Student-created Canvases as a Way to Inform Decision-making in a Capstone Design Sequence

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Introduction

Canvases are becoming more prominent in a variety of curricular and extracurricular educational settings (Blank, 2013; Kline et al., 2014; Hixson et al., 2015). This prominence manifests in multiple forms including: the increasing use of certain canvases (e.g., the Business Model Canvas (Osterwalder & Pigneur, 2010)) in university settings and, as a quick internet search will reveal, the increasing number of unique canvases that are being developed to address specific needs/contexts. At their most fundamental level, a canvas is a one-page visual framework modeling the critical elements of a real-world system. The elements chosen are those that the canvas’ creator(s) have deemed essential in order to design, add value or make changes to a system out in the world. Visually, a canvas is often divided into segments, with each segment corresponding to one of the elements that should be considered. Based on this structure and our experience using canvases in educational settings, a canvas can

- Focus a learner, change agent, or innovator on the most important levers within a system
- Support the collection and synthesis of information
- Reveal where critical information is missing
- Provide individuals with a framework for making decisions
- Offer a holistic view of both a system and a solution/opportunity.

In a prior study, we analyzed a subset of these canvases and proposed a systems approach to better understand how canvases work in the classroom (Kline, 2014; Tranquillo, 2016). From this analysis, we discovered that canvases are often created by experts capable of determining the nuances of a particular real-world system. The canvas can then serve as way to guide a learner or designer through information gathering, information synthesis and decision-making processes that enhances their likelihood of adding value to the system (Osterwalder, 2004; Tranquillo, 2016). As such, using a canvas encourages students to adopt a dynamic and iterative design process, which more closely resembles the behaviors of real-world designers (Nigel, 2004; Crismond & Adams, 2012).

With these affordances in mind, we propose that utilizing a canvas supports students as they tune their design processes to the relevant design activities. Therefore, this paper explores the development and use of student-created canvases in a capstone design course. It is important to note that we are not proposing a new type of design process or framework but rather how canvases can be used as a tool to navigate existing design processes. We offer example assignments and classroom activities that demonstrate how instructors can guide students in creating their own canvases. We provide examples of student-created canvases, along with student and faculty perspectives regarding the use of canvases in design courses. Lastly, we highlight the use of canvases as a means to assist students in transitioning from beginner to expert designers.
Overview of Supporting Literature

Teaching an Adaptive Design Process

Most engineering students are exposed to design as a rigid and linear process early in their curricula, often through a first-year engineering course (Dym et al., 2005). Design is typically presented as a step-by-step process because teaching it this way is more straightforward for students (Ulrich & Eppinger, 2011). The depth and breadth of the design activities and examples utilized in early academic settings are carefully chosen, which further reduces confusion and offers a higher probability of producing a desired outcome (e.g., fundamental exposure to engineering design or a solution to a specific problem). For introductory engineering activities, this rigid process can be effective; however, as students progress through their education and encounter more real-world or complex design projects, that same rigid process can fail to effectively support students’ design needs.

Nigel (2004) and Crismond & Adams (2012) have compared the design processes of expert and novice designers. These studies found that novices conform to a rigid process and may overlook collecting important information, whereas experts reinvent the process as necessary to suit the problem at hand. An expert designer has experience with a range of possible design actions. Their design process emerges over time as they determine which actions should be performed next to gain the critical information needed to make the next decision. In effect, expert designers are adaptively navigating a network of possible design actions and creating a process that will be slightly different each time. When an expert designer is addressing very similar problem-solution pairs, they may notice patterns in the sequence of design actions taken. As a result, pathways through the design network become reinforced and over time take the form of a design framework. Over 100 frameworks are cataloged by Dubberly (2008), ranging from spirals and helices to a 229-step design process. Importantly, expert designers use frameworks as a guide and not as rigid step-by-step processes.

This discrepancy between notice and expert designers means that design instructors should begin transitioning their students away from rigid, linear processes and introduce the idea that design is actually a series of design actions that evolve over time to suit the problem. Further straining this instructional issue is the fact that most senior engineering students are neither novice nor expert designers, but exist somewhere on the spectrum between those poles. Crismond and Adams (2012) propose that these intermediate designers be called ‘informed designers’ and the usual means of transitioning students to become informed designers is to impose upon students more complex design frameworks. We propose that this pedagogical approach may in fact impede their progress toward design expertise, and instead, agree with Szykman et al. (2005) suggesting that design pedagogy should move toward a more adaptive process that is grounded in collecting, synthesizing and acting on relevant information. This adaptive and information-oriented process should support students as they make design action decisions similar to expert designers. We believe these adaptive design actions can be enhanced by using canvases and will present a pedagogical strategy below to support students as they transition from novice to expert designers.
Pedagogical Innovation: Student-Created Canvases to Enhance Design Actions

As described previously, design can be thought of as a process that iteratively gathers, synthesizes and acts on relevant information needed to move the design process forward. These decisions cannot (and should not) be made too far in advance; therefore, both the design and the process unfold together over time. Early in the design process, design actions are often aimed at collecting information regarding the fundamental problem or opportunity. Middle-process design actions are aimed at developing actionable information via brainstorming solution concepts and analyzing the results of feasibility tests. Toward the end of the traditional design process, additional information is collected and synthesized, often serving to validate design actions (e.g., user feedback on prototypes). In this sense, developing prototypes, conducting literature searches, performing design reviews, budgeting, sourcing parts, validating tests, gathering customer feedback and other activities are all design actions that aim to gather, organize and process information that will inform future decisions. Using this logic, the many design frameworks outlined by Dubberly (2008) can be thought of as variations in the order and regularity of information-based actions.

The dilemma in teaching design is then how to choose a design framework that supports students’ ability to gather, synthesize and act on the information needed to make adaptive design decisions. One of the key insights from our previous systems analysis was that a canvas might serve as an ideal framework to meet this need (Kline 2014; Neck and Greene, 2011; Schindel, 2011). Based on our prior use and study of canvases, we propose that the visual, holistic and systems perspectives offered by canvases intentionally support the identification and communication of information needed to determine the next design action. For example, a canvas approach can be used during any aspect of design and can take the form of the creation or completion of a single comprehensive canvas or a series of more-specific canvases. This will be detailed further in the next section.

Furthermore, we believe that asking students to create canvases that meet their real-time information and design action needs represents an innovative and effective use of canvases in the classroom. A student-created canvas is a methodology for helping students identify the critical elements or information that they will need to consider for their next major design action. We propose having students create their own canvases for multiple reasons. First, while a wide range of canvases already exist, there are still gaps in the context of the design (Tranquillo, 2016). For example, the design process in many academic settings generally begins by helping students understand the problem or opportunity. There are currently no canvases that focus specifically on the dimensions of a good problem; one that, if addressed, will simultaneously create value and serve as an educational opportunity. As an instructor, a possible solution would be to ask students to create a canvas that visually and holistically captures the information related to a good problem/opportunity definition. In this case, students could identify the 8-10 dimensions of the information needed to understand and communicate a problem/opportunity. Second, the creation of the canvas provides many opportunities for learning and instruction. For example, while creating their canvases, students have the opportunity to ask detailed questions related to both the current design action (e.g., problem definition) as well as questions related to their specific design project (e.g., doctors’ need for new surgical instruments). Using canvases in this
way also offers opportunities for peer learning, enhanced student-instructor interaction and just-in-time teaching. Lastly, we previously stated that canvases are often created by experts to model a real-world system and that capstone students operate somewhere between novice and expert. The process of creating the canvases as students, while not necessarily resulting in “expert” canvases, can help students as they take the next steps in their transition from novice to expert designers. Student-created canvases can be implemented in many ways, and we will provide some example cases illustrating how we’ve used student-created canvases in the design classroom.

Actions in Capstone Design
Throughout the capstone experience, various canvases can be created by students, ranging from determining the metrics for a high-quality design to synthesizing stakeholder feedback. As such canvases can be utilized to teach any number of learning objectives in a design course. In this section, we highlight a few examples demonstrating how student-created canvases have been used. The examples provided here are not meant to be prescriptive or build upon one another, and are highly context dependent; therefore, we are not advocating that these specific canvases or approaches be used. Instead, the examples are meant to help faculty recognize how student-created canvases can drive both the design process and student learning forward.

Design Action 1: Developing a capstone design metrics canvas
The instructor begins the semester by giving a prompt such as, “What makes a good capstone design project?” After a brainstorming session, students list out and then rank the top features. They are then asked to turn their ranked features into a one-page graphical canvas, with a graphical element corresponding to each feature. This activity can occur over a short period of time (0.5-1 course sessions) and then be iterated upon using multiple forms of feedback to make the canvas better. Examples of two student-created canvases utilizing this process are shown in Figures 1 and 2 (captions provide additional detail).

Figure 1: Several students used sticky notes to brainstorm ideas for their design metrics canvas. This approach enabled them to cut, add, modify and recombine based on group discussions and instructor feedback until they had approximately nine distinct elements. Once fully refined, the elements were organized and assembled into a more formal canvas layout.
**Design Action 2: A problem selection canvas**

The first two months of the senior capstone design course in the Biomedical Engineering Department at Bucknell University focuses on problem identification. Student teams are challenged to make multiple clinical observations and develop a list of 100 real clinical needs. In this context, a canvas was used to help students sort and select a need-based problem for their design project. Students were asked to identify the elements that would result in a good senior design project and each team was challenged to create a canvas with at least 9 boxes. Once completed, groups were asked to draw their canvases on whiteboards for all to see (e.g., Figures 3). The course then had students discuss the common elements in all (or most) canvases as well as any uncommon elements that stood out. Teams were then given time to refine their canvases for later use (e.g., Figures 4). The course coordinator did not collect the final canvases but did instruct the group advisors (other faculty in the department) to review their respective canvases. Some advisors helped their teams further revise their canvases.

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**Figure 2:** Students created a metrics canvas prototype and then used design solutions that had been previously-determined “good” and “bad” to test whether their canvas elements fully captured the essential metrics to evaluate capstone design projects.

**Figure 3:** A student-created canvas demonstrating what students believe is essential when selecting a design problem.
In a follow up class session, teams were asked to use their canvases to perform an initial sort of the problems. As there were 100 (or more) problems to sort, the first pass was meant to disqualify problems based upon one (or more) of the elements. For example, many canvases had a box indicating that clinical access to equipment was critical to the problem. Such an approach might disqualify a project on functional Magnetic Resonance Imaging (fMRI) because students would not have regular access to an fMRI device. Teams were encouraged to record the reason for the disqualification and share that with their advisor. In a second round of sorting and refinement, students were asked to fill in minimal information and current impressions about the problem for the remaining problems. This helped the students further reduce the number of problems to 8-10, on which they then gathered additional information in order to continue the narrowing process. Students were required to fill in their canvas for each of the 8-10 problems, completing as much of the canvas as possible. They were asked to place a “?” in boxes where more information was needed, as shown in Figure 4. These “?” entries allowed teams to clearly see and communicate where information was missing. A completed problem selection canvas for each problem led students to a formal problem statement.

Extending this example in another class, students were asked to use the information documented in their problem selection canvases to write a first draft of a problem statement. This was accomplished by combining the information within their canvases with a MadLib template for problem statements (Tranquillo, 2016). Such an approach quickly encouraged the generation of 8-10 problem statements that could be compared and shared with the team advisor.

**Design Action 3: A solution concept (idea) brainstorming canvas**

Once a problem has been defined, the generation of solution concepts (or ideas) is often the next design action. This design action is typically completed through 6 hats, 6-3-5, C-sketch or other brainstorming techniques. A student-generated canvas can be used to develop the generated ideas further. Inspired by the work of Tina Seelig (Seelig, 2014), this canvas prompted students to take an existing concept and alter it in some way. Examples of canvases entries were:
• a $2 solution for the developing world
• a solution to be used by children
• as expensive or high-tech a solution as possible
• a Rube Goldberg version of the solution
• an emergency version of the solution
• a solution that could work outside of a clinic (Point of Care solution)
• a solution driven by a policy or procedural change

When placed on a canvas, students can then take each initial idea and imagine what it would become if passed through each box of their canvas. This exercise utilized canvases to multiply the overall number of possible solution concepts and generate diverse ideas.

*Design Action 4: A functions canvas*

Another way to generate solution concepts is to identify critical functions that a solution will likely exhibit. Often these are phrased as a verb-noun pair, such as “support weight” or “move fluid”. Design textbooks suggest a very top-down process, whereby students develop verb-noun phrases by looking at their problem statement. As informed designers, most senior-level students can quickly think of specific solutions and then work to abstract those function. This type of bottom-up process is in fact a characteristic of a more seasoned designer, to move back and forth between solution concept and solution, out of which several solutions emerge. In our experience, the most difficult aspect of this process is to develop abstract functions and then develop alternative ways to achieving them.

To this end, students can create canvases to aid their ability to abstract functions. All functions are achieved by exploiting some law of nature. In this example, students participated in an in-class exercise to determine the means of exploiting various laws of nature. The instructor gave a first hint and then let the students generate the remainder of the list. The results were:

• Electrical
• Mechanical
• Fluid
• Optical
• Pneumatic
• Chemical

Of course, the list is not complete. Within each item above there may be multiple means of achieving a function. For example, within electrical storing power may be achieved by multiple means (e.g. capacitors, batteries). These general ways of achieving a function can then be put in the form of a canvas. The function is placed in the center of the canvas and the surrounding boxes are the means of achieving this function. Operationally, students must then take each function of a solution and generate alternative ways of achieving that function. From these canvases, students can begin to recombine various ways of achieving the desired functions transforming their solution concept into a final design.
Moving Engineering Design Students from Beginner to Informed

Having demonstrated how student-created canvases can be used in the classroom, the next step was to assess their use. The canvases themselves were not assessed or graded because the pedagogical goal was not to have a right or wrong canvas. We were more interested in how the process of making a canvas might impact students’ design learning and design solutions. A preliminary assessment of the use of student-created canvases as a pedagogical tool took multiple forms. At the conclusion of the first semester of two capstone courses, a student survey was administered (n=16 for Fall 2015 and n=16 for Fall 2016). The survey contained the following questions relevant to this assessment: “How has the use of a canvas help move forward your design decisions?” As there were no significant differences in the demographics of the cohorts, the classroom execution of the course or canvas assignments, or the execution of the survey, all responses have been combined together.

In addition to the survey, at four times during each semester, a full class period was used to produce open-ended responses to a reflection prompt (n=16 for Fall 2015 and n=16 for Fall 2016, a total of 126 reflections). Reflections prompts were not focused on the canvas (e.g. “Explain a struggle you have had during the design process to this point and describe the various ways you overcame that struggle. What might you abstract that you can use in other design experiences?”). Lastly, a faculty assessment focus group met on May 21, 2015 and considered two prompts: 1) “I like…” and 2) “I wish…” regarding the course as a whole.

As mentioned previously and important to our assessment, Crismond and Adams (2012) propose that students learning design be considered ‘informed designers’ – existing on the spectrum between novice and expert. They describe informed designers using seven performance dimensions (summarized below from (2012, pp.744-745)).

- **Learning While Designing** - designers engage in continuous learning throughout the design process.
- **Making and Explaining Knowledge-Driven Decisions** - a combination of physical laws, how things work, and a variety of methods come together to make and explain decisions.
- **Working Creatively to Generate Design Insights and Solutions** - designers gain insights though confronting uncertainties.
- **Perceiving and Taking Perspective Intelligently** - priorities are established that help the designer focus on what is relevant.
- **Conducting Sustained Technological Investigations** - designers collect, organize and analyze evidence throughout the design process.
- **Using Design Strategies Effectively** - designers work flexibly in groups to accommodate constraints such as time, budget, skill set and past experience.
- **Integrating and Reflecting on Knowledge and Skills** - designers continually reflect on how design actions, knowledge and skill are intertwined.

In our assessments, students and faculty described student-created canvases as a tool to positively impact six of the seven performance dimensions (all except “Integrating and
Reflecting on Knowledge and Skills”). We will now provide evidence from the assessment data for these six dimensions.

**Learning While Designing - designers engage in continuous learning throughout the design process.**

Students described using canvases as a mechanism to keep learning throughout their design course. For example, the following student assessment data demonstrates how students used the canvas to learn about “wrong turn[s]” and getting “back on track”.

“We took a wrong turn, which we probably should have seen coming. But the info in some of our other canvases helped us get back on track. It was a lot easier to catch back up.”

Another student learned that the canvas concept could be applied to other contexts and “tough decisions”, such as deciding which job to accept.

“In this, although it won’t be similar to potential value charts, the layout could be similar but just include different boxes that would be important to consider when choosing which companies to apply to or which job to accept. This is only one example, but frameworks can be useful in multiple areas of my life when ultimately I might have to make a tough decision and need to narrow down my ideas.”

From the faculty perspective, some questioned whether undergraduate students are ready for the ambiguity inherent in a traditional linear design process, let alone the nonlinear process suggested by canvases. After using student-generated canvases, faculty mentioned that students more readily accept ambiguity when it is acknowledged as a part of a learning process over which they have a measure of control. Canvases did not reduce any of the ambiguity in the design process or the outcome, but provide a measure of acknowledgment and control over what was known and not known. Additionally, faculty members expressed that student-created canvases do not need to be perfect. When they are created, they can be a way for students and faculty to agree on what is most important going forward. After additional learning and testing, canvases can be revisited, in some cases refining existing boxes and in others adding/removing boxes.

**Making and Explaining Knowledge-Driven Decisions - a combination of physical laws, how things work, and a variety of methods come together to make and explain decisions.**

Students described various ways that student-created canvases supported their decision making. For example, the following piece of feedback discusses standardization, ranking, documentation, and credibility.

“Using a framework … standardizes decision making across each problem. Without a framework, it would be difficult to compare different problems accurately and make a final decision. By ranking problems objectively, it also gives you a way to document and
record your work that way you can come back to it later and see why you made certain decisions. It gives you some credibility to have a system in place.”

Another data point describes that the framework students created through their canvas supported their ability to make decisions in non-linear, “no correct answer” situations that include a large amount of information and many variables.

“I think a good amount of decision-making is very non-linear whether the people making those decisions know that or not. Complex decisions have so much information and variables to take into consideration that there really are no correct answers. Therefore, having a framework that allows for backup is beneficial for that team or person.

From the faculty perspective, faculty members discussed that student-created canvases increased the amount of responsibility students had in their decisions. When students make their own canvases, they gain more autonomy and responsibility for their decisions. If students generate a poor canvas, leading to poor decisions, some students would take greater responsibility and put less blame on the faculty member.

**Working Creatively to Generate Design Insights and Solutions** - designers gain insights though confronting uncertainties.

The following student feedback demonstrates that the canvas approach was effective in supporting students’ ability to generate insights.

“It showed a lot in the canvas stage when we truly had three problems that all of us were okay with tackling and could not think of a way to decide.

In this example, students weren’t struggling to overcome the uncertainty of whether or not there was a possible problem to address. Likewise they were not generating a solution. Rather, they were using a canvas to clarify the nature of the problem and gain team insights into which problems may be promising to pursue further.

**Perceiving and Taking Perspective Intelligently** - priorities are established that help the designer focus on what is relevant.

Students’ assessment data discussed how canvases support students’ ability to think using different perspectives. In the following example, one student links using the canvas to assessing a problem from different lenses and thinking in ways she/he normally would not have though. This student also provides interesting insights on how frameworks can influence bias.

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“Using a canvas directed me to assess the problem from different lenses; this brings to light information that normally would not have crossed my mind. In addition, a framework can allow for either an unbiased decision or a knowingly biased decision. By this I mean that a decision matrix, while in reality should provide an unbiased decision,
based on weighting, I always know which topic I want to “win,” so I am knowingly biased.”

From the faculty perspective, faculty members stated that those groups who have used canvases have a more complete picture of their project. This of course does not mean that the students necessarily executed well (in their writing or prototyping), but students who took canvases more seriously tended to be able to better connect their problem to their solution.

**Conducting Sustained Technological Investigations** - designers collect, organize and analyze evidence throughout the design process.

While less direct statements were made by students and faculty in this dimension, student did acknowledge that canvases supported developing “common measures” for comparisons and identifying/organizing “missing information”. Both of these elements support a designers’ ability to conduct sustained technology investigations.

**Using Design Strategies Effectively** - designers work flexibly in groups to accommodate constraints such as time, budget, skill set and past experience.

Students described the canvas approach as a tool that supported their ability to work in groups, make team decisions and communicate. This is evidenced in the following examples.

“Most often, these kinds of frameworks [canvases] can be very effective in group dynamics when a team decision needs to be made in a cooperative and inclusive manner.”

“And it [their canvas] helps communicate why a decision was made.”

While faculty also discussed a canvas as an effective communication tool, they discussed the positive impact canvases had on students’ task tracking and their ability to manage the class. This is demonstrated through the following faculty assessment focus group notes.

Some student groups used a canvas rather than a Gantt Chart to assign and track tasks. A Gantt chart is helpful when a job is very large, and everyone is working on several projects at once. But it has a good deal of overhead to create and keep updates. The use of “?” on a canvas can perhaps better serve them as it calls attention to task that need to be done. When a task is complete the “?” is replaced with the information gained.

The assignment to create a particular canvas can become a checkpoint that helped normalize the class (e.g. the assignment to design a feasibility canvas strongly implied that teams should be ready to begin designing and conducting feasibility studies). This is similar to some models such as the stage-gate where there are critical milestones that must be reached at particular points in time, but the pathway to reach a milestone may be different depending on the problem, solution, and team.
Based upon this preliminary assessment, there is reasonable evidence that student-created canvases positively support the development of student designers. That said, more work is required to robustly justify the claim that canvases are effective tools for helping students transition from novice to expert designers.

**Discussion**
In this paper we have discussed the limitations of rigid design frameworks, a new approach to design using student-created canvases and this approach’s promise in supporting students as they transition from novice to expert designers. Overall, we believe student-created canvases provide an instructor with many ways to support students as informed designers without being overly prescriptive. The guidance provided by an instructor can be about the elements on, the organization of or the decisions resulting from a canvas, as opposed to making decisions for the students. At the same time, a canvas intentionally exposes students to a more iterative and dynamic design framework which resembles that of expert designers. Additionally, students creating canvases can be encouraged to seek out the advice of others – including other students, faculty, staff, industry leaders, or clinical mentors. This not only enhances students’ ability to communicate, but also consider unique and diverse perspectives.

Implementing canvases in the classroom can also take many forms and the process of creating a canvas is therefore itself part of discovery. The instructor can lead the entire class in creating a canvas together or perform a type of think-pair-share, where groups create a canvas and share it with the class. Such an exercise was conducted while developing feasibility and validation studies as well as outlining a large design report. In this instance, after seeing other canvases, students refined their own canvases. First drafts of a canvas may be vetted by experts to ensure that all relevant variables have been included. Lastly, the instructor can always review a student-created canvases and make suggestions for revisions.

From an instructor perspective, there are challenges. Convincing students to start developing a canvas can be challenging. However, once they have created one canvas we have found that students can create future canvases much more quickly. The most common stumbling block is students often try to create the ‘perfect’ canvas, not realizing that a canvas can easily be revised. Likewise, once a canvas is created it can be difficult for some students to begin filling in the elements and making decisions on when a “?” should be added. Our experience has taught us that creating the first few canvases in class as a group is helpful as we are able to demonstrate the iterative nature utilized when creating and populating a canvas.

Overall, the use of canvases suggests a more fluid way of collecting, synthesizing and acting on information as well as a potentially effective way to teach students the details of critical design actions. Unlike the traditional decision matrix, where numerical scores are generated, the canvas approach offers a more holistic evaluation, which can be followed up by discussion. Too often, the numerical output of a decision matrix implies a final decision, whereas a canvas approach suggests directions that appear promising but require additional communication and negotiation. Lastly, canvases are an excellent way for students to document and summarize their progress. A one-page filled in canvas can be submitted as evidence of the process followed and is also useful at design reviews and mentor or client meetings as a way to focus discussions.
Conclusion
Many capstone design instructors argue that the most enduring take-away from an upper-level design course is the process, not the product. But when much of the course is focused on the product, or even the documentation, students leave with a very narrow view of how to make design decisions. Student-created canvases are a way to keep students focused on design as an iterative and dynamic means to engage with processes and information. Pedagogically, student-created canvases mirror how seasoned designers allow the design process to emerge as information is collected and the product takes shape. Our assessment evidence has demonstrated that using canvases, at least in our context, positively impacts all but one of Crismond and Adams’ informed designer performance dimensions. What students truly learn by using student-created canvases is not merely a process, but a versatile design tool that can be used to enhance and tune a larger design process. Importantly, student-created canvases empower students to generate their own tasks by identifying, collecting, synthesizing and acting on information that will move their designs forward.

References


