouraged.

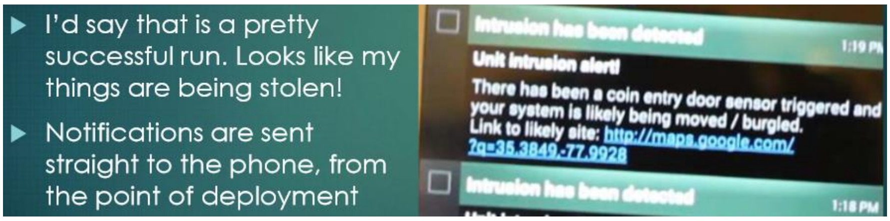


Figure 4: Presentation screenshot of capstone project completed by Anthony Warner titled *CabSec Integrated Security*

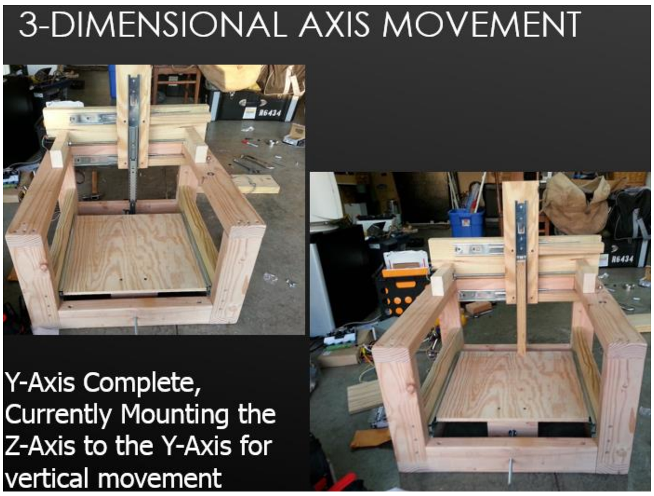


Figure 5: Presentation screenshot of capstone project completed by Bryan Roark titled *3D C&P [CNC and Printer] Machine Mk. 1*

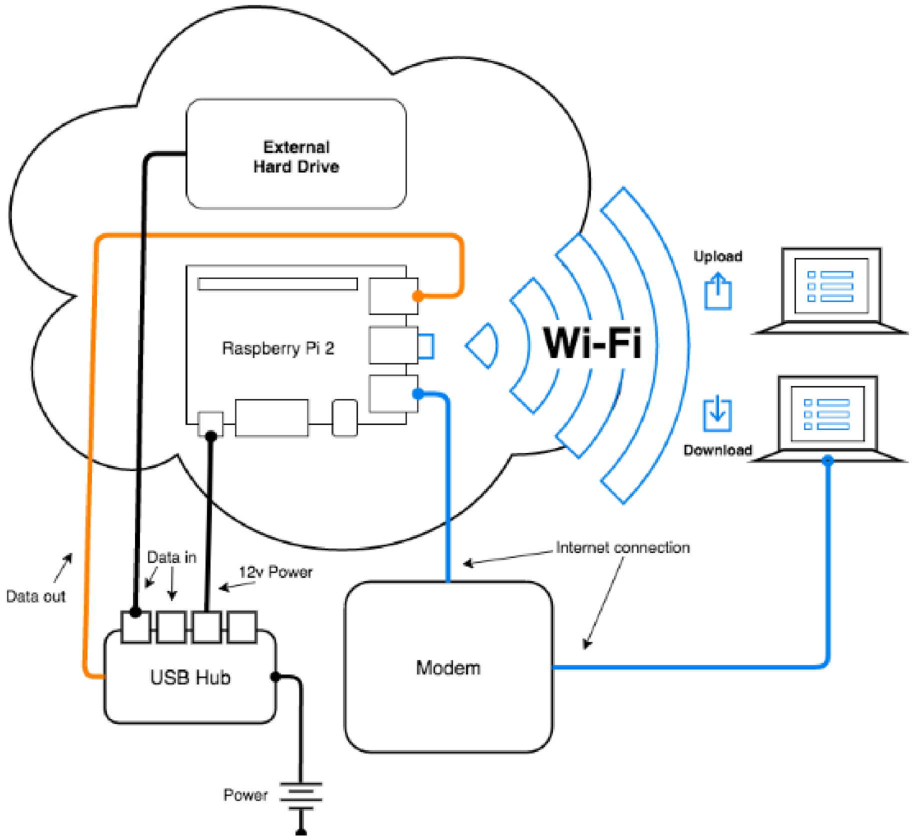


Figure 6: Section of capstone project brochure developed by capstone student Tyler Persley
Pi Cloud: Raspberry Pi Cloud Storage

In order to gauge the level of motivation about the project, pre-capstone, mid-semester, and post-capstone surveys are currently being trialed. Students are also invited to include a personal learning/reflection statement regarding how their thinking about tackling large technical projects has changed over the course of the semester. They may discuss any misconceptions or assumptions held prior to starting the capstone, along with effective strategies that are working well. These strategies could serve them well while transitioning to the technical workforce.

Conclusions and Future Work

Solution-based learning (SBL), introduced in this paper, is proposed as a means of keeping the focus on developing and refining solutions for a given system, situation, or scenario. The interdisciplinary nature of modern systems necessitates basing these solutions on existing research in the discipline, using critical/creative thinking effectively, and on active experimentation using prototypes. Learning that is solution based and informed by the principles of systems engineering provides students with a proactive mindset for continuously improving various facets of any complex system.

Ongoing development of the capstone course aims to help strengthen students' thinking- and hands-on skills, as well as professional work practices. Online tools such as electronic portfolios, videos, and brochures are assigned to provide students with additional opportunities for showcasing their competencies in solving technical workplace issues. The successes in using this learning framework within the capstone course suggests that it may be beneficial in other project-oriented classes as well. By successively enlarging and deepening the scope of projects within a course or across the entire curriculum, students can be provided with multiple opportunities for revising their designs over an extended period of time. Learning to reflect and build on prior project experiences can provide students with a blueprint for future success.

Acknowledgements

The author would like to acknowledge valuable discussions regarding ongoing course development for "closing the assessment loop" with Network Security & Electronics (NET) program curriculum committee faculty members at Eastern Kentucky University, Jeff Kilgore, Ray Richardson, and David Freet; and with advisory committee members Andy Hall, Charley Hamilton, James Hoskins, Joey Zwahlen, Byron Sims, Stephen Crump, Wes Chitwood, Lenin Vera, and Brandon Verhoeven. The 2015 BS/AAS capstone projects of Charles Judd, Anthony Warner, Bryan Roark, and Tyler Persley are featured in this paper.

Financial support for the ASEE conference is made possible thanks to departmental funds through the Applied Engineering & Technology (AE&T) chairperson, Dr. Tim Ross; travel funds support for scholarly work through the College of Business & Technology (CB&T) Associate Dean, Dr. Ed Davis; and the President's Research and Scholarship Fund (PSRF) Travel Grant, through the Dean of the Graduate School, Dr. Jerry Pogatshnik.

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