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Examining African American and Caucasian Interaction Patterns Within Computer-Mediated Communication Environments

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Abstract

This study explored the extent to which student emotion management factors and normative orientation (belief that chat rooms have normative standards of conduct similar to face-to-face interaction) circumscribe the sending of hostile messages within electronic relay chat rooms on the Internet. A questionnaire survey collected data from 114 undergraduate and graduate students from a large university in southeastern Michigan. The results of the survey revealed statistically significant differences between African American and Caucasian chat room users in terms of how the emotion management factors of shame, guilt, and embarrassment affect communication. The normative orientation of the chat room users was shown to have an inverse relationship regarding the flaming messages between both ethnic groups. This article describes how these factors are influenced by gender and ethnicity/gender. Findings regarding the perceptions of racism within electronic chat rooms are also discussed.

Introduction

The utilization of information technology, such as the Internet and its ancillaries,- including the World Wide Web, is increasingly becoming an icon symbolizing economic and social well being, technological literacy, and employability in the information age. Its implications for social and political transformation and liberation have been clearly identified in the media and academia. Due to the cue less structure of the Internet, many have predicted that it would be a mechanism to ameliorate the social inequalities commonly associated with race, gender, physical handicaps, and social class (Connolly, Jessup, & Valacich, 1990; Sproull & Kiesler, 1986, Wasserman & Richmond-Abbott, 2005).

With the exception of studies that cite the statistical disparity between African Americans and Caucasians in Internet utilization (Nielsen Media Research, 1997; Novak, Hoffman, & Venkatesh, 1997) few researchers have systematically examined the ways in which ethnicity influences behavioral differences found in cyberspace. Given the saliency that has been recently attached to Internet accessibility among the Black population (Clinton, 1997), there seems to be a parallel need for research that explores social psychological dynamics occurring within the inchoate and amorphous structure of computer-mediated communication environments. This type of research is expected to provide a broader perspective of Internet behavior than the previous descriptive studies of Internet utilization.

Purpose of Article

In this article, the authors discuss findings pertaining to the ways in which Blacks and Whites differ in perceptions and communication behaviors as they participate in Relay Chat Rooms (RCR). A RCR includes a group of people and mass communication technology in which users send and receive text-based messages. The time delay of these computer-mediated messages can be nearly instantaneous or a “real- time” text interchange (Walther, et al., 1994; December, 1996). In comparison to studies that merely describe Internet utilization, this study’s goal is to explain the variances found among Blacks and Whites for these variables, utilizing social psychological frameworks as a conceptual guideline. The researchers will primarily examine communication differences between Blacks and Whites with focused attention given to the sending of “flaming” messages in relay chat rooms.

Flaming is a term that refers to the sending of hostile messages (Lee, 2005; Orton-Johnson, 2007). The absence of informational cues pertaining to one’s identity within the chat room environment has prompted many authors to allege that the Internet fosters a social context in which conventional normative standards that typically circumscribe behavior found in face-to-face interactions has been relaxed (Kiesler, Siegel & McGuire, 1984). It has been further alleged that the suppression of normative standards of conduct will create a social condition where individuals feel free to engage in antisocial communications such as flaming, sending hostile messages, and expressing anger.

Very little research has been done on the influence that social psychological factors have on flaming behavior and the moderating influence that ethnicity and gender may have on this relationship within the "cues-filtered-out" (Culnan & Markus, 1987) context of electronic chat rooms. More specifically, given that flaming and other hostile-type behaviors do indeed occur in computer-mediated communications (CMC), s we explore the following general research questions:

1. To what extent do differences in communication behaviors (such as sending hostile messages and expressing anger) exist between Blacks and White RCR users, and what are the differences by gender within and between each of these groups?

2. In what ways do social psychological factors (such as emotions) affect CMC communications and to what extent is this relationship moderated by ethnicity and gender?

Theoretical Framework of Paper

The principal conceptual scheme of this paper is symbolic interaction (SI). Symbolic interaction is a social psychological approach (within sociology) to studying the ways in which humans create and use symbols in formulating social organization (Blumer, 1969; Goffman, 1959; Mead, 1934). Central to this framework are the following concepts:

1. Interaction – "Symbolic interactionism concentrates on the interactive processes by which humans form social relationships" (Turner, 1998, p. 364). Most important, interaction is delineated as the focal point for analyzing the nature of social organization.

2. Taking the Role of the Other – is an interaction process by which the individual's perception of self is obtained through interpreting the expectations of others in a given social situation. The self, then, is defined as a social self, which could consist of a specific other or a *generalized other*, which consists of a broader community of attitudes such as one's culture. Successful interpretation among "actors" in a given situation is what enables communication to take place. An emergent "pattern" of such communication is what imparts a semblance of "structure" to the interaction. Thus, the focal point of analyses here is *role* behavior (Stryker, 1987).

3. Definition of the Situation – pertains to the covert cognitive process of determining the nature of a particular social situation in terms of its role expectations and normative standards. By mentally defining the situation, the individuals are able to present themselves in "socially acceptable" ways (Goffman, 1959). The cognitive landscape of the situation is influenced by the symbols contained in both the situation itself and the culturally derived mental pictures that the person has internalized.

4. Mind – is a concept that represents the internalization of the structure and processes of the factors described previously. Within this context, mind is the epistemological expression of form and process. However, the mind as described here is not a static construct as referred to in various psychoanalytical frameworks. Rather it is an entity that is dynamically homeostatic with emergent social processes. As such, the study of individual identity takes the form of analyzing the ways in which the self simultaneously maintains and creates itself in varying situational contexts.

This conceptual framework was selected for this article because its core tenets appear to be a heuristic guideline for analyzing ethnic and gender behavioral differences on the Internet whose peculiar cultural differences are expected to reflect differences in role-taking and situation-defining processes. Frameworks similar to the interactionist approach that are used to examine behavioral processes within the CMC context consist of sociocognitive theory Walther et al., 1982; (Kern & Warschauer, 2000; LaRose, 2001) and sociocultural theory (Block, 2003; Brignall & Van Valey, 2005). Furthermore, the theory's propositions concerning the dynamic interrelation between structure and mind allude to the idea that these processes may have a different epistemology within cyberspace as compared to face-to-face communication platforms.

Relay chat rooms on the Internet represent a very distinct type of situation to analyze communications because of the absence of symbols that characterize traditional face-to-face communication. Subsequently, some authors have predicted that communication in cyberspace would reduce differences in cultural (i.e., ethnicity and gender) communication styles (Connolly, Jessup, & Valacich, 1990). However, symbolic interaction theorists would argue that people do not leave their culture at home when faced with new situations, such as CMC. Rather, they define novel situations according to culturally learned definitions of the situation (Blumer, 1969; Shott, 1979). SI proponents would propose that individuals have covert conversations with "self" as they define the CMC interaction episodes. If this is the case, differences in communication patterns are expected both between African Americans and Caucasians and according to gender, because each group has its own unique cultural orientation that creates differences in how its members define situations.

Examining whether African Americans and Caucasians differ on such things as flaming behavior will indicate whether or not CMC is reducing cultural differences in interaction behavior. Using the symbolic interaction conceptual framework, these researchers will seek to explore if African Americans and Caucasians define the CMC environment in different ways and to determine if any such differences lead to different tendencies in interactive behavior. It is a well-documented idea that African Americans and Caucasians differ in cultural orientations. These differences are conceptualized within this article to refer to differences in the ways each group may define the cyberspace situation.

The Sociology of Emotion

The sociology of emotion (Heise, 1977; Hochschild, 1979; Kemper, 1991; Ridgeway, 1982; Hochschild, 1992; Shott, 1979; Stryker, 1987; Turner, 1994) is a symbolic interaction approach which postulates that emotions influence the interaction process. Emotions are attested to as sociologically relevant phenomena because particular types of emotions as expressed toward others are moderated by situational and normative constraints. More important, emotions are considered as factors that circumscribe various types of behaviors within the context of particular social situations. Emotions will be framed in this article as *emotion management* factors. This framework is particularly relevant to the present study given the attention to the management of emotions within the context of emotional intelligence (Salovey & Mayer, 1990).

In order to operationalize the concept of emotion management, the emotive theory of Shott (1979), which delineates specific emotion types, will be drawn upon. Taking the role of the other is the focal point in Shott's emotion management schema. "Much role-taking is reflexive in that the individual has an internal conversation with self as an object, seen and evaluated from the perspective of specific and generalized others. In this evaluation process, emotions are aroused and labeled; and if these emotions are negative, they mobilize the individual to adjust behavior" (Turner, 1994. p20). Shott (1979) delineates six emotion management factors: guilt, shame, embarrassment, empathy, vanity, and pride. Of these, the first three appear to be relevant to the present discussion, and brief definitions follow:

1. Guilt – Guilt is a feeling that emerges when a person acknowledges that her/his behavior is incongruent with the normative and moral standards within a specific social situation.

2. Shame – Relates to an individual's judgment of self relative to situational expectations (Ausubel, 1955). Shame occurs when after taking the role of the other, the person learns that the other's perception of the behavior is not congruent to her/his idealized image of self.

3. Embarrassment – Is a feeling that exists "when an individual's presentation of a situational identity is seen by the person and others as inept" (Turner, 1998).

Each of these variables, which are referred to as emotion management factors, will be tested in terms of the degree to which they influence flaming behaviors among African American and Caucasian relay chat room users and among males and females. A negative correlation between these factors and the interaction variables would indicate that they do indeed circumscribe antisocial behavior within chat rooms. This is the expected relationship between these variables.

Methodology

Participants

Data for this study was collected from 114 undergraduate and graduate students in a relatively large university in southeast Michigan. The undergraduate students were enrolled in a technology and society-type class, which satisfies a basic studies requirement at the university. Subsequently, the sample population represents a wide spectrum of undergraduate degree programs and career orientations within the university. This improves upon the generalizability of the sample (for the university population).

A full sample was taken among students who identified themselves as chat room users (for both undergraduate and graduate students). The graduate students were enrolled in an interdisciplinary technology program. Each student completed a 104-item questionnaire (during class time) that measured a variety of Internet and chat room utilization factors. (There were two Asian respondents and one Hispanic respondent in this survey. They are not included in the present analyses).

Shott's emotion management factors.

Guilt - "I feel guilty if I say something to offend someone in a chat room."

Shame - "I feel a sense of shame when someone in a chat room points out to me that my messages are inappropriate."

Embarrassment - "There have been times that I have felt embarrassed in a chat room because of how I presented myself."

Moderator factors.

A moderator variable is a categorical factor that is examined to determine the influence that it has on the *relationship* between the independent and criterion factors. In this article, we attempt to determine if the correlations between the emotion management factors, cybernorm, and the communication variables are altered within categories of user's ethnicity, gender, and ethnicity/gender.

Chart 1. The following chart presents an overview of the demographic characteristics of the sample:

Demographic Structure of Study

Ethnicity		Gender		Ethnicity/Gender				College Level				
B	W	M	F	BM	BF	WM	WF	F	S	J	S	Gr
36	73	64	45	18	18	46	27	37	35	20	14	3

Instruments criterion factors.

The dependent variables within this paper pertain to the sending of antisocial messages in chat rooms (interaction). Each variable and its measurement are as follows:

Flaming. "I send flaming (hostile) messages."

The tendency for sending hostile messages while in chat rooms as compared to face-to-face communications: "I am more likely to send hostile messages in chat rooms than in face-to-face communications" (This variable will be referred to as "Hostility" within the statistical analyses).

Perception of displaying anger in chat rooms. "It is more appropriate to display anger in chat rooms than in face-to-face communication" (Will be referred to as "Anger").

Independent Variables:

Cybernorm. "I believe that there is an unwritten code of conduct that people must follow in chat rooms."

Ethnicity – African American and Caucasian sample populations.

Gender/ethnicity – African American male, female and Caucasian male, female categories (ethnicity and gender ethnicity are also used as independent factors).

Statistical Procedures

The statistical procedures for analyzing the data are mean comparisons and Pearson correlation. The Statistical Package for the Social Sciences (SPSS) was the statistical software used for this analysis.

Results

Mean Comparisons of Interaction Variables by Ethnicity and Gender/Ethnicity

Table 1 illustrates mean differences in the communication variables found between ethnic and gender groups, and ethnicity/gender. Very little difference was revealed between African

Americans and Caucasians according to their propensity for sending hostile messages in chat rooms. The most significant differences appear among gender and ethnicity/gender categories. To begin with, males are more prone to send flaming messages than are females ($p = .006$). This finding holds true within each category of ethnicity for the Caucasian male/female comparison ($p = .07$) and the African American male/female comparison ($p = .01$). There is also a slightly higher difference between the African American male/female comparison (.95) than the Caucasian male/female comparison (.63). African American males show the highest mean on flaming among all of the groups.

Very little difference is shown among each of the groups for the hostility variable. However, once again, the data indicates a larger mean difference between African American males and females (.32) than between Caucasian males and females (.06), and African American males show the highest mean on this variable. Neither difference, however, revealed statistical significance ($p = .88$ and .46, respectively).

For the anger variable, very little difference is shown according to ethnicity or gender, but there are larger differences shown by ethnicity/gender. Also, the direction of the differences was different for each ethnicity/gender category. Among Caucasian RCR users, females have a higher mean value than do males. The opposite is true for the African American users, where males have a higher mean value on anger than do females. Further, the African American male/female difference is significant at the .05 level, whereas the Caucasian male/female does not reveal significance ($p = .26$).

Differences on whether or not RCR users believe that there are norms of conduct operative in chat rooms are shown within and between each of the groups. None of these differences, however, were found to be statistically significant.

The next tasks were to determine the extent to which the variances in chat room behavior can be explained by the social psychological factors of cybernorms and emotion management factors and then to ascertain the moderator effect of ethnicity on these relationships.

Table 1. Mean Comparisons of Interaction Variables by Ethnicity, Gender, and Ethnicity/Gender

N = 110								
	Ethnicity		*Gender*		*Ethnicity/Gender*			
Interaction Variables	n = 73 *Caucasian*	n = 37 *Afr.-Am.*	n = 67 *Males*	n = 46 *Females*	n = 46 *Caucasian Males*	n = 27 *Caucasian Females*	n = 18 *Afr.-Am. Males*	n = 18 *Afr.-Am. Females*
Flaming	2.21 S = 1.49	2.35 S = 1.23	2.56 S = 1.45	1.83 S = 1.27	2.44 S = 1.56	1.81 S = 1.30	2.89 S = .96	1.94 S = 1.27
Hostility	3.15 S = 1.56	3.34 S = 1.29	3.34 S=1.44	3.27 S = 1.54	3.13 S = 1.51	3.19 S = 1.66	3.61 S = 1.14	3.19 S = 1.36
Anger	2.90 S = 1.41	2.78 S = 1.17	2.81 S = 1.31	2.83 S = 1.37	2.76 S = 1.39	3.15 S = 1.43	3.17 S = .99	2.47 S = 1.20
Cybernorm	3.00 S = 1.48	2.89 S = 1.23	3.07 S = 1.43	2.76 S = 1.51	3.07 S = 1.42	2.89 S = 1.60	3.00 S = 1.37	2.65 S = 1.42

Correlation Analyses for Cybernorms and Interaction Variables

Table 2 presents the correlations between cybernorm and the interaction variables by ethnicity and ethnicity/gender. For the entire sample, cybernorm is significantly correlated with only the flaming variable, and the negative sign indicates that it operates as a constraining factor to sending flaming messages in chat rooms.

The same finding is found within each of the ethnicity and gender categories. Cybernorm is more strongly correlated with sending flaming messages for males than females, and for Caucasian males in particular. Stronger correlations are shown for Caucasians, both male and female, than for African Americans on the flaming variable.

Relatively weak correlations are found between cybernorm and the hostility variable among all of the categories. The only strong correlation (in the expected negative direction) between cybernorm and anger is revealed among African American females.

Based upon the moderately strong inverse relationships between cybernorm and flaming, the viewpoint that one's definition of the situation affects behavior is confirmed, and it is confirmed in the expected direction.

Analyzing the Impact of Emotion Management on RCR Behavior

In attempting to present oneself in an appropriate manner during face-to-face encounters, a person's concern for not feeling guilty, not being ashamed, or not being embarrassed are seen as factors that would circumvent the sending of antisocial behaviors, such as flaming. This has been the commonplace proposition relative to face-to-face communication situations (Goffman, 1974). Our concern here is to test whether this proposition holds true for electronic communication platforms.

The weak correlations shown in Table 3 between the emotion management factors and interaction variables for the population as a whole, does not support this proposition in relation to relay chat room environments. However, in examining the moderator influence of ethnicity upon these relationships, a different and interesting finding is revealed. As shown in Table 4, there are moderate correlations between two of the emotion management factors (guilt and shame) and the flaming variable for Caucasian RCR users, and although the correlation between flaming and embarrassment is small, it is nevertheless in the anticipated

Table 2. Correlations between Cybernorm and Interaction Variables for Entire Sample, and by Ethnicity, Gender, and Ethnicity/Gender

Cybernorm									
		Ethnicity		*Gender*		*Ethnicity/Gender*			
Interaction Variables	*N = 109* *Entire Sample*	*n = 73* *Caucasian*	*n = 36* *Afr.-Am.*	*n = 67* *Males*	*n = 45* *Females*	*n = 4 6* *Caucasian Males*	*n =27* *Caucasian Females*	*n = 18* *Afr.-Am. Males*	*n = 18* *Afr.-Am. Females*
Flaming	-.325**	-.331	-.204	.-395**	-.301*	-.378*	-.305	-.223	-.287
Hostility	-.092	-.090	-.164	-.020	-.153	-.035	-.165	-.153	-.138
Anger	.042	.120	-.127	.170	-.085	.234	-.026	-.085	-.307

*p < .05
**p < .01

Table 3. Zero Order Correlations between The Interaction and Emotion Management Variables

N = 108			
	Interaction Variables		
Emotion Management	*Flaming*	*Hostility*	*Anger*
Guilt	-.199*	.215*	.197*
Shame	.025	.050	.201*
Embarrassment	-.002	.045	.179

*p < .05

Table 4. Zero-order Correlations between Emotion Management and Interaction Variables within Ethnicity Categories

N = 109						
	Interaction Variables					
	Flaming		*Hostility*		*Anger*	
	Gender					
Emotion Management	*n* = 36 *Afr.-Am.*	n = 73 *Caucasian*	n = 36 *Afr.-Am.*	n=73 *Caucasian*	n = 36 *Afr.-Am.*	n =7 3 *Caucasian*
Guilt	.319	-.363**	.409*	-.081	.066	.232*
Shame	.455**	-.166	.226	.062	-.085	.262*
Embar.	.373*	-.098	-.198	.154	-.069	.268*

*p < .05
**p < .01

Table 5. Correlations between Interaction and Emotion Management Variables by Caucasian Male and Female Categories

N = 73						
	Interaction Variables					
	Flaming		Hostility		Anger	
	Ethnicity/Gender (Caucasian)					
Emotion Management	N = 46 *Male*	n = 27 *Female*	n = 46 *Male*	n = 27 *Female*	n = 46 *Male*	n = 27 *Female*
Guilt	-.267	-.464*	-.039	-.153	.173	. 269
Shame	-.115	-.228	.148	-.075	.323*	.136
Embar.	-.071	-.134	.221	.073	.264	.271

*p < .05
**p < .01

inverse direction. This indicates that these factors do indeed operate as emotion management factors within computer-mediated communication environments, but only among the Caucasian users for this sample. Table 5 shows that this pattern is maintained among both Caucasian males and females, although stronger correlations are revealed among Caucasian females.

Comparatively, each of the correlations for the same variables among African American (Table 6) users is positive, indicating that the emotion factors operate as interactive, rather than as suppressive factors. Furthermore, these are moderately strong correlations when compared to those found within the Caucasian population sample.

Table 6. Correlations between Interaction and Emotion Management Variables by African American Male and Female Categories

N = 36						
	Interaction Variables					
	Flaming		Hostility		Anger	
	Ethnicity/Gender (African American)					
Emotion Management	N = 18 *Male*	n = 18 *Female*	n = 18 *Male*	n = 18 *Female*	n = 18 *Male*	n = 1 8 *Female*
Guilt	.180	.472	-.255	.723**	.021	-.043
Shame	-.027	.700	.023	.379	-079	-.166
Embar.	.189	.510	-.482*	.092	-.143	-.183

*p < .05
**p < .01

This is a very surprising, yet interesting finding. These extreme statistical differences implicate that African Americans and Caucasians are defining the CMC situation in different ways. A possible explanation of this finding as it relates to symbolic interaction theory is that each group engages in different role taking and cognitive rehearsal processes, which are affected by the unique cultural experiences of the two groups.

More specifically, African Americans, who have historically experienced more prejudice in social encounters than Caucasians, (with other Caucasians) may be putting more emphasis on chat rooms as a "liberator" of traditional social inequities Kiecolt, 1997). Electronic communications suppress identity traits, such as race, enabling a person to fully participate in the communication act, not as an African American person per se, but as the individual or role that the user *perceives* is the represented group. Subsequently, when African American users are taking the role of the other within this electronic context, they may be taking the role of the Caucasian participants from an *assumed* Caucasian role, as compared to an African American role as would be more likely the case in an face-to-face (FTF) situation. The question to be raised in this instance would be the following: How does an African American person performing a Caucasian role define both the chat room situation and the expectations of the assumed Caucasian role from the perspective of other Caucasian roles?

Given that the acting out of this assumed role does not contain the complete genome of the Caucasian culture, there is a real likelihood that some perceptions would be erroneous, thereby causing behavior that is not isomorphic to that group's actual chat room expectations. In short, African American users, in comparison to Caucasian participants, may be defining the chat room situation as an appropriate place for expressing hostile feelings, such as flaming. For example, "it is something that Caucasian people do, I am in a Caucasian environment, and therefore, I should behave (role acting) accordingly." Furthermore, they also may conceptualize the Caucasian role as one that has this expectation, where in essence this may not be the case. This idea appears to be supported by the higher mean scores on the cybernorm variable among Caucasians in comparison to that of African Americans, which was reported previously in this article. The lower correlations between cybernorm and the interaction variables among African Americans in comparison to Caucasians described previously also give support to this proposition. The positive direction of the correlations is maintained for both African American males and females. However, these positive correlations are much stronger for African

American females than for African American males. This finding indicates that cultural dynamics are occurring that are peculiar to the African American female culture.

Our attempt to explain this dubious finding from a symbolic interactionist perspective is merely theoretical conjecture. We intend to conduct further research on this particular CMC phenomenon.

Discussion

Several important social psychological conclusions can be drawn from this study. The first is that the extent to which hostile type communications is displayed in a virtual communication environment is affected by the user's normative orientation. The perception that norms exist in relay chat rooms was shown to be a constraining factor for sending hostile-type communications in RCR among each of the categories of ethnicity and gender. This finding negates recent claims that characterize electronic communications as relatively normless. The results of this investigation suggest that individuals take with them culturally learned symbols of conduct to situations, including emerging social systems, such as those found on the Internet that have not yet reached organizational homeostasis. From a historical perspective, electronic communications such as relay chat rooms, because of their faceless architecture, are expected to make revolutionary changes in social organization at the societal level. Although this may indeed be true, this study clearly indicates that such changes will not be completely divorced of traditional mental categories of social order. These conventional categories of images and thought will serve as a mental map for traversing the landscape of the new cyberculture. This means that symbolic categories of conventional racism and sexism will also be copied and pasted within the so-called new social structure along with normative standards of conduct.

Second, although cybernorms were shown to influence CMC behavior, the degree of its affect varies according to ethnic and gender groupings, which reflect differences in cultural orientation within these groups. Such variance supports the notion that the relatively one-dimensional analyses of CMC dynamics that is currently commonplace should be replaced by more systematic research strategies that attempt to explore how a larger number of factors covaries in relation to explaining CMC behavioral dynamics. Moreover, in the future researchers should continue to examine the within-group variance among African Americans, according to gender and other factors (Schuman et al., 1997; Carter, DeSole, Sicalides, Glass, & Tyler, 1997).

Along the same lines, the interesting finding that emotion management factors circumscribe the sending of hostile RCR messages among Caucasian users and not those of African Americans raises some intriguing issues about identity formulation (or reformulation) and computer-mediated communications. It is important to consider the epistemological implications of CMC interaction processes. The mind, as conceptualized within the symbolic interaction framework, is the energic outcome of the recursive interfacing of form and process (social structure). That is to say, a person becomes what he/she does (interactions). These interactions, when developed as a pattern, become the structure or condition that gives direction to the individual. Most important, from the perspective of identity development, the person internalizes this structure, and this internalized perception of social reality becomes the basis of that person's mind or consciousness. The format of virtual communication enables users to more freely define their symbolic context, and this will subsequently allow people to present themselves in various ways (; Tanis & Postmes, 2007; Tynes, 2007).

We believe that the drastic differences between African Americans and Caucasians on the emotion management factors allude to the idea that chat rooms are serving different epistemological purposes for the two groups. This idea is supported by a study by Weiser (2001) that revealed that processes such as flaming are driven by social psychological factors pertaining to the needs that the Internet serves for the users.

From a practical standpoint, it may mean that such recent psychological phenomena, such as Internet addiction should be approached by psychological practitioners with the" personal epistemology" of the client in mind. Although the design of this research project does not delineate the particular aspects of such an epistemological model, the profound differences that African Americans and Caucasians revealed for the emotion management factors in this study suggest that ethnicity would be a valuable starting point or a component for its development. As the diversity within the data among ethnic and gender categories points out, authors must be careful not to reify CMC technology with deterministic powers as espoused in the constructivist perspective inherent within previous studies and theoretical postulations. Rather, the mind is a very dynamic construct, wherein there is the potential for a lexicon of variants in consciousness within the boundaries of culturally derived symbols that can be created by the individual. The individual here is not seen as a receptacle of social and cultural ideas, however, her or she is understood as an entity who has the ability to define and redefine her/his situational context (Savicki et al., 1998). CMC, particularly as it pertains to African Americans, makes this process a more viable possibility.

Finally, the results of this study should be considered a preliminary investigation into the differences between African American and Caucasian CMC utilization. Future studies along these lines should be conducted with a different and wider sampling population (i.e., non-collegiate population) to determine the generalizability of the patterns shown among college students in this present study. Studies that strategically address the findings that relate to identity development among African American users should be conducted to create a more comprehensive understanding of this dynamic as it occurs within the context of electronic communication.

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References

Ausubel, D. P. (1955). Relationships between shame and guilt in the socializing process. *Psychological Review, 62*(5), 378-390.

Block, D. (2003). *The social turn in second language acquisition.* Washington, DC: Georgetown University Press.

Blumer, H. (1969). *Symbolic interactionism.* Englewood Cliffs, NJ: Prentice-Hall.

Brignall, T. W., III, & Van Valey, T. (2005, May-June). The impact of internet communications on social interaction. *Sociological Spectrum*, 25(3) 335-348.

Carter, R. T., DeSole, L., Sicalides, E. I., Glass, K., & Tyler, F. B. (1997). African American racial identity and psychosocial competence: A preliminary study. *Journal of Afro-American Psychology, 23*(1), 58-73.

Clinton, W. J. (1997, February 4). [State of the Union Address]. Speech presented to a Joint Session of Congress, House of Representatives, Washington, DC. Retrieved from: http://www.whithouse.gov/WH/SOU97/

Connolly, T., Jessup, L. M., & Valacich, J. S. (1990). Effects of anonymity and evaluative tone on idea generation in computer-mediated groups. *Management Science, 36*, 689-703.

Culnan, A. & Markus, M. L. (1987). Toward a critical mass theory of interactive media: Universal access, interdependence and diffusion. Communication Research, 14(5), 322-344.

Culnan, M. J., & Markus, M. L. (1987). Information technologies. In F. Jablin et al. (Eds.), *Handbook of organizational communication: An interdisciplinary perspective* (pp. 420-443). Newberry Park, CA: Sage Publications.

December, J. (1996). Internet communication. *Journal of Communication, 46*, 14-33.

Dubrovsky, V. J., Kiesler, S., & Sethna, B. N. (1991). The equalization phenomenon: Status effects in computer-mediated and face-to-face decision-making groups. *Human-Computer Interaction, 6*, 119-146.

Goffman, E. (1959). *The presentation of self in everyday life.* Garden City, N.Y: Doubleday Anchor.

Goffman, E. (1974). *Frame analysis.* New York: Harper Colophon.

Heise, D. (1977). Social action as the control of affect. *Behavioral Science, 22*, 163-177.

Hochschild, A. R. (1979). Emotion work, feeling rules, and social structure. *American Journal of Sociology, 85*(3), 551-575.

Hochshild, A. R. (1992). The managed heart: Commercialization of human feelings. In C. Clark & H. Robboy (Eds.), *Social interaction: Readings in sociology* (4th ed., pp. 136-149). New York, NY: St. Martins Press.

Kemper, T. (1991). Predicting emotions from social relations. *Social Psychology Quarterly, 54*, 330-342.

Kern, R., & Warschauer, M. (2000). Communicative foreign language teaching through telecollaboration. In K. van Esch & O. St. John (Eds.), *Network-based language teaching: Concepts and practice* (pp. 1-19). Cambridge: Cambridge University Press.

Kiecolt, K. J. (1994). Stress and the decision to change oneself: A theoretical model. *Social Psychology Quarterly, 57*, 49-63.

Kiesler, S., Siegel, J., & McGuire, T. W. (1984). Social psychological aspects of computer-mediated communication. *American Psychologist, 39*(10), 1123-1134.

LaRose, R. (2001). On the negative effects of e-commerce: A sociocognitive exploration of unregulated on-line buying. *Journal of Computer Mediated Communications, 6*(3), 114-122.

Lee, H. (2005). Behavioral strategies for dealing with flaming in an online forum. *Sociological Quarterly, 46*(2), 385-403.

Mead, G. H. (1934). *Mind, self, and society.* Chicago, IL: University of Chicago Press.

Nielsen Media Research. (1997). *The Spring 1997 Commerce Net/Nielsen Media Internet Demographic Survey,* Full Report, Volume I of II.

Novak, T. P., Hoffman, D. L., & Venkatesh, A. (1997, October). *Diversity on the internet: The relationship of race to access and usage.* Paper presented at the Aspen Institute's Forum on Diversity and Media, Queenstown, MD.

Orton-Johnson, K. (2007). The online student: Lurking, chatting, flaming and joking. *Sociological Research Online, 12*(6), 223-245.

Ridgeway, C. L. (1982). Status in groups: The importance of emotion. *American Sociological Review, 47*, 76-88.

Salovey, P., & Mayer, J. (1990). Emotional intelligence. *Imagination, Cognition and Personality, 9*, 185-211.

Savicki, V., Lingenfelter, D., & Kelly, M. (1998). Gender language style and group composition in internet discussion groups. *Journal of Computer Mediated Communication, 2*(3), 1-12.

Schuman, H., Steeh, C., Bobo, L., & Krysan, M. (1997). *Racial attitudes in America: Trends and interpretations* (Rev. ed.). Cambridge, MA: Harvard University Press.

Shott, S. (1979). Emotion and social life: A symbolic interactionist analysis. American. *Journal of Sociology, 84*(6), 1317-1334.

Siegel, J., Dubrovsky, V., Kiesler, S., & McGuire, T. W. (1986). Group processes in computer-mediated communication. *Organizational Behavior and Human Decision Processes, 37*, 157-187.

Stryker, S. (1987, August). *The interplay of affect and identity: Exploring the relationship of social structure, social interaction, self and emotions.* Paper presented at the American Sociological Association Meetings, Chicago, IL.

Tanis, M., & Postmes, T. (2007, March). Two faces of anonymity: Paradoxical effects of cues to identity in CMC. *Computers in Human Behavior, 23*(2), 955-970.

Turner, J. H. (1994). A general theory of motivation and emotion in human interaction, *Osterreichische Zeitschrift fur Soziologie, 26*, 20-35.

Turner, J. H. (1998). *The structure of sociological theory* (6th ed.). Belmont, CA: Wadsworth.Publishing Company.

Tynes, B. M. (2007, November). Role taking in online "classrooms": What adolescents are learning about race and ethnicity. *Developmental Psychology, 43*(6), 1312-1320.

Walther, J. B., Anderson, J. F., & Park, D. W. (1994). Interpersonal effects in computer-mediated interaction: A meta-analysis of social and antisocial communication. *Communication Research, 21*(4), 460-487.

Walther, J. B., & Burgoon, J. K. (1992). Relational communication in computer-mediated interaction. *Human Communication Research, 19*(1), 50-88.

Wasserman, I. M., & Richmond-Abbott, M. (2005, March). Gender and the internet: Causes of variation in access, level, and scope of use. *Social Science Quarterly, 86*(1), 252-270.

Weiser, E. B. (2001). The functions of internet use and their social and psychological consequences. *Cyberpsychology and Behavior, 4*(6), 723-743.

Active Learning Through Toy Design and Development

Arif Sirinterlikci, Linda Zane, and Aleea L. Sirinterlikci

Abstract

This article presents an initiative that is based on active learning pedagogy by engaging elementary and middle school students in the toy design and development field. The case study presented in this article is about student learning experiences during their participation in the TOYchallenge National Toy Design Competition. Students followed the product development process to design and realize toys. They started with marketing surveys and conception, and then followed through by making prototypes to realize these designs. The experience generated an engaging and fun learning environment that promoted higher level, divergent, and creative thought processes—an effort that is needed in today's climate of increased attention on STEM education. Collection of two years of student work is included within this study to depict both the students' work and their perceptions toward this work.

Active Learning through Toy Design and Development

Active Learning

Increased public attention is being paid to the education of American students within the areas of science, technology, engineering, and mathematics (STEM) (Congressional Research Service, 2006). Concern is particularly heightened for K-12 education, since such students provide the foundation for rising stars in such fields. It has been reported that, when comparing K-12 students with international peers, on average American students fare more poorly on mathematics and science assessments the longer they are in school (National Academy of Sciences, 2007). The stakes are high, and most Americans would agree that something must be done to energize this generation of youth—drawing them toward positive attitudes in relation to STEM fields. Active learning is one way to capture the students' attention because it involves hands-on and collaborative methodology.

In traditional formal education, students typically learn in a didactic manner, that is, taking notes within a classroom lecture setting. Contemporary educational research indicates that such a passive environment is not effective and results in limited retention of knowledge by students (Prince, 2004). Active learning is an instructional methodology that engages students in the learning process to improve the results of the process (Bruner, 1961). Active learning is a multifaceted and directional approach where various interactions are welcomed (e.g., teacher-to-student, student-to-teacher, and student-to-student) (Grabinger & Dunlap, 2000).

In *The Seven Principles in Action: Improving Undergraduate Education,* Hatfield (1995) stated that active learning is not solely a set of learning activities, but rather it is more of an attitude-altering approach on the part of both students and faculty. According to the author, the goal is to channel the students to think about how and what they are learning, and thus having them take responsibility for their own education. As the students take a greater role in their education, self-management and self-motivation become a critical part of the learning process (Glasgow, 1996; Hatfield, 1995).

Through active learning, knowledge is directly experienced, constructed, acted upon, tested, or revised by the learner (Holzer, 1994). Active learning's critical components include using multiple senses and doing; problem defining, generating, and solving; interacting within and outside teams; high-level thinking; and relieving stress. Active learning involves using multiple senses (e.g., hearing, seeing, and feeling), interacting with other people and materials, and responding to or solving a problem. Students engaged in successful active learning tasks within team environments develop good communication skills, higher-level thinking skills, an emphasis on teamwork, a positive attitude toward the subject, and motivation to learn. Such benefits result from a team's perseverance, whereby teams continue to tackle problems that individuals often abandon. A team that includes fellow students also generates an environment with less pressure and fear of failure (Grabinger & Dunlap, 2000).

Other academic sources agree with the critical importance of problem solving, but ask students to be engaged in higher order thinking tasks as analysis, synthesis, and evaluation, especially at higher levels of education. According to Silberman (1996), the students should do most of the work. They need to study ideas, solve problems, and apply what they learn. Learning should be fast-paced, fun, supportive, and engaging. Hearing something, seeing it, questioning it, and discussing it with others allow students to learn the subject matter more thoroughly. Students need to manipulate their learning, figure things out by themselves, come up with examples, try out skills, and complete assignments that depend on the information they either have acquired or should acquire.

Problem-based, experiential, and inquiry-based learning are the most often cited forms of active learning (Kirschner, Sweller, & Clark, 2006). Similar concepts (such as discovery learning and cooperative learning), whereby students work in teams on problem solving under project management structures, lead to self-confident students who feel accountable and become team members (Grabinger & Dunlap, 2000). It does not matter what the methodology or at which level it is applied, it should address at least one or more of the following concepts:

- *Dialogue with Self.* This concerns a learner thinking reflectively about a topic of interest or work. Students write about what they learn, how they learn it, and the role this knowledge plays in their own life, and perhaps how they feel. Tools used to facilitate such reflective thinking may include journals and learning portfolios.

- *Dialogue with Others.* This is more than listening to an instructor, which is one-way interaction. A more active form of dialogue occurs when teachers create small-group discussions on a topic. They also can involve students in dialogue situations with practitioners or experts either inside or outside of class. Additional activities can include “pair-shares,” and collaborative learning groups, such as teams, student debates, and student-led review sessions.

- *Observing.* This occurs whenever a student either watches or listens to another person doing something related to the subject being studied. This might be observing a teacher, listening to musicians, or observing natural, social, or cultural phenomena.

- *Doing.* This refers to any learning activity in which the learner actually does something: writing a research proposal and conducting the research, completing a project (e.g., designing and developing an engineering structure), critiquing an argument or piece of writing, and making an oral presentation. Analyzing case studies and role-playing in simulation activities also can be employed, but these *indirectly* engage students in the doing process.

Adopting an active learning methodology does not necessarily require the replacement of highly structured teaching methods or eliminate the lecture format. Kirschner, Sweller, and Clark (2006) suggested that 50 years of empirical data do not support using active learning very early in the learning process. They suggest that formal and structured methods are needed early to establish a strong basis or background within any given area, and this then can be strengthened by the active learning activities.

The following case study was used to investigate the relationship between active learning and the “TOYchallenge” National Competition. The authors questioned whether involvement in the competition increased the student participants’ levels of interest in and understanding of scientific inquiry and engineering-related processes. The next section provides background information on the initiative and the TOYchallenge competition.

TOYchallenge National Competition.

In the fall of 2005, Robert Morris University (RMU), located in suburban Pittsburgh, PA, and its neighbor Moon Area Elementary School Challenge (Gifted) Program started a unique means of collaboration. Elementary school students from two local elementary schools were transported to RMU every Monday at noon, to work for two hours on their projects. These students were introduced to the TOYchallenge National Toy Design Competition at RMU; they were given the challenge to design and develop toys or games as entries to the competition. At the time, the burgeoning competition was sponsored by the Sigma Xi International Science Honor Society, Southwest Airlines, and Hasbro Toy Company, and it was organized by Sally Ride Science.

The TOYchallenge, for student teams from grades 5-8, offered them the chance to design and develop toys and games (Sally Ride Science, n.d.). Teams were coached by an adult who was 18 or older. A team could include 3 to 6 members. In order to encourage greater levels of scientific inquiry and interest in STEM careers among young women, at least 50% of the group members were girls. Each person could belong to only one team, and each team could submit only one design. The young developers submitted their original design ideas in a proposal form, which served as the preliminary elimination round. Each team was allowed $150 during the initial development process that led to the preliminary round. Any items purchased or donated had to be included within the total cost figure.Teams kept an itemized expenditure list, including signed receipts, and submitted it with their preliminary entries. Teams that qualified for the national round were expected to build the working prototype of their designs within a $200 budget constraint. If a team did not spend the initial $150, it could roll over that money toward purchases during the final preparations stage. An additional $50 could be used in preparation for the final presentation in excess of the $200. The following rules were enforced to maintain originality of design: (a) Any toy or game that has previously been recognized with a prize in a competition including TOYchallenge cannot be reentered, (b) The toy or game cannot include parts from existing commercial toys or games, (c) A team can only choose one category within which to work.

Categories for the 2006 and 2007 competitions included (Sally Ride Science, n.d.):

- *Get Out and Play:* a category that promoted outdoor activities.
- *Games for the Family:* an exciting game designed for the whole family to enjoy.
- *Toys that Teach:* the competitors designed toys that can be used in teaching people of all ages.

The TOYchallenge organization saw this competition "as a chance for teams of imaginative kids to create a new toy or game. Toys are a great way to learn about science, engineering, and the design process" (Sally Ride Science, n.d.). The following design steps were presented by the competition organization on the competition web page:

- Determining the definition of the toy/game, the category, and its objective
- Conducting research to gather more information about the possible designs
- Brainstorming
- Picking a design idea from alternatives
- Planning by recording in the logbook what you are trying to do and how you will get it done
- Preparing working drawings for prototyping
- Preparing the preliminary entry
- Prototyping to realize the design idea chosen

The most recent TOYchallenge web sources include a brief reference on the engineering design process, which is slightly different and improved as compared to the original one (Sally Ride Science, n.d.). The current site includes the following steps (a) Brainstorming, (b) Research, (c) Developing ideas, (d) Creating a drawing for the preliminary and prototype for finals, (e) Testing and Evaluation, (f) Communication, (g) Redesign. This engineering design process replicates the process of scientific inquiry, which should be encouraged in K-12 classrooms.

The preliminary entry report was limited to 6 pages. It is similar to an engineering design proposal and includes the following content:

- *Section 1: Your Toy or Game (no more than _ page)*
  - What category did you choose?
  - What is the name of your creation?
  - What is the object of your toy/game?
  - Who is the target market for your toy/game, and why?
- *Section 2: How Does it Work? (no more than _ page)*
  - Explain how your toy/game works. Be specific.
- *Section 3: Your Team (no more than _ page)*
  - Where are you from?
  - How did you work together to develop your idea?
  - How did you divide up the responsibilities and complete your creation?

- *Section 4: Your Design Process (no more than 2 pages)*

- *Section 5: Photos/Sketches of Your Toy/Game (no more than 2 pages)*

- *Section 6: Preliminary Round Entry Budget (no more than 1 page)*

Development process. At the first meeting, students were given the necessary forms; also the lead author gave a presentation on the competition. Mini-lessons would be followed by complementary workshops on an as-needed basis. The students also were directed to develop their games or toys based on the product development methodology in a creative and imaginative way. After studying the various categories of competition, students briefly discussed the categories of interest. However, they did not select their final categories until the results of their Marketing Survey (in which they surveyed their relatives and friends) were compiled. Based on the results of these surveys, they chose their game categories. In the process, they collected the following data from the survey participants:

- Age of the participant
- Gender of the participant
- Type of TOYchallenge category the participant likes the most
- Most favorite toy/game that the participant own/owned

After the determination of the category – Toys that Teach – student groups (a large group was associated with each elementary school) conducted layered brainstorming activities (Birch & Clegg, 2000). Students were given 2 minutes to think about the topic and then read their answers to the group; as the process was repeated, they were encouraged to consider others' ideas and to combine these ideas. The students discussed alternative concepts through brainstorming, and then they voted for the "best" design. The original design ideas included each student's (within the respective group) vision of the design (a sketch) and its object (problem statement). The object included the details of the designs. Students were presented the *concept of constraints*. Thus, students were told that some of the design components may not be realized within the physical, temporal, and financial restraints of the project, which helped them to refine their concepts.

Two entries were submitted to the 2006 TOYchallenge Competition. One group submitted a board game called *"3D Animal Rescue."* The other group submitted a music-based board game entitled *"MUSIC MANIA,"* which could double as two separate games. During the decision-making process for both groups, gender played a major role. This was evident when the girls in the *3D Animal Rescue* group wanted to submit a game that included less action but more learning, while the boys focused on male-favored activities. Because the teams contained more girls, most of their ideas were chosen.

After the preliminary round, the 3D Animal Rescue board game qualified for the East Coast Nationals, which was held at Sigma Xi Headquarters in Raleigh, North Carolina. In order to prepare for the national competition, the team followed the product development process. Students studied the details of their proposal and finalized the rules for their game. They also made solid models of the game pieces and models of animals to be included as a part of the 3D design scheme (Figure 1). The students used both AutoCAD and Mastercam software tools in

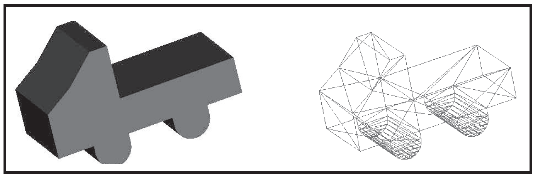

Figure 1. Models of game pieces (Solid Model/STL Model).

making the solid models. However, Mastercam was used as the main program because it can be used in simple and effective ways to generate STL (Stereolithography) files. Parts were built in the RMU Rapid Prototyping (RP) Laboratory under the supervision of the lead author. Students painted the game pieces after they were

Figure 2. Prototypes of game pieces being painted.

built by the SLA (Stereolithography) RP machine. Figure 2 shows group members painting the game pieces. Students also decided to use a wooden game box that coupled as a game board. These two components were built by the students under supervision of the lead author. The construction process is illustrated in Figure 3. The group completed the game cards and game board at one of the final meeting sessions. In addition to the CAD and RP components, students built basic electrical circuits to realize one of their most creative ideas—turning the lights on at the winning player's animal hospital (Figure 4). As the winning player rescued the last required animal, he or she pushed the

Figure 3. Board game fabrication.

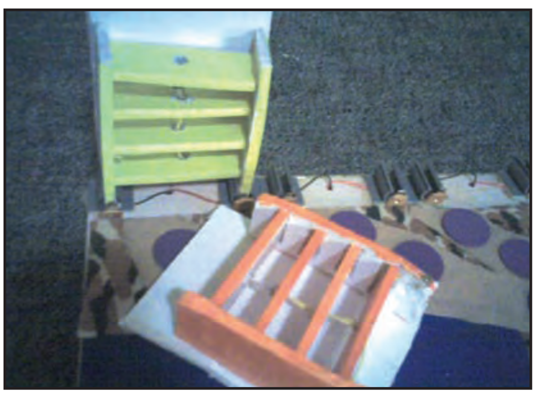

Figure 4. Electrical design for the game.

Figure 5. Final product.

hospital into a slot that illuminated the lights at the hospital. The completed game board is shown in Figure 5.

At the 2006 East National Finals, two group members gave a successful presentation, even though the group did not earn any awards. The items required for the final presentation consisted of the project budget, the logbook, team members' t-shirts, and a presentation board.

The 2007 project was conducted as an after-hours activity at the lead and third author's residence due to other gifted activities occupying students' school schedules. The second year's qualifying project was a life-sized board game that could be played outdoors. It was named *"PALM ISLAND,"* and it included coconuts, makeshift purses, a giant palm tree, and the board. Similar to the process followed in the

Figure 6. Second year's design: Life-sized outdoor board game, "PALM ISLAND," being tested by the team before the competition

first year's competition, after the students completed the development process, these students and their friends tested the game to make sure it worked and was ready to use (Figure 6).

Student responses. As mentioned previously, in the second year the initiative became an after-hours activity held outside the RMU Engineering Department, even though the lead author was still involved. Thus, the team also had limited access to both the engineering laboratories and the equipment.

After the successful completion of the projects and presenting them at the 2007 Nationals, students answered surveys about the experience. The surveys were based on the original surveys developed by the TOYchallenge organization. These questions tried to gauge the students' perceptions of the engineering field (as a result of the toy design and development process mirroring the engineering product design and development process). These questions were designed to learn if time spent engaged in active learning and toy development dispelled any myths or preconceived notions regarding STEM careers, engineering in particular. The first survey section contained the following questions:

1. Engineers probably have interesting stories to share about their work.
2. Engineering is boring.
3. It would be fun to be an engineer.
4. I think I will take engineering classes in college.
5. I might pursue a career in engineering.
6. Engineers usually work alone on projects.
7. Most people my age think engineering is cool.

Maximum point value of each response was 7 points, representing "Strongly Agree," whereas 1 point represented "Strongly Disagree." Most students indicated that they were neutral toward the engineering discipline. This could be a result of less exposure to engineering tools or the group being an all-girls' team.

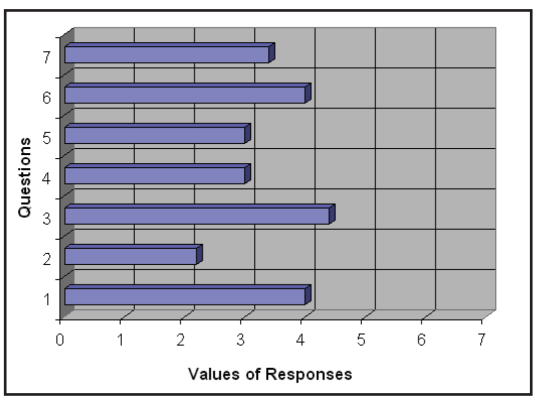

Figure 7. Students' view of engineering – average values.

To the contrary, the students moderately disagreed with engineering as being boring. This could reflect a somewhat positive attitude toward the engineering process, even if the students did not anticipate entering into the field as an adult. The results of the survey section are displayed in Figure 7.

A second set of questions focused on the development process and students' attitudes toward active learning. This set of questions was intended to be more global, and to ascertain the students' holistic attitudes toward the process of toy development and design. It was surmised that although students' singular involvement in the process might not push them into a STEM career, being actively involved in the process of inquiry might promote initial positive feelings toward foundational scientific procedures. Introductory positive feelings and levels of comfort with scientific processes, utilizing active learning methodology, is the first step toward students becoming scientifically literate.

Better results were obtained from the second set of questions. The maximum point value for each of the following three questions was 5. A score of 1 indicated "Strongly Disagree," and a score of 5 indicated "Strongly Agree." As one can see in Figure 8, the students' level of comfort in using technology and building things was extremely high, and their comfort with the engineering design process was average.

1. Comfortable using technology
2. Comfortable using the engineering design process
3. Comfortable building things

Conclusions

At a time when many educators are considering ways to strengthen America's scientific and technological foundations, it is imperative that students be given numerous and varied experiences within STEM fields (National

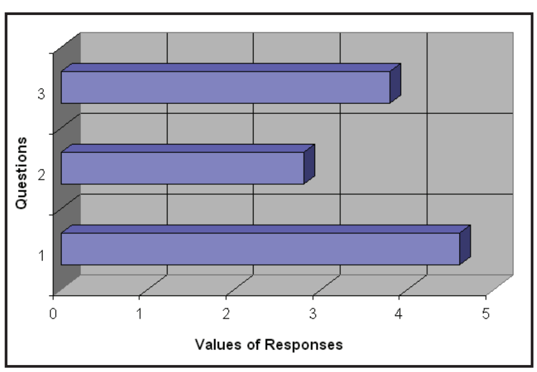

Figure 8. Students' view of engineering design process and being hands-on/actively engaged - average values.

Academy of Sciences, 2007). This focus is evident, starting with a mandate from the Oval Office in November 2009. President Obama, in an effort to focus more attention on scientific inquiry and technological innovation in the United States, launched the *Educate to Innovate* campaign—an effort to make STEM education a priority for the next decade (The White House, 2009).

Although STEM education is facing a resurgence in popularity, school districts remain bound by the standards set forth by the *No Child Left Behind Act of 2001* (NCLB). In an effort to increase students' reading and mathematics scores, NCLB legislation has pushed science to the sidelines, often leaving such instruction to the discretion of the classroom teacher. Many students are lacking in the types of scientific experiences that will inspire future leaders in STEM fields (Marx & Harris, 2006). If national leaders truly believe in motivating and encouraging the next generation of leaders in scientific and technological fields, identifying educational approaches that promote collaborative scientific inquiry is essential.

Active learning represents an effective method of dynamically engaging students in the learning process, and it promotes scientific inquiry in an authentic manner. This case study, detailing the processes involved in the TOYchallenge competition, exemplified the benefits of active learning, that is, gaining hands-on experience in engineering design and development, especially regarding the product design and development process. The products used in these cases were toys and games, items that the students can relate to.

After guiding the students through the TOYchallenge competition for two consecutive years, it became evident to the authors that the hands-on learning required by the competition was a highly effective means of promoting the scientific method with young learners. In addition, some of the student survey responses reflected positive attitudes toward the engineering process, albeit their lack of interest in pursuing the field as an adult. Survey responses also showed positive attitudes toward students' comfort levels with utilizing technology and building things. Although it is not possible to ascertain whether TOYchallenge experiences actually caused these attitudes, observations by the instructors provided anecdotal evidence that students enjoyed the process. The active learning process also was interactive and collaborative, as evidenced by student-to-teacher, teacher-to-student, and most important, student-to-student interactions. By using cooperative learning, students were able to assume different roles, communicate their thoughts, work collaboratively on projects, and negotiate to settle differences. The team environment, with an enjoyable project at its core, also induced less pressure and fear of failure. It became evident that the knowledge-construction process was enhanced by the high level of collaboration and communication (Edelson, Pea, & Gomez, 1995). Scientific endeavors rely on the collaborative process, and the students benefited from seeing this in action (Edelson, 1998).

The students took charge of their projects, and self-management and self-motivation played a critical role for most of the students. This is similar to the problem-based learning process, as promoted by Duffy and Cunningham (1996). According to Duffy and Cunningham, the problem-based model best exemplifies a constructivist method of learning, whereby students manage their own learning in order to solve authentic, real-life problems. True learning occurs when students are provided authentic problems, and they encouraged to be both collaborative and self-directed in order to find creative solutions, under the guidance of a facilitator who provides the necessary resources. Such learning was evident throughout the two years of involvement with the TOYchallenge competition.

The active learning experiences also promoted scientific inquiry by heightening the students' observation skills. The students heard, saw, spoke, wrote (in logbooks), drew (sketches), and questioned during the development process. They explored a set of ideas, and used high-level thinking in making decisions and solving problems, replicating the process of scientific inquiry used by experts in STEM fields. The students also benefited from being able to apply what they learned throughout the product development process--from the initial marketing survey, to ideation, and finally to the realization of the working prototype stages. By moving sequentially through each phase of the process, the students not only gained valuable experiences in marketing, product development, and execution, but they also witnessed the practicality of scientific pursuits. By applying knowledge to real-world problems and settings, the students were able to experience the benefits of an authentic learning experience—learning that is concrete and useful (Edelson, 1998).

At the conclusion of their active learning experience, the students successfully exchanged ideas with themselves and others, were self-reflective and self-directed in their learning, enhanced their powers of observation, and brought their ideas to fruition via an excellent product. They accomplished what engineers and product designers do in their professional lives—realization of a successful and useful product. In addition, the students were immersed in the process and its steps, both technical and not technical. They had to understand and enact budget constraints, project management principles, and the implications of their designs on production.

Due to the heightened awareness of STEM education among the nation's students, the evidence put forth for active learning within science education is compelling. Building a strong foundation for students in science education will (we hope) encourage students to pursue careers in STEM fields, thereby returning the competitive advantage of the United States within the areas of science and technology. The aforementioned processes of active learning could be extremely beneficial to science educators because they promote scientific thought and attitudes in an engaging and authentic manner.

This case study reflects a group of students who demonstrated two essential attitudes that are characteristic of scientists—uncertainty and commitment (Edelson, 1998). They forged through the uncertainty by collectively brainstorming solutions to problems, by discovering the needs of the public through marketing surveys, and by collaboratively agreeing upon solutions to their problems. Each step of the process required the second essential characteristic—commitment. The students were self-directed learners, who followed through with each discovery to realize its final outcome.

Such experiences promote scientific inquiry and knowledge construction in a way that no textbook or lecture could; an active learning methodology is challenging, engaging, and enlightening. It is our belief that all students would benefit from exposure to scientific inquiry through an active learning model, and it is our hope that future STEM education includes the resources and training to promote authentic, hands-on learning within all K-12 classrooms.

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References

Birch, P., & Clegg, B. (2000). *Imagination engineering: A toolkit for business creativity.* New York: Prentice Hall.

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review, 31*, 21-32.

Congressional Research Service. (2006). *Science, technology, engineering, and mathematics (STEM) education issues and legislative options.* Washington, DC: The Library of Congress.

Duffy, T. M., & Cunningham, D. J. (1996). Constructivism: Implications for the design and delivery of instruction. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 170-198). New York: Simon & Schuster Macmillan.

Edelson, D. C. (1998). Realising authentic science learning through the adaptation of scientific practice. In K. Tobin & B. Fraser (Eds.), *International handbook of science education* (pp. 317-331). Dordrecht, Netherlands: Kluwer Academic.

Edelson, D. C., Pea, R. D., & Gomez, L. (1995). Constructivism in the collaboratory. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design.* Englewood Cliffs, NJ: Educational Technology Publications.

Glasgow, N. A. (1996). *Doing science: Innovative curriculum for the life sciences.* Thousand Oaks, CA: Corwin Press.

Grabinger, R. S., & Dunlap, J. C. (2000). Rich environments for active learning: A definition. In D. Squires, G. Conole, & G. Jacobs (Eds.), *The changing face of learning technology* (pp. 8-38). Cardiff: University of Wales Press.

Hatfield, S. R. (1995). *The seven principles in action: Improving undergraduate education.* Bolton, MA: Anker Publishing Company.

Holzer, S. M. (1994, Spring). From constructivism to active learning. *The Innovator, 2*. Retrieved March 5, 2009, from http://www.succeednow.org/innovators/innovator_2/innovator002.html.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist 41*(2), 75-86.

Marx, R. W., & Harris, C. J. (2006). No Child Left Behind and science education: Opportunities, challenges, and risks. *The Elementary School Journal 106*(5), 467-477.

National Academy of Sciences. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, DC: National Academies Press.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231. Retrieved October 13, 2008 from http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Prince_AL.pdf.

Sally Ride Science. (n.d.). *Toy Challenge.* Retrieved June 12, 2007 from http://www.sallyridescience.com/toychallenge/.

Silberman, M. (1996). *Active learning: 101 strategies to teach any subject.* Des Moines, IA: Prentice-Hall.

The White House. (2009). *President Obama launches "Educate to Innovate" campaign for excellence in science, technology, engineering, and math (STEM) education.* Retrieved January 5, 2010 from http://www.whitehouse.gov/the-press-office/president-obama-launches-educate-innovate-campaign-excellence-science-technology-en.

Proposed Model for a Streamlined, Cohesive, and Optimized K-12 STEM Curriculum with a Focus on Engineering

Edward Locke

Abstract

This article presents a proposed model for a clear description of K-12 age-possible engineering knowledge content, in terms of the selection of analytic principles and predictive skills for various grades, based on the mastery of mathematics and science pre-requisites, as mandated by national or state performance standards; and a streamlined, cohesive, and optimized K-12 engineering curriculum, in terms of a continuous educational process that starts at kindergarten and/or elementary schools, intensifies at middle schools, differentiates at high schools and streamlines into four-year universities through two-year community colleges, integrating solid mastery of particular analytic skills and generic engineering design processes. This article is based upon a "Vision Paper" that was presented at the International Technology Education Association's 71st Annual Conference held in Louisville, Kentucky under the sponsorship of Dr. John Mativo, from the University of Georgia. It is hoped that many ideas explored in this article could provide answers to the problems in the current practice of K-12 engineering education, as discussed in the authoritative report issued several months later, on September 8, 2009, by the Committee on K-12 Engineering Education established by the National Academy of Engineering and the National Research Council, titled *Engineering in K-12 Education: Understanding the Status and Improving the Prospects,* which included the absence of cohesive K-12 engineering curriculum and the lack of well-developed standards.

Introduction

In the last decade, it has been perceived by scholars and administrators involved with K-12 STEM education as well as concerned business leaders that the shortage of engineering graduates from U.S. colleges must be resolved. In fact, the numbers of engineering degrees awarded over the last 20 years by U. S. universities was quite small. The National Science Foundation Statistics (2008) indicated that, in the years 1985 - 2005, the number of earned bachelor's degrees ranged from approximately 60,000 to 80,000; the number of earned master's degrees ranged from approximately 20,000 to 34,000; and the number of earned doctorate degrees ranged from approximately 3,700 to 6,000. Wicklein (2006, p. 29) indicated that in the United States, "currently, engineering education has close to a 50% attrition rate for students. […] Georgia currently seeks 50% of the engineering workforce from out-of-state sources." In an effort to solve this problem, K-12 schools across the United States have begun to incorporate engineering design into technology education curriculum. Hill (2006) indicated that "initiatives to integrate engineering design within the field of technology education are increasingly evident." Smith (2007, pp. 2-3) affirmed the achievements made so far throughout U.S. high schools by noting, "the integration of engineering design into secondary technology education classes," but also indicated that the "fragmented focus and lack of a clear curriculum framework" had been "detrimental to the potential of the field and have hindered efforts aimed at achieving the stated goals of technological literacy for all students." An authoritative report issued on September 8, 2009, by the Committee on K-12 Engineering Education established by the National Academy of Engineering and the National Research Council, titled Engineering in *K-12 Education: Understanding the Status and Improving the Prospects,* confirmed the existence of similar problems in the current K-12 engineering curriculum. To be more specific, the most serious problems in K-12 engineering education explored in the report by the Committee on K-12 Engineering Education (2009) include (a) absence of cohesive K-12 engineering curriculum ("Engineering design, the central activity of engineering, is predominant in most K-12 curricular and professional development programs. The treatment of key ideas in engineering, many closely related to engineering design, is much more uneven;" pp. 7-8; p. 151); and (b) lack of well developed standards ("the teaching of engineering in elementary and secondary schools is still very much a work in progress . . . no national or state-level assessments of student accomplishment have been developed;" p. 2).

During the International Technology Education Association's 71st Annual

Conference, and under the sponsorship of Dr. John Mativo, from the University of Georgia, this author presented a proposed model for:

- A Clear Description of K-12 Age-Appropriate Engineering Knowledge Content: Selection of K-12 age-appropriate engineering analytic principles and predictive skills for various grade levels should be based on the mastery of mathematics and science (notably physics and chemistry) prerequisites, as mandated by national or state performance standards for previous or same grade levels.

- A Streamlined, Cohesive, and Optimized K-12 Engineering Curriculum: A cohesive and continuous educational process that starts at kindergarten and elementary schools, intensifies at middle schools, differentiates at high schools, and streamlines into four-year universities through two-year community colleges could be a solution to various problems in U. S. engineering education. This principle of streamlining could also apply to various fields of STEM (see Figures 1 and 2). The optimization of K-12 engineering education could be achieved through (a) the integration of particular analytic and predictive principles and skills, with different modes of generic engineering design process, both transferable to collegiate engineering studies and (b) the integration of traditional formula-based analytic computations and physical laboratory experiments with modern digital simulation technology. The proposed curriculum is intended to seamlessly link K-12 engineering and technology curricula to university engineering programs, by making engineering knowledge content learned at K-12 schools transferable to engineering courses taught at the university level; this is the "missing E" (engineering) that has been neglected by existing models of K-12 STEM curricula.

This proposed model might contribute to the solution of the problems described in the report by the Committee on K-12 Engineering Education (2009).

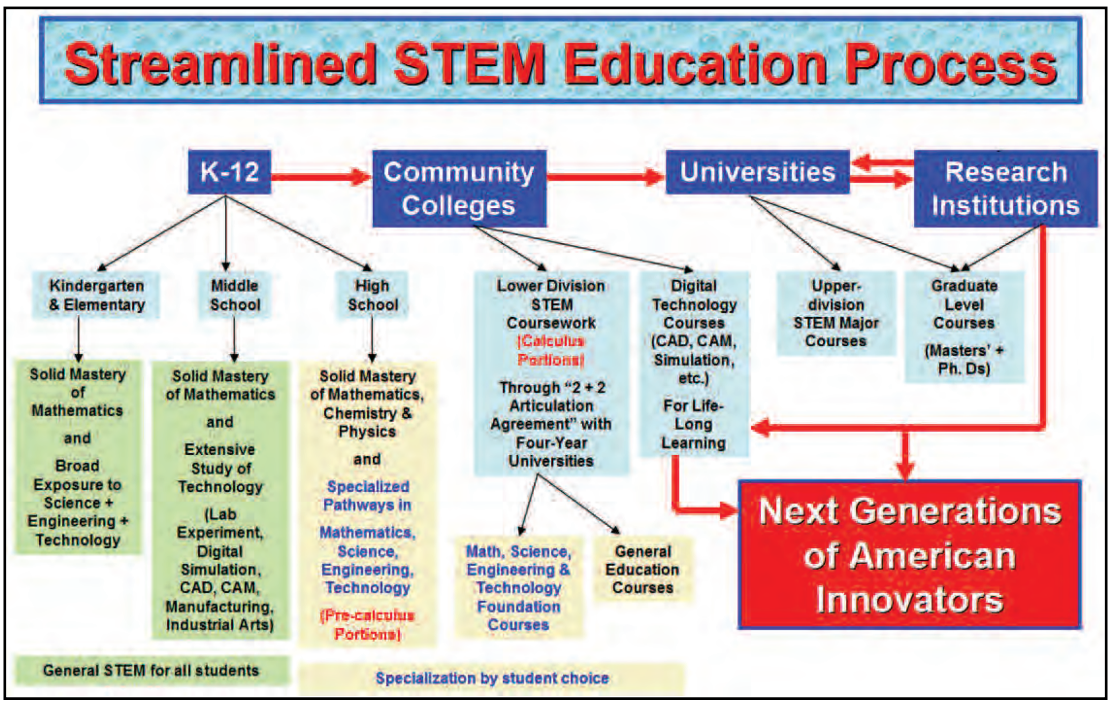

Figure 1. A streamlined vision for a life-long STEM education.

Proposed Model for a Clear Description of K-12 Age-Appropriate Engineering Knowledge Content

The key to understanding how to scientifically, rationally, and effectively infuse engineering analytic content knowledge and the design process into K-12 curriculum can be related to the understanding of the following four basic types of relations:

(1) Relations among mathematics, science, engineering, and technology: Mathematics provides computational tools for the predictive analysis in sciences, engineering, and technology; it is the primary gatekeeper for the inclusion

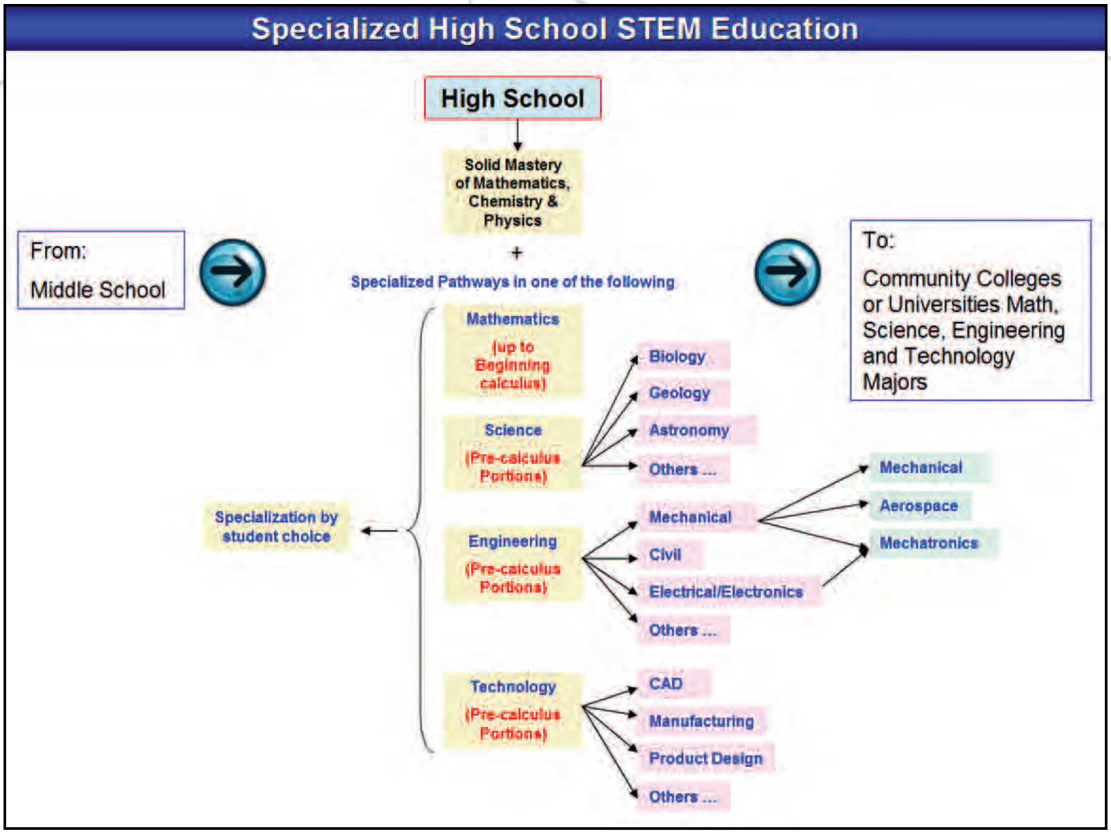

Figure 2. A streamlined model for STEM education.

or noninclusion of any science, engineering, or technology topic into any course taught at any grade level. Sciences (physics, chemistry, biology, etc.) are concerned with discovery and delivery of knowledge, and they form the foundation for engineering and technology; additionally, sciences (notably physics and chemistry) constitute the secondary gatekeeping determinants. Engineers apply knowledge gained through the scientific process in the creative design of products and systems to be used in solving everyday problems, and they are the vital link in the STEM system that transforms "pure" knowledge into usable and financially profitable assets (products and systems), through the process of innovation. Technology is the skills of applying, maintaining, and arranging products and systems in the solution of daily problems. Based on this understanding, the selection of engineering topics for any grade level must be based on the prior mastery of prerequisite principles and skills in mathematics and science courses.

(2) Relations between specific engineering analytic knowledge content and the generic engineering design process: Mastery of a sufficient amount of specific analytic knowledge content (principles, concepts, computational skills using formulas or simulation software, as well as experimental and research methods) constitutes the foundation for meaningful engineering design; in contrast, engineering design gives students an opportunity to synthesize knowledge and skills gained from various branches of engineering into workable solutions that help create and maintain usable products and systems. Based on this understanding, the inclusion of engineering as a meaningful K-12 subject must be based on an appropriate balance between instruction of specific engineering analytic knowledge content and the inculcation of the ability of using engineering design processes.

(3) Relations between different modes of design and different stages of K-12 students' cognitive developmental level: Design processes could include different modes.

- Creative and Conceptual Design: Examples of this mode include conceptual imagination, ideation for simple product and tools (e.g., everyday items, such as shopping bags, benches, chairs, tables). Kindergarten and elementary school students are good at wild imagination with little training, but at this age they are just beginning to learn basic mathematics and sciences; thus, this mode could be used in Grades K-5.

- Technology Education Design: This mode of design is based on "trial-and-error" or "hypothesis-and-testing" experiments; and it is an important method of scientific inquiry. An example of this mode could be the design, fabrication, and testing of composite materials, based on a rational hypothesis and its proof or disproof through experiments. This mode could be used in Grades 6-8.

- Analytic Reduction: This mode is good for solving well-structured, simple, and usually closed-ended engineering design problems (e.g., designing a gear set that changes speed and direction of rotational motions) that are focused on scientific and technological issues. It is suitable for stand-alone engineering foundation or specialty courses that deal with particular sets of knowledge content. This mode could be used in Grades 9-11.

- Systems Thinking: This mode of design is good for solving ill-structured, open-ended, and complex engineering design problems, which involve not only many branches of science and engineering, but also social studies (culture and economics), ecology and arts. It generally could lead to multiple results that satisfy the original design requirements. This is the most frequently used mode in real-world engineering design practice. Examples of this mode include senior-year design projects in any typical university undergraduate engineering program. This mode would be most suitable for Grade 12 or graduation year "capstone" design courses, and it could be used for extracurricular interdisciplinary design projects throughout Grades K-12.

Engaging K-12 students in the design process is feasible. Previous research conducted by Fleer (2000) and funded by the University of Canberra and the Curriculum Corporation of Australia for the development of a technology curriculum concluded that children as young as 3 to 5 years of age can engage in oral and visual planning as part of the process of making things from materials; their planning involved the use of lists and designs of what they intended to make. Claxton, Pannells, and Rhoads (2005) indicated that the level of developmental maturity occurred around 5 to 6 years of age; that a creative peak occurred at 10 to 11 years old; and that "after age 12, a gradual but steady rise in creativity occurred through the rest of adolescence until a second peak was reached around 16 years of age" (p. 328).

(4) Relations between kindergarten/elementary education and secondary education: Throughout the Grades K-6, students barely learn the basics of STEM, English language, and other mandated subjects; they have a very limited set of mathematics skills to carry out engineering analysis and prediction-related computations; thus, an integrative STEM approach in general science courses, with broad exposure to a variety of science, engineering, and technology subjects, would be very age-appropriate. At the secondary level, students either have mastered or are in the process of mastering more in-depth and specialized mathematics skills (algebra, geometry, trigonometry), and they have mastered basic scientific principles that are needed for understanding engineering analytic principles; thus, more extensive engineering studies could be implemented; here, depth and specialty should be emphasized.

Method for the Selection of K-12 Age-Appropriate Analytic Principles and Skills

Up to this date, "hard-core" engineering content from various subjects, such as statics, dynamics, and fluid mechanics, are generally not systematically taught until students enroll in university undergraduate courses; however, textbooks used in these courses could be analyzed to determine the mathematics and science (notably physics and chemistry) prerequisites for various topics covered therein. Topics whose prerequisites are covered at various K-12 grade levels could be selected for pedagogic experiments at higher grade levels, to determine their age-appropriateness. This author's research on high school age-appropriate statics and fluid mechanics topics, during Spring 2009, at the University of Georgia, incorporated the following steps:

(1) Select textbooks and instructor solution manuals that are among the most popular for undergraduate engineering statics and fluid mechanics courses;

(2) Read carefully every paragraph in the body text to find and record the prerequisite science knowledge content needed for each topic (notably physics and chemistry);

(3) Find the relevant computational formulas to determine and record the mathematics skills needed; and

(4) Compare the recorded data with the mandates of the Performance Standards for Mathematics and Sciences of the Department of Education of a selected state, to determine the grade level for the inclusion of the topic.

This previous research indicated that, using the mandates of the Performance Standards for Mathematics and Sciences of one of the "low-performing" states in the United States, around 50% of all topics in the textbooks used in undergraduate statics and fluid mechanics courses are based on precalculus mathematics skills and on scientific principles that are covered prior to 9th grade, and therefore, could be taught to 9th Grade high school students. For other foundation engineering courses common to all undergraduate programs, such as dynamics, strength of materials and material science, heat transfer, thermodynamics, engineering economics, and aerodynamics, the percentage figure ranges from 30% to 50% based on this author's rough estimates using similar standards.

Even though high school students could learn engineering topics, this does not automatically mean that they would have enough energy to proceed. Due to many factors, K-12 schedules are crowded with many mandated subjects; and the academic resources for implementing engineering curriculum are rather limited. Thus, realistically only the most important engineering analytic content knowledge can be attempted to be infused in the curriculum. Expert opinions of the relative importance of various topics can be collected, possibly through a five-point Likert scale, four-round Delphi survey. This survey could be used to determine the relative importance of various engineering analytic principles and computational skills for inclusion into a potentially viable K-12 engineering curriculum and eventually to establish a set of national or state K-12 engineering performance standards.

Proposed Model for a Streamlined, Cohesive, and Optimized K-12 Engineering Curriculum

Based on the above mechanism for the development of a clear description of K-12 age-appropriate engineering knowledge content, in this article the author proposes a new model for a streamlined, cohesive, logical, and optimized K-12 Engineering Curriculum, which could also be used as a general model for STEM, including mathematics and sciences (Figures 1 and 2). This new model could provide a workable framework for organizing and sequencing the essential knowledge and skills to be developed through K-12 engineering education in a rigorous or systematic way, making the future K-12 Engineering curriculum optimally connected to college-level engineering programs and to real world practice, and eventually lead to the establishment of formal national and state learning standards or guidelines on K-12 Engineering Education.

The Proposed Model would include two components: a Regular Curriculum (Table 1) for all students enrolled in K-12 Engineering Curriculum or "Career Pathways," and an Extracurricular Enrichment Program for selected groups of students.

First Component - Regular Curriculum

Lewis (2007) indicated that, "to become more entrenched in schools, engineering education will have to take on the features of a school subject and argued in terms of what is good for children" (p. 846). In addition, Lewis (2007) discussed the need to (a) establish a "codified body of knowledge that can be ordered and articulated across the grades" with focused attempt to systematize the state of the art in engineering in a way that is translatable in schools (instead of short term efforts focused on a particular topic or unit) and (b) make engineering education a coherent system with the creation of content standards for the subject area, in line with science and technology education (pp. 846-848).

As shown in Table 1, the Regular Curriculum is designed for all students who are interested in STEM Career Pathways and could be adequately trained in basic mathematics skills; it is aimed at implementing engineering design process step-by-step, progressing from simple to complex, from easy to difficult, from broad to deep, from generic to special, in an incremental, logical, systematic, and cohesive sequence. This is based on age-appropriateness, with a deep respect for time-proven traditional pedagogy while incorporating the positive achievements of the recent decade in instructional technology, especially in terms of digital modeling and simulation technology. This curriculum is divided into several stages, each corresponding to the infusion of engineering

Table 1. Regular K-12 Engineering Curriculum Flow Chart

Grades K-5 (Kindergarten & Elementary School) → For all students	**Grades 6-8 (Middle School)** → For all students, especially the STEM-oriented ones	**Grades 9-11 (High School)** → For all Engineering Pathway students	**Grade 12 (High School Graduation Year)** → For all Engineering Pathway students
Knowledge Content (Course Works)			
STEM Courses (2 courses; throughout Grades K-5): 1st Course (Grades K-5) - Mathematics. 2nd Course (Grades K-5) - Integrated Science, Engineering and Technology: • General Principles of Science, Engineering and Technology; • Diverse Topics in Science, Engineering and Technology; • Ecologically Sustainable Application of Science, Engineering and Technology. • Careers & Ethics in Science, Engineering and Technology. →	Mathematics & Science (2 courses; throughout Grades 6-8). Technology (8 Subjects organized into 4 Full Year Courses; 1 Course per Grade/Year): 1st Course (Grade 6) - Product Design & Manufacturing: • Engineering Drafting, Solid Modeling & Product Design; • Manufacturing Systems. 2nd Course (Grade 7, an extension to Grade 6 Science Course) - Humans & Environment: • Power & Energy; • Construction Systems. 3rd Course (Grade 8) - Technology Aesthetics & Ergonomics: • Digital Graphics Design & Product Aesthetics; • Ergonomics, Safety & Appropriate Technology Development. 4th Course (Grade 8, to be taught as a part of Science Course) - Electronics & Control Technology: • Electrical Circuitry Design, Component Selection & Digital Simulation; • Robotics Assembly & Programming. →	Mathematics & Sciences (2 courses; throughout Grades 9-11. For Sciences, Physics and Chemistry are mandatory). Engineering Foundation (Several Subjects organized into 3 Courses; 1 Course per Semester): 1st Course (Grade 9, 1st Semester) - Engineering Mechanics I: • Statics & Dynamics; 2nd Course (Grade 9, 2nd Semester) - Engineering Mechanics II: • Fluid Mechanics & Aerodynamics; • Heat Transfer & Thermodynamics. 3rd Course (Grade 10, 1st Semester) - Engineering Materials: • Strength of Materials; • Materials Properties, Treatment & Selection. Engineering Pathway (3 courses; 1/semester; 2nd Semester of Grade 10, 1st and 2nd Semester of Grade 11). → Note: For non-Engineering Pathways (Science, Technology and mathematics), the Foundation and Pathway courses would be different.	Design "Capstone" (2 Courses at Grades 12). 1st Course (Grade 12, 1st Semester) - Engineering Design Capstone I: • Mini Lesson: Engineering Economics, and other topics relevant to the design project; • Design activities (teamwork). 2nd Course (Grade 12, 2nd Semester) - Engineering Design Capstone II: • Design activities (teamwork). • Prototyping activities (teamwork). Note: For non-Engineering Pathways (Science, Technology and mathematics), the Design "Capstone" courses would be changed to Research or Manufacturing "Capstone."
Mode of Design Process			
Creative, Conceptual and light analytic (assignments). →	Engineering & Technology Experiment (assignments). →	Analytic Reduction" for "Well-structured problems ("Mini Capstone" or final design or research project for each course) →	Ill-structured and Systems Thinking" ("Capstone" graduation project)

design into a period of K-12 education: (a) kindergarten and elementary schools; (b) middle schools; (c) high schools; and (d) graduation year.

At Grades K-5 (kindergarten to elementary schools): All students would be introduced to science, engineering, and technology, while they built a solid foundation in mathematics.

Students would be given an opportunity to: (a) have a broad exposure to diverse aspects of science, engineering and technology (the "breadth"); (b) foster ability of creative imagination (the "wild"); and (c) foster a systemic and holistic view of technological systems as interactive and interconnected. Students would master similar knowledge content that is traditionally required of college engineering and technology students in the following courses: Introduction to Science, Engineering and Technology; Engineering Ethics; and Appropriate Engineering and Technology. This stage would be similar to what many of U.S. K-12 schools have practiced during the past decade. Minimal modifications would be made regarding infusing age-appropriate engineering knowledge content through contextual, hands-on, and creative design activities.

At Grades 6-8 (middle schools): Courses included in this stage should be made available to all students and taken by all STEM-oriented students. During this stage, all students would consolidate their mathematics and science foundation and explore the basics of traditional and modern technology with more specialized and stand-alone courses. Students would master the fundamentals of modern technology that are associated with engineering (e.g., CAD and 3D modeling, traditional and CNC manufacturing process, and others). This coursework would prepare them for a lifelong career related to STEM. For non-STEM-oriented students, technology courses included in this part of the Proposed Model could still help them to gain practical skills with lifelong benefits. The mathematics and science portions of this part of the Proposed Model would still be similar to what most of U.S. schools have practiced in the past, except that the content knowledge would be more specialized and intensive, including some relevant engineering topics, either as "word problems" or as mini research projects. In addition, specialized and intensive engineering-related technology courses would be offered.

At Grades 9-11 (high schools): Selective courses included in this stage should be taken by students enrolled in separate STEM Career Pathways; as shown in Figure 2, these Career Pathways could be any branches of science (biology, chemistry, physics, etc.), technology (CAD, manufacturing, product design, etc.), engineering (mechanical, civil, electrical and electronics, etc.), depending on changing national and local needs. During this stage, students would be branched out to different STEM "Career Pathways" of their choice, take a sequence of precalculus based, well-connected, and specialized courses. The specialized STEM "Career Pathways" would directly streamline students into relevant STEM majors at colleges or universities through cross-institutional transfer and/or articulation agreements, which might include dual high school and college credits (for technology courses such as engineering drafting and CAD/CAM) and the High School Certificate Examination in a particular area of STEM, for the completion of certain courses (such as Introduction to Science, Engineering, and Technology, Engineering Ethics, Appropriate Technology, etc.) or their precalculus portions. In the future, special examinations modeled after Fundamentals of Engineering (FE) could be designed to test the abilities of high school graduates to solve precalculus-level engineering problems. For students who pass these examinations, special accommodations could be granted (e.g., they would still be enrolled in undergraduate engineering courses to continue studying relevant topics beyond the precalculus portions they have learned at high schools, but they could be exempt from specific homework and quizzes related to precalculus portions, allowing them to devote their time to calculus-based course materials and to engineering design and research projects.

At Grade 12 (high school graduation year): The mathematics and science portions of this part of the Proposed Model would still be similar to what most U.S. schools have practiced during the past decade, leading to graduation from high school and entry into college education. In the last year of K-12 education, students enrolled in STEM "Career Pathways" would spend two semesters in a research or design "Capstone" project to demonstrate their ability to synthesize the knowledge content from various courses taken previously and to solve an open-ended real-world problem with reasonable complexity, in a "System Thinking" mode. This project could constitute the masterpiece of the students' academic portfolio. The instructors would advise, guide, and evaluate students, and they would teach additional topics relevant to the "Capstone" projects.

Core engineering concepts "go beyond tool skills… and beyond the digital skills that have captured the interest of the profession over the past two decades. Tools will change but even more important is the cognitive content and intellectual processes fundamental to effective technological problem solving and literacy" (Sanders, 2008, p. 6). The idea of a precalculus but "hard-core" high school engineering curriculum, the centerpiece of the Proposed Model is feasible. Most basic scientific principles and analytic skills related to engineering design that practical engineers work with on a regular basis are based on precalculus mathematics (trigonometry, algebra, geometry, and functions) with some needs for beginning calculus (integration and differentiation) and substantial needs for linear algebra. Traditionally, "hard-core" engineering topics are taught in lower division courses of undergraduate engineering programs. However, because precalculus mathematic is offered in most U.S. high schools, there is a reasonable possibility that some portions of traditional college-level engineering content knowledge could be downloaded to high school students, in order to streamline their pathway to engineering careers. Therefore, it is feasible to develop and implement a high school engineering curriculum that could be seamlessly connected to college engineering programs.

The Proposed Model for K-12 Engineering Curriculum is designed to solve the problem of the chronic shortage of engineering graduates in the United States, by offering K-12 students a better preparation for college-level engineering majors; it can selectively teach high school students appropriate engineering knowledge content (the "precalculus portions"), which up to this point, remain the domain of university undergraduate engineering programs. Adopting this model could allow high school graduates from engineering and technology curricula to have mastered a sufficient amount of engineering analytical skills that are transferable to undergraduate engineering courses, so they could spend a few weeks reviewing the "precalculus portions" of the course materials and then concentrate on the more difficult calculus-based portions. This would (a) give academically challenged high school students a better chance to pursue engineering studies as "early birds" and thus increase the enrollment of domestic students in undergraduate engineering majors; (b) give U.S. undergraduate engineering students the same "early bird" advantage over those in many other countries; and (c) give college engineering professors a better way to manage course schedules. The students would be more adequately prepared to handle, the coursework, and this should improve the quality of undergraduate engineering education and reduce the dropout rate.

Second Component - Extracurricular Enrichment Program

The Extracurricular Enrichment Program could be operated in two formats.

Table 2. Commonly Shared Undergraduate Lower-Division Engineering Foundation Courses Among Various Engineering Programs at the University of Georgia, Based on Data from Undergraduate Engineering Program Handouts (Available from Room 120, Driftmier Engineering Center, Athens, Georgia 30602).

University of Georgia Engineering Program	University of Georgia Engineering Foundation Courses								
	ENGR 1120 Graphics & Design	ENGR 2120 Statics	ENGR 2130 Dynamics	ENGR 2140 Strength of Materials	ENGR Fluid Mechanics	ENGR 3140 Thermo-dynamics	ENGR 3150 Heat Transfer	ENGR 2920 Electrical Circuits	ENGR 2110 Engineering Decision Making
B.S. in Agricultural Engineering									
Electrical & Electronic Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mechanical Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Natural Resource Management	✓	✓	✓	✓	✓	✓	✓	✓	✓
Structural Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Process Operations	✓	✓	✓	✓	✓	✓	✓	✓	✓
B. S. in Biological Engineering									
Environmental Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biochemical Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biomedical Area of Emphasis • Biomechanics Track • Instrmentation Track	✓	✓		✓	✓	✓	✓	✓	✓

Infusing Engineering Topics Into K-12 Mathematics and Science Courses.

In addition to teaching engineering analysis and design through special Career Pathway courses, suitable engineering content could be incorporated into regular middle school and high school mathematics, chemistry, and physics courses, as extra teaching materials, word problems, and simple design projects. For example, in a geometry course, the engineering application of the triangular shapes could be explained to students, such as a triangle is "indestructible," unless the side lengths are changed, the shape would stay intact. In addition, triangular members are widely used in structural design; bridge design projects could be incorporated, with learning materials from the Internet, to study the subject of force equilibrium, to simulate bridge design with West Point Bridge Design software (http://bridgecontest.usma.edu/), and to build a scale model. Moreover, because triangles have one straight edge opposite a sharp corner, they can accommodate different shapes in three-dimensional space and are used in the development of irregular or curved surfaces; thus, some topics of engineering sheet-metal design could be taught, giving the students an opportunity to design a transition piece, as shown in Figure 3. In a chemistry course, subjects of material selections could be incorporated. Other appropriate engineering topics could be identified by engineering and technology faculty and graduate students using well-established criteria, and gradually added to regular K-12 mathematics, physics, and chemistry courses as extra learning materials, through a process of pilot study or other mechanism of pedagogic experiment. This approach is simple, easy to implement, and virtually risk-free. It would not likely cause any disturbance to routine K-12 mathematics and science instruction.

Interdisciplinary Design Projects

Engineering design projects involving knowledge and skills from a variety of subjects could be implemented through after-school club activities or through training sessions during summer vacations. Such enrichment programs could provide students enrolled in STEM pathways an opportunity to (a) review previously learned scientific principles and skills while learning new ones that are relevant to the design projects; (b) integrate principles and skills from various STEM subjects and non-STEM subjects (e.g., social study, arts.), into practical design

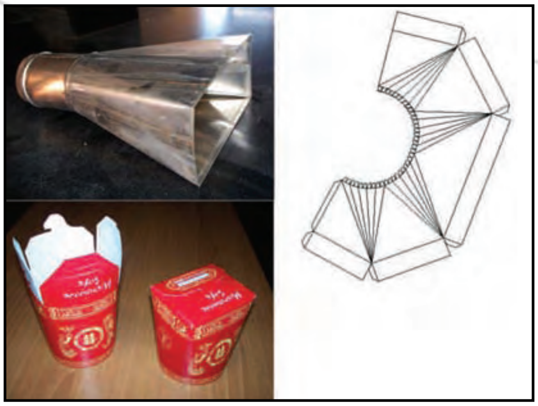

Figure 3. Examples of circle-to-square transition pieces (sheet-metal connector and restaurant take-home food container).

solutions; and (c) foster the ability to combine both "analytic reduction" and "system thinking" modes of the engineering design process, for solving real-world problems in a real-world manner. Mativo and Sirinterlikci (2005) developed an "animatronics" design project for student (Grades 7-12) It included an open-ended and creative project for the design of lifelike entertainment robots or dynamic and interactive animated toys with a mechatronic blob, penguin, robotic trash can, and a human-monster hybrid. These could cruise, wave swords, flip wings, and light eyes, in fun and creative team environments. They combined analytic and design skills from the following different but interconnected fields: (a) mechanical engineering (material and manufacturing process selection, including metals, ceramics, plastics and composites; mechanism design and assembly of levers and cranks, etc.); (b) electronics (actuators, sensors, controls); (c) microcontrollers' structure and programming; (d) emerging technologies, such as muscle wires, air muscles, micro- and nanocontrollers; (e) two- and three-dimensional art (costuming from fabrics to rubber Latex, and modeling), and (f) industrial product design. The implementation of this project indicated that students' academic performance improved through interdisciplinary engineering design activities. See figure 4. In summary, in addition to a Regular Curriculum, an Extracurricular Enrichment Program would be an effective supplement to help consolidate students' mastery of fundamental knowledge and creative design ability.

Potentially Realistic Students' Learning Outcomes

For students enrolled in K-12 Engineering Curriculum, when they graduate from high

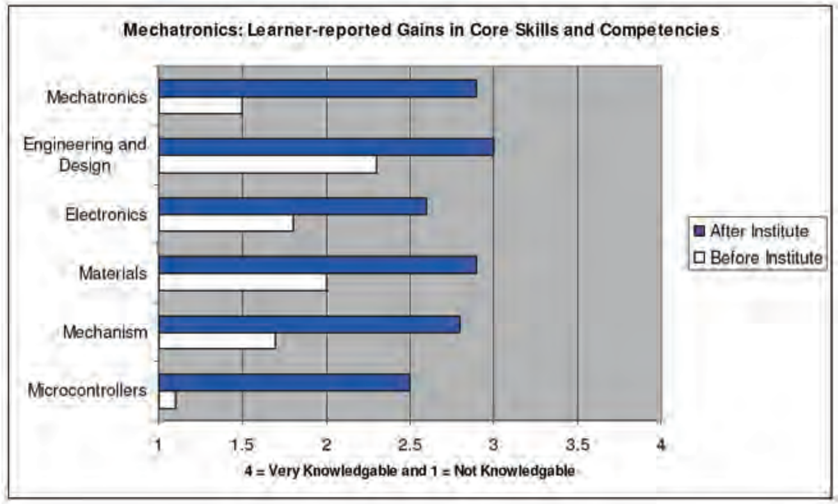

Figure 4. Sirinterlikci and Mativo's Animatronics project helped students improve STEM learning through inclusion of engineering design (Mativo & Sirinterlikci, 2005a).

schools, they could realistically be expected to have (a) built a solid foundation in precalculus mathematics and sciences; (b) learned the basics of engineering-related industrial arts and digital modeling and simulation technology; (c) mastered a sufficiently large portion of precalculus-based engineering analytic principles and predictive computational skills; and (d) become familiar with various modes of the engineering design process. These potentially realistic learning outcomes could give these students the freedom to choose any of the following:

(1) Enrollment in college engineering programs as full-time students with a solid mastery of the precalculus-based portions of foundation courses as well as practical engineering design and research skills; or

(2) Entry into job market as technical employees, such as CAD drafters with some entry-level ability to design simple products (e.g., furniture, tools, toys with electronic devices and kitchen appliances with simple circuitry and mechanical components), while enrolling as part-time students in engineering and technology programs, including two-year technical certificate or four-year bachelor of science degrees; or

(3) Enrollment in non-engineering university undergraduate majors (e.g., science and mathematics) with useful abilities and skills for lifelong career enhancement; for example, a future scientist or mathematicians would be able to design and prototype devices to facilitate experiments or teaching.

Notice that the aforementioned choices are simply convenient suggestions, and by no means do they constitute any intended idea about "academic tracking." If the Proposed Model were adequately implemented, then all students enrolled in K-12 STEM Career Pathways (all types of achievers), could be better prepared for a science or engineering major at the college level. Therefore, the Proposed Model should be considered as an egalitarian (although upward mobile and flexible) model that promotes equal preparation for college engineering majors from an academic perspective; it would be up to the students to choose their Career Pathways. The ultimate purpose of the Proposed Model is to educate new generations of innovative engineers or professionals in other fields. This could be accomplished by launching K-12 students early into engineering studies, so that they could foster analytic and innovative capacities early in life. Modern engineering education is more complicated than ever before, due to the explosion of new knowledge and technologies, especially those related to digital modeling and simulation. In addition, traditional engineering education has been somehow challenging to students due to heavy requirements on calculus-based mathematics, physics, and engineering course work. Therefore, engaging students early in the Engineering Career Pathways would make sense. It is not this author's expectation for K-12 students to become instantaneous robotic designers or spacecraft engineers (although the highest academic achievers among them should be given adequate preparation for careers of vital national interests). This is generally beyond their cognitive maturity (except in some high-achieving communities where economic and educational conditions might magically allow this to happen); instead, we should aim at matching K-12 engineering and technology education with the cognitive maturity level of average K-12 students. Taking the Mechanical Engineering Career Pathway as an example, they could be expected to graduate from the program with some creative abilities and analytic skills to design and prototype everyday products or systems, with simple mechanical and electronic components (either of their own design or from out-of-shelf selection), which are professionally ready for production or installation; and these could include toys, utensils, furniture, clothing, and fastening devices. This might be doable for average high school graduates. But they should not be expected to design robots except the very simple ones using out-of-shelf components. Expecting too much from K-12 students without a reasonable chance to succeed would not be the best way to prepare them for a brilliant engineering career. This line of thinking is compatible with the "everyday technology" idea of broadly defining "the term technology to include the artifacts of everyday life as well as environments and systems," of "focusing on the technologies of everyday life," and of allowing children to "solve problems of real significance in their lives," which have been explained by Benenson (2001, pp. 730-732), in presenting his 10-year long City Technology project.

Potential Benefits of the Proposed Model

The Proposed Model's most important potential benefit is the symbiotic integration of specific engineering analytic knowledge content with various modes of generic engineering design process, for it is self-evident that without teaching K-12 students particular age-appropriate engineering analytic and predictive knowledge content, they could not build a solid foundation of knowledge and skills for further study of engineering at college level. Also, without giving such students opportunities to practice age-appropriate engineering design, they would not be able to synthesize various sets of knowledge and skills into practical solutions of real-world problems and to form appropriate engineering thinking habits. The aim of infusing engineering analytic and predictive principles and computational skills into a potentially viable K-12 engineering curriculum is NOT to make students instruments of computations, or to encourage rote memorization of engineering analytic principles and computational formulas, or their applications in solving a few simple homework problems in the purely "Analytic Reduction" model (although all of the above are necessary tasks); however the aim is to foster the real ability of solving real-world problems, which involve integration of engineering analytic principles. It also involves, of course, computational formulas, from various subjects, as well as knowledge from art, social and ecological studies, and others, into a "system thinking" model of holistic problem solving. This focus on solving problems could foster students' real ability in innovative engineering design that is based on solid mastery of necessary analytic tools. This would allow them to use the generic engineering design approach to create real-world quality products and systems, which are appropriate to their age, technically feasible, and socially and ecologically appropriate.

Conclusions

This article has provided a workable framework for defining K-12 age-appropriate engineering knowledge content and an outline for a new paradigm for a streamlined, cohesive, and optimized lifelong STEM education in the United States, with a focus in engineering. For additional details of the Proposed Model, please contact the author at edwardnlocke@yahoo.com. In order to improve K-12 engineering education, the following recommendations and plans are hereby presented for consideration, support, and implementation:

1. <u>Organization:</u> Establish a network of stakeholders, to include, (a) government officers in charge of K-12 STEM education at Federal and state levels, (b) leaders of National Centers for Engineering and Technology Education and other institutions of authority in K-12 engineering education, (c) scholars in the fields of engineering and technology education from universities and research institutions, (d) school district administrators and engineering and technology teachers, (e) representatives from the business community and nonprofit organizations, and (f) university engineering students. This network could offer stakeholders an opportunity

to discuss specific policies, measures, actions to be taken for the solution of problems listed in the report by the Committee on K-12 Engineering Education (2009). It could also offer them criticism and advice regarding the improvement of the model of the K-12 Engineering Curriculum proposed in this article, so that it could eventually become a collective proposal accepted by all or most of the stakeholders.

2. Research: Continue research on defining K-12 age-appropriate engineering knowledge content from the following subjects: dynamics, strength of materials, material science, heat transfer, thermodynamics, engineering economics, aerodynamics, and mechanism design; this will lead to the eventual publication of *The Handbook of Proposed Engineering Topics with Analytic Principles, Computational Formulas and Units for K-12 Schools (with Reviews for Mathematics and Sciences).* This research constitutes the most important prerequisite for the implementation of the K-12 Engineering Curriculum proposed in this article. It would be an important reference for the development of K-12 engineering teaching materials and the improvement of K-12 engineering and technology teacher training programs.

3. Pilot study: K-12 schools (especially high schools, including charter schools) could be found to conduct pilot pedagogic experiments to determine the age-appropriateness of all K-12 feasible engineering analytic knowledge content to be identified in the above-mentioned *Handbook* to be published in the near future.

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References

Benenson, G. (2001). The unrealized potential of everyday technology as a context for learning. *Journal of Research in Science Teaching, 38* (7), 730-745

Claxton, A. F., Pannells, T. C., & Rhoads, P. A. (2005). Developmental trends in the creativity of school age children. *Creativity Research Journal, 17* (4), 327-335.

Committee on K-12 Engineering Education (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: National Academy of Engineering and the National Research Council.

Fleer, M. (2000). Working technologically: Investigations into how young children design and make during technology education. *International Journal of Technology and Design Education, 10*, 43-59.

Hill, R. B. (2006). New perspectives: Technology teacher education and engineering design. *Journal of Industrial Teacher Education, 43* (3), Retrieved February 2, 2009, from http://scholar.lib.vt.edu/ejournals/JITE/v43n3/hill.html

Lewis, T. (2007). Engineering education in schools. *International Journal of Engineering Education, 23*(5), 843-852.

Mativo, J., & Sirinterlikci, A. (2005a). AC 2007-730: *Innovative exposure to engineering basics through mechatronics summer honors program for high school students.* Retrieved January 30, 2009, from http://www.coe.uga.edu/welsf/faculty/mativo/index.html

Mativo, J., & Sirinterlikci, A. (2005b). *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition: A Cross-disciplinary study via animatronics.* Retrieved January 30, 2009, from http://www.coe.uga.edu/welsf/faculty/mativo/index.html

Mativo, J., & Sirinterlikci, A. (2005c). 2006-2505: *Summer honors institute for the gifted.* Retrieved January 30, 2009, from http://www.coe.uga.edu/welsf/faculty/mativo/index.html

National Science Foundation. (2008). *General science and engineering indicators of the digest of key science and engineering indicators 2008.* Retrieved January 30, 2009, from http://www.nsf.gov/statistics/digest08/pages/figure8.htm

Sanders, M. E. (2008, December). Integrative STEM education: Primer. *The Technology Teacher, 68*(4), 20-26.

Smith, P. C. (2007). *Identifying the essential aspects and related academic concepts of an engineering design curriculum in secondary technology education.* Unpublished internal research report, NCETE. Retrieved January 30, 2009 from http://ncete.org/flash/publications.php

Wicklein, R. C. (2006). Five reasons for engineering design as the focus for technology education. *Technology Teacher, 65*(7), 25–29.

Green Printing: Colorimetric and Densitometric Analysis of Solvent-based and Vegetable Oil-based Inks of Multicolor Offset Printing

H. Naik Dharavath and Dr. Kim Hahn

Abstract

The purpose of this study was to determine the differences in the measurable print attributes (Print Contrast and Dot Gain) and color gamut of solvent-based (SB) inks vs. vegetable oil-based (VO) inks of multicolor offset printing. The literature review revealed a lack of published research on this subject. VO inks tend to perform (color reproduction) better than petroleum inks; in recent years many printers have come to prefer using VO inks. This research adopted an experimental research method. The experiment was conducted in a computer to plate (CTP) based workflow. During the printing, once the density values met the standard (GRACoL) ink density values, the press was run continuously without operator interference and 1,000 sheets were printed, from which 278 were randomly selected for colorimetric and densitometric analysis. The color gamuts of both inks were derived by using colorimetric data. The comparison of SB inks to VO inks led to the conclusion that the latter provides a greater color gamut. VO inks offer greater color perception in printed images. The densitometric findings make it difficult to draw conclusions about print contrast, as each of the inks had statistically significant higher levels of print contrast for two of the four ink colors. Further study is needed to control the variables.

Keywords: Colorimetry, Densitometry, Vegetable Oil-based inks, Solvent-Based inks, Offset Printing, Dot Gain, and Print Contrast

Introduction

In multicolor offset printing, a paste ink of a given color – yellow, magenta, cyan, and black (CMYK) is transferred from the ink fountain to the series of inking rollers and from there to the image areas of the plate (image carrier). The inked image area of the plate is then transferred to the blanket, and from the blanket it is transferred to the paper. A continuous tone color, or black and white photograph, is composed of a full spectrum of shades and color, from near white to dense black. The method by which the continuous tone of a photograph is transformed to a printable image is called *halftoning*, in which varying percentages of the press sheet are covered with halftone dots to represent the varying tones in the image. In the conventional halftoning process these dots are equally spaced. However, the size or diameter of the dots will vary according to the amounts of light reflected from the tones in the original photograph. The ink printed by each dot, of course, has the same density. At normal viewing distance, the dots of a printed image combine to create an optical illusion of a single-tone image.

Lithographic (offset) printing is a planographic process, also known as *offset lithographic printing*. It uses a flat aluminum plate (image carrier) on which image and non-image areas are photochemically or electronically generated. The principle of lithographic printing (lithographic offset process) is that water (or dampening solution) and inks (or oil) do not mix. The image area of the plate is receptive to ink; the non-image area of the plate is receptive to water (Hseih, 1997). The dampening solution is a mixture of chemical concentrate in a water-based solution. The single color offset press consists of three cylinders: plate, blanket, and impression. The plate, which holds image areas in a readable direction, is mounted on the plate cylinder, its surface is dampened, and then the surface of the plate is contacted by a series of inked rollers. The inked areas (image areas) transfer first onto the surface of the blanket cylinder where they become reversed (or mirrored) and then onto the paper where they become legible. The paper passes between the impression cylinder and blanket cylinder. In order to print a quality halftone image according to the established production standards, the printer (or press operator) must carefully manage several variables and attributes that are associated with the printing process. The print attributes are individual characteristics within the printing process that can be monitored during the production process so as to maintain the color consistency. The commonly monitored attributes are solid ink density, dot gain and print contrast. For this study, only the attributes of dot gain, print contrast, and color gamuts of both inks were used to examine the differences between these types of printing inks. Most of the image details were evaluated with the use of these screened tints only.

Purpose of the Research

The purpose of this study is to identify the differences in measurable print attributes (or characteristics) and color gamuts of SB and VO inks that are used in multicolor (CMYK) offset printing. The following questions were investigated.

1. Is there a difference in the print contrast values (CMYK) of SB and VO inks?

2. Is there a difference in the dot gain values (CMYK) of the SB and VO inks?

3. Is there a difference in the color gamuts of the SB and VO inks?

Limitations of the Study

The print and color characteristics associated with the SB and VO inks are characterized by, but not restricted to, type of printing process, type of paper, and type of ink. Several variables affect the facsimile reproduction of SB and VO ink printed images and most of these variables are mutually dependent. The research was limited to the offset (lithography) printing systems and materials used at the University of Wisconsin-Stout's graphic communications laboratory, and the findings are not expected to be generalizable to other printing environments. For the purpose of densitometry, only the attributes of dot gain and print contrast were used to compare the two inks, because these were the two attributes that measured patches made up of dots or screened tint percentages. In addition, the color gamuts of SB and VO inks were also compared.

Review of Literature

Green printing is defined as a movement in the printing industry to use natural resources to develop sustainable solutions for the future of printing and print advertising (Argent, 2009). Choosing low-volatile organic compound (VOC) inks, using recycled or tree-farmed paper, working with local suppliers, and reducing the use of chemical products in the plate-making and printing areas are all part of this effort. In this article, we discuss using soy oil based ink or vegetable oil based ink for offset printing as one of the elements of green printing.

Print attributes are the individual characteristics within the printing process that can be measured and monitored during production so as to maintain a consistent quality. The most commonly monitored print attributes, and the ones of most interest to the researchers, are solid ink density, ink trapping, hue error, dot gain, print contrast, grayness, and gray balance (Lustig, 2001).

Solvent-based Inks vs. VegetableOil-based CMYK Inks

There are many environmental and technical design advantages to the use of vegetable-based oils. Vegetable oil in printing inks is a renewable resource and conserves finite petroleum supplies. Soybean oil does not evaporate the way petroleum does, and soybean oil does not release harmful VOCs into the air that contribute to smog. Petroleum-based inks contain relatively high levels of VOCs, which are regulated by the updated Clean Air Act, as are the alcohol in fountain solutions and the solvents used to wash presses between jobs. VO inks will reduce VOC emissions because they contain less than half the VOCs, require less alcohol, work more easily with alcohol substitutes, and can be washed up without solvents. These inks reduce emissions from >30% VOC to as low as 2 - 4% VOCs (Eco- and Mild Solvent, 2009). The printing press can be cleaned with a water-based cleaner, replacing a high-solvent cleaner and further reducing VOC emissions. The printed product is easier to de-ink in the recycling process and results in a less hazardous sludge (Evans, 1997).

VO inks tend to perform better than petroleum inks, and many printers have come to prefer them. Vegetable oils tend to be more translucent than the naturally murky petroleum oils (Comparing Inks, 2009). This makes pigment, especially reds and yellows appear brighter, deeper, and richer. Furthermore, a more vibrant color enables a given amount of VO ink to produce more impressions than the same amount of petroleum-based ink, which can result in a 5-50% increase in transfer efficiency. VO inks are less likely than petroleum-based inks to build up on the printing plate, so facilities remain cleaner. This is the case because vegetable oil's boiling point is significantly higher than that of petroleum oil; it is less likely to become volatile at high temperatures. In addition, VO inks can reduce ink and paper waste because the balance between ink and water is easier to achieve. These inks are well suited to uncoated and recycled stocks because they do not spread as much. In addition, they are not more costly than petroleum-based inks. Another benefit of VO inks is their "low rub-off" quality in which the ink is less likely to stain readers' fingers or clothing.

However, the disadvantages of VO inks include their slower drying time, particularly on uncoated paper because they penetrate paper more slowly and are set primarily by oxidation (Alternatives to Petroleum, 1997). Most VO inks contain some petroleum oil to speed up drying or setting time and the amount of vegetable oil replacing the petroleum oil can vary by manufacturer and by press type and ink color. Pure formulation VO inks cannot be used in heat-set ink processes. To achieve appropriate drying times for these processes, vegetable oil may replace a portion of the petroleum oil. If no petroleum oil were used, print shops would increase their energy use for heating and drying the ink, thus counteracting the environmental benefits of using VO inks (Alternatives to Petroleum, 1997).

Densitometry

A densitometer indirectly measures the amount of light absorbed by a surface (Brehm, 1992). There are two types of densitometers: transmission and reflection. Transmission densitometers measure the amount of light that is transmitted through a transparent material, such as a halftone film or color negative. Reflection densitometers measure the amount of light reflected from printed material or continuous tone photographs (Brehm, 1992). In the prepress and printing/press areas of the industry, densitometry allows one to find a balance for accurate tone reproduction. Hseih (1997) stated that a densitometer can measure either incident light reflected from a substrate (reflection density), light transmitted through a film (transmission density), or both. In prepress and printing/press areas, Status T densitometers have been used extensively. Status T is the American National Standard Institute/International Organization for Standardization (ANSI/ISO) standard for wide-band densitometer response for measuring print attributes (Brehm, 1992). These instruments are important quality control tools for the industry. In the printing/press area, a reflection densitometer measures the characteristics of print attributes, such as solid ink density, ink trap, dot gain, print contrast, and gray balance. In the prepress area, a transmission densitometer measures halftone film density and dot area values, which are used to linearize the filmsetter.

Dot Gain (DG)

Dot gain, also called tone value increase (TVI), is the apparent increase in halftone dot size from the halftone film to the printed sheet (Hsieh, 1997). It is caused by several technical variables associated with prepress and press devices, and it directly affects the accuracy of reproduction by causing darker tones or stronger colors. For technical reasons and because of the effect of light entrapment, printing without dot gain is impossible (Hsieh, 1997). Lychock (1995) stated that dot gain is inherent to the printing process and will always be present in conventional pressrooms. Dot gain is a function of density and compares a tint CMYK patch to a solid CMYK patch. Dot gain includes both mechanical and optical gain. Mechanical gain is the actual growth of the physical halftone dot; optical gain is how the dot appears to the human eye due to the refraction of light on the substrate (X-Rite, 2003).

Most of the pictorial information in printed halftone images is present in the tonal or tinted areas. Measuring dot gain value at 25% (highlight), 50% (midtone), and 75% (shadow) dot area for each CMYK color is a quick indication of the tone reproduction quality. Dot gain affects the midtones (50%) the most, because the 50% dot is the largest dot formed in the halftoning process (Lychock, 1995). Dot gain can cause an overall loss of definition and details, color changes, and problems with contrast, ink hues, ink density, and "trapping" (Hsieh, 1997). The dot gain among the three CMY colors is critical for gray balance and for maintaining critical overprint colors, such as flesh tones, green grass, and blue sky (X-Rite, 2003). Apparent dot area is the percentage of dot area, as measured and calculated with a densitometer, using the Murray-Davies (M-D) equation. The following equation is used to calculate the dot gain or TVI values (CGATS. 1993, Reaffirmed 1998, p. 7).

Percentage of Apparent Dot Area =

$$(1-10^{-(D_{(t)} - D_{(p)})}) / (1-10^{-(D_{(s)} - D_{(p)})}) \times 100$$

where: $D_{(t)}$ = Density of tint
$D_{(s)}$ = Density of solid
$D_{(p)}$ = Density of the paper/substrate

Print Contrast

Print contrast is also known as shadow detail of an image. A multi-colored (or grayscale) printed image is evaluated its image quality by examining the shadow details, approximately at 70% - 80% dot area. It indicates how well shadow detail is maintained or kept open in a halftone printed image. Print contrast is a ratio of the 75% screen dot density to solid density. It means the visual performance characteristic that illustrates the printing system's ability to hold image details in the upper tonal areas. Print contrast is a good indication of print quality because shadow detail carries important information in many CMYK printed images. Print contrast values correlate well to the subjective evaluations of print quality, such as low print contrast values as opposed to high print contrast values (X-Rite, 2003). The print contrast values require both high density and sharp printing to maintain shadow detail. The following equation is used by the densitometers to calculate the percentage print contrast values (CGATS1993, Reaffirmed 1998, p. 8).

Percentage of Print Contrast =
$(D_{(s)} – D_{(t)}) / (D_{(s)}) \times 100$

where: $D_{(s)}$ = Density of solid
$D_{(t)}$ = Density of tint, typically 75%

Colorimetry

A spectrophotometer measures the amount of light reflected from a surface. The result will be a dataset of reflectance values that represents response values can be obtained in CIE XYZ and L* a* b* scales. The following equations are used by the spectrophotometer to calculate the CIE L* a* b* values (CGATS2003, p. 28).

$L^* = 116 (Y/Y_n)^{1/3} – 16$

$a^* = 500 [(X/X_n)^{1/3} – (Y/Y_n)^{1/3}]$

$b^* = 200 [(Y/Y_n)^{1/3} – (Z/Z_n)^{1/3}]$

where: X_n, Y_n, Z_n: Tristimulus Values of XYZ for 2° Standard Observer

***CIE Color Difference* ΔE)**

Assessment of color is more than a numerical expression. In most cases it's an assessment of the deviation in the color sensation (delta) from a known standard. In CIELAB color model, any two colors can be compared and differentiated. These color differences are expressed as **ΔE** (Delta E or Difference in Color Sensation). The following equation is used to calculate the **ΔE** (CGATS. 2003, p. 29).

$\Delta\mathbf{\Delta E} = ÷(L_1 – L_2)^2 + (a1 – a_2)^2 + (b_1 – b_2)^2$

where: 1 = Color 1 and 2 = Color 2

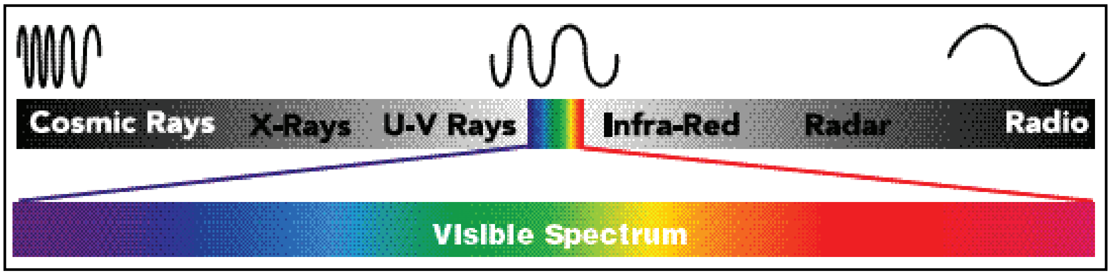

Figure 1. Schematic diagram of visible spectrum (Courtesy of X-Rite).

the spectral distribution of the light reflected from the point of the measurement. This means that the starting point will be at 380 nanometers (nm). The spectrophotometer then controls how much of the particular wavelength is reflected. The result will be a percentage value. This procedure is then repeated for the entire spectrum (each wavelength), and the resulting dataset can be visualized as a spectral curve. The visible spectrum normally ranges from 380 nm to 780 nm, and most spectrophotometers sample it every 10th nm (see Figure 1). These data are general and can vary depending on the device being used. When comparing data in colorimetry, it is important to consider both the structure of the device and the illumination source. A spectrophotometer is the most accurate instrument with which to measure color. The spectral distribution curve can also be used to calculate densitometric and colorimetric values. Spectral

Research Method

This research included an experimental research method. A layout was created for a 17.5" x 23" press sheet utilizing a custom Four-Color target. The target contained the following elements: CMYK tone scale, RGB overprints, IT8.7/3 image with 1379 patches, P2P25X image, ISO 300 image, color control bars, and other multicolor images. During the printing, these elements are used to evaluate the subjective and objective aspects of the image quality (see Figure 2). Figure 2 represents a partial portion of this test target. The data contained in this study were obtained by measuring the printed patches of this target (see Figure 2).

The layout was processed through Prinergy Evo Raster Image Processor (RIP). It was output using a conventional halftone screen at 175 lines per inch (LPI), with elliptical dot shape by using the Creo Trendsetter Computer to Plate (CTP)

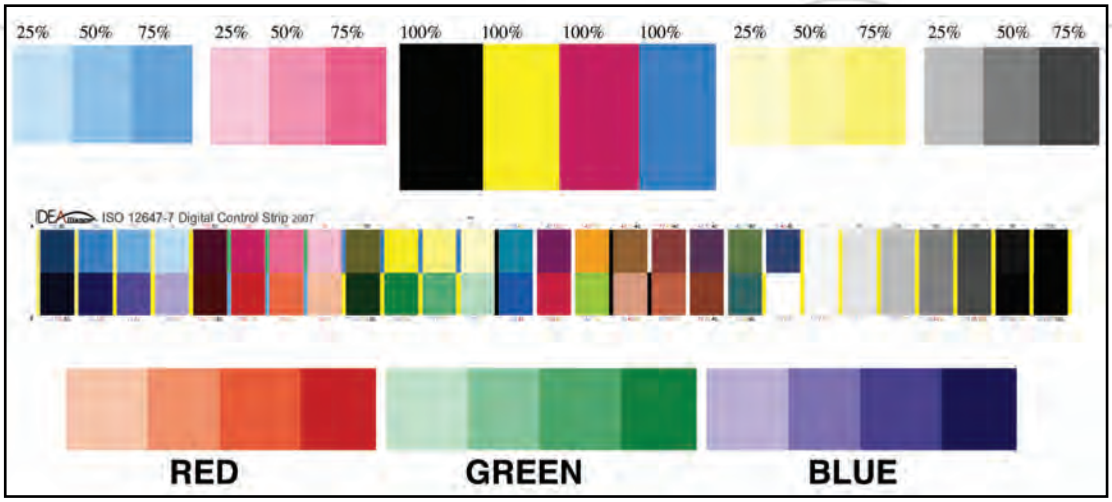

Figure 2. Custom four-color (CMYK) test target.

device and two sets (VO and SB inks) of linear CMYK (four) offset plates were made, each set for the two types of ink. Linear plates were made by not using the previous dot compensation curve at the RIP in order to have input dots equal to output dots. Output dot values on the plates were measured and recorded for the plate curve (see Figure 3) by using Troika LithoCam plate dot reader via the LithoCam 2.5 interface application.

After the plates were made for the SB inks, a pilot test was conducted to achieve the target ink density values according to GRACoL standards. During the pilot test, 1000 (*N*) sheets were printed. Once density values had been achieved according to the standard ink density values, the press was run continuously without operator interference and another 1000 (*N*) test sheets were printed, from which a total of 278 (*n*) sheets were randomly selected for the analysis. The machine (ink/printing units) was cleaned for the second run. Table 1 presents the variables, materials, conditions, and equipment associated with the prepress and press parts of this experiment.

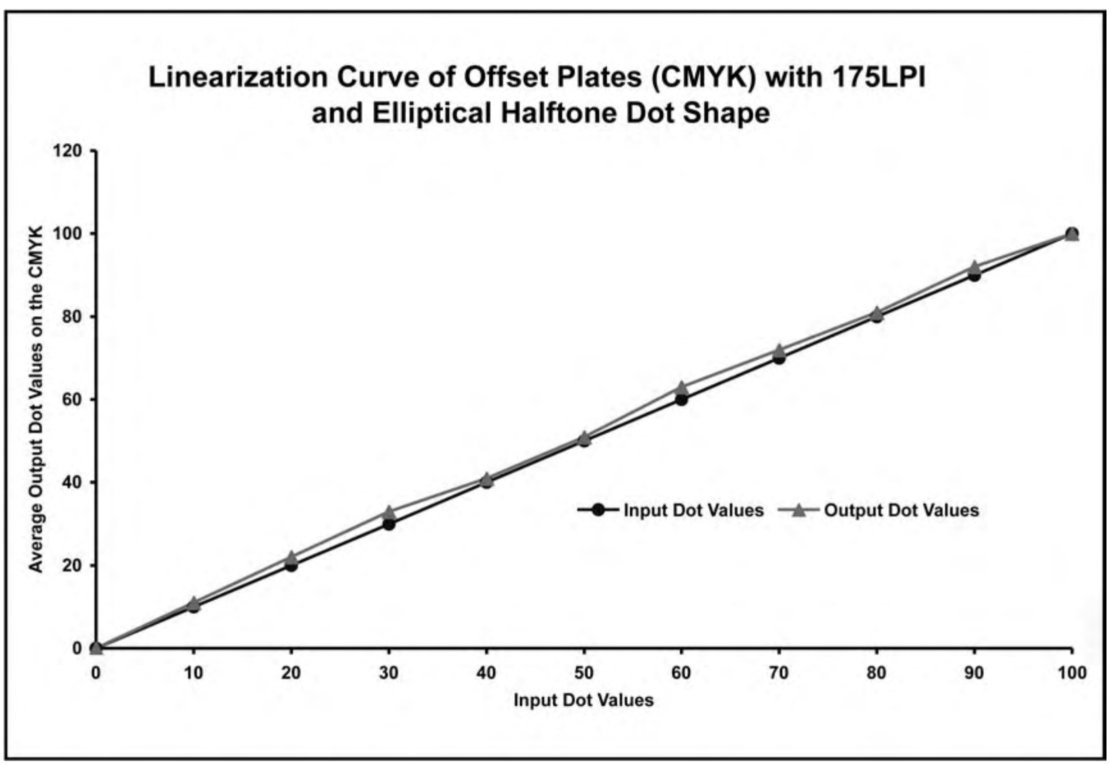

Figure 3. Plate linearization curve

Table 1. Prepress and Press: Experimental and Controlled Variables.

Variable	Material/Condition/Equipment
Test Image	GCM Custom 17.5" x 23" Four-Color (CMYK)
Page Layout	Adobe In Design CS-3
RIP	Prinergy EVO
CTP	Creo Trendsetter 400 Quantum
Plate	Kodak SWORD Digital Thermal
Plate Processor	Kodak Polychrome
Plate Chemistry	Kodak Polychrome Developer and Fixer
Dot Reader	Troika LithoCam
Dot Reading Application	LithoCam 2.5.4
AM Screen Line Ruling	175 LPI
AM Screen Dot Shape	Elliptical Dot
AM Screen Angles	C = 105°, M = 45°, Y = 90°, & K = 75°
Target SID values (+/- 0.10)	K = 1.30, C = 1.15, M = 1.15, and Y = 0.90
Achieved average SID values (+/- 0.10)	K = 1.30, C = 1.15, M = 1.15, and Y = 0.90
Paper (Substrate)	Unisource 80 LBS. Uncoated
Solvent-based ink	Flint Sheetfed Solvent Offset Process Colors
Vegetable (soy bean) oil-based ink	Handschy Soybean Offset Process Colors Printing
Press	Heidelberg SM-74 Four Color
Press Speed	6000 IMPH
Blanket to Impression Pressure	0.04 to 0.10 mm
Ink Sweeps (KCMY)	53, 53, 55, and 52
Dampening Solution	RBP Fountain Solution
Dampening Solution PH	4.5
Dampening Sweeps (KCMY)	6
On-Press SID Measurement/Control	X-Rite ATD Scanning Densitometer
Data Collection	X-Rite 528 Spectrodensitometer
Press Operator(s)	Lab Manager and Students
Data Collection and Analysis Software	MS-Excel and ColorShop X

The same procedures were applied for printing with the VO inks. The sample size was selected in order of the specific confidence interval (a = 0.05). A random sampling technique was used to identify the sample size because of the large size of total population. During the printing, an X-Rite ATD Scanning Densitometer was used to control the solid ink density on the press. After the printing, an n X-Rite 528 Spectrodensitometer was used to collect the colorimetric and densitometric data from the sample. Christensen (1980) provides an objective method to determine the sample size when the size of the total population is known. The total population for this study is 1000 (N) printed sheets. The following is the formula to determine the required sample size. It was determined that the sample size for this study is 278 (n) printed sheets.

$$n = x^2 NP (1-P) / d^2 (N-1) + x^2 P (1-P)$$

n = the required sample size

x^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.84)

N = the total known population size

P = the population proportion that it is desired to estimate (.50)

d = the degree of accuracy expresses as a proportion (a = 0.05)

Data Analysis and Research Findings: Vegetable Oil-based Inks vs. Solvent-based Inks

A total of 278 randomly selected samples (printed sheets) were analyzed for each set of ink. Colorimetric and densitometric data were generated by using an X-Rite 528 Spectrodensitometer from the printed sheets. Descriptive and inferential statistics were the statistical procedures used to analyze the data. An independent samples one-tailed *t*-test was conducted to determine if any statistical differences exist between the mean scores of print attributes (dot gain and print contrast) of both inks. Colorimetric data and ΔE was used to compare the color gamuts of both inks. In comparing the differences between two colors, a higher ΔE is an indication of a greater color variation and lesser the ΔE is an indication of less color variation. However, the subjective judgment of color difference could differ from person to person. For example, people see colors in an image, not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003). In addition, people see colors by mentally processing contextual relationships among colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (A New Test Method, 2003). The results of analysis are presented in the following section.

Dot Gain

The mean scores, standard deviations, and *t*-values associated with the dot gain at the 50% dot area of VO and SB inks are compiled in Table 2. A significant difference was found in the dot gain at the 50% dot area when comparing the dot gain of the VO inks to that of the SB inks (CMYK). Dot gain in three (CMK) of four color inks (CMYK) of the SB inks were higher than in the VO inks, while the dot gain of VO yellow ink was higher. All details in an offset printing are achieved by the use of a halftone dot. The greatest dot gain at 50% dot area was found in the yellow VO ink and the magenta SB ink, while the black color of both inks had the smallest standard deviation when compared to the other colors (see Table 2). Even small differences in dot gain at the midtone area can lead to color shift (see Figures 4 to 6).

Table 2. Comparison of Mean Scores (Vegetable oil and Solvent-based Inks) of CMYK Dot Gain (DG) at 50% Dot Area.

	Vegetable Oil		Solvent		
	n = 278		n = 278		
Process Ink	M (%)	SD (%)	M (%)	SD (%)	t-value
Cyan	25.00	2.00	27.00	3.00	2.00*
Magenta	27.00	1.00	29.00	2.00	2.00*
Yellow	29.00	1.00	27.00	1.00	12.50*
Black	23.00	1.00	25.00	2.00	2.00*

*t 0.05 (554 df) = 1.648

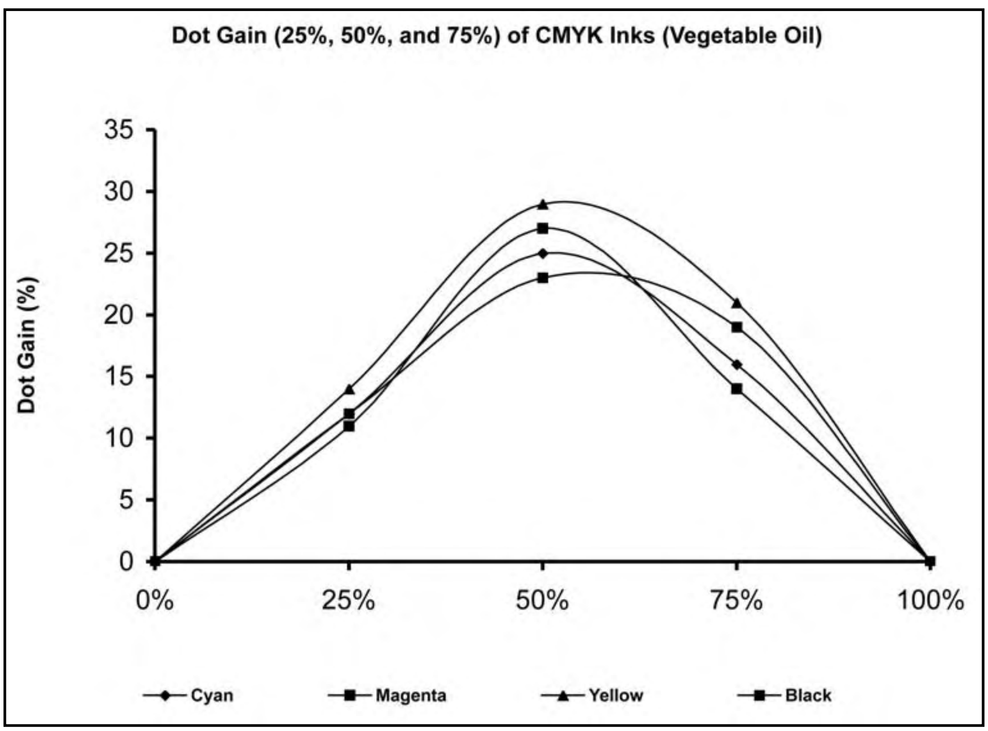

Figure 4. Dot gain curve of vegetable oil-based CMYK inks

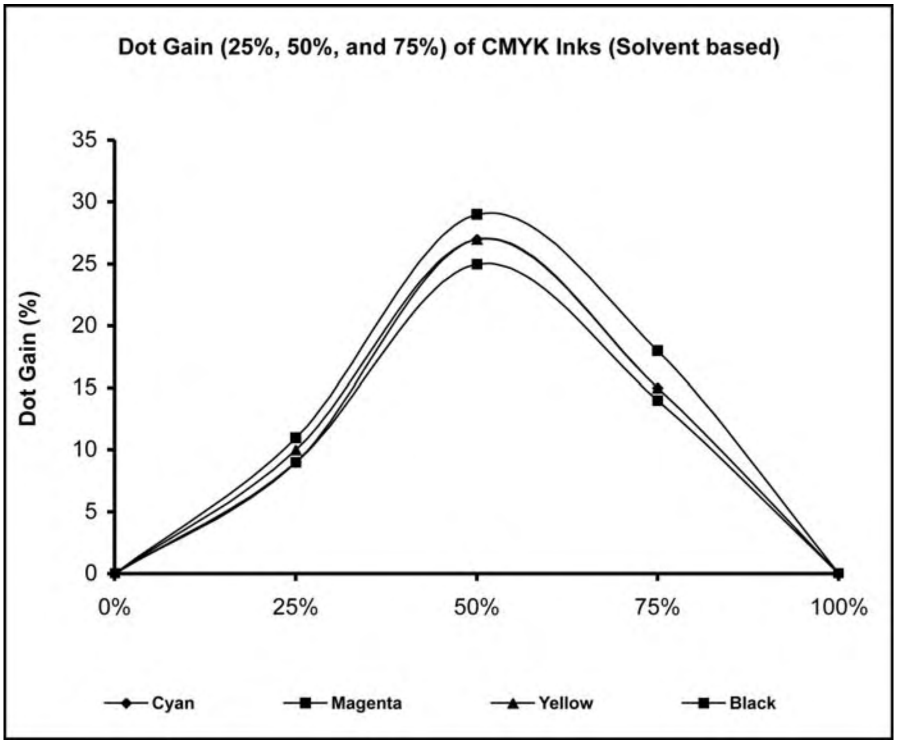

Figure 5. Dot gain curve of solvent-based CMYK inks

Color Variation in the Midtone (50% dot) Area of Vegetable Oil vs. Solvent-Based Inks

The CIE L* a* b* values associated with the CMYKRGB colors in midtone (50% dot area) color areas of VO vs. SB inks are compiled in Table 3. Numerical and visually noticeable color differences (ΔE) were found when comparing the VO inks (color) with the SB inks in the midtone area of the printed image on all seven colors (CMYKRGB). VO inks produced higher L* a* b* values in yellow, red, and green inks (bigger gamut) than for SB inks. In contrast, both inks have not produced same/similar color gamut in the midtone areas (see Figure 6), except the printed proof consists of same colors in magenta, cyan, and blue. The 2D color gamut comparison (see Figure 6) reveals a significant color difference between the two inks.

Print Contrast

The mean scores, standard deviations, and t-values associated with the print contrast of vegetable oil- and solvent-based inks are compiled in Table 4. Statistically significant differences were found when comparing the print contrast of the VO to SB inks (CMYK). The print contrast in two (CM) of four color inks (CMYK) of the VO ink was higher than that of the SB ink, while the color print contrast of the black and yellow inks was higher for the SB inks. A low print contrast indicates loss of details in shadow areas, while high print contrast requires both

Table 3. Color Variation in the Midtone (50% Dot) area of CMYKRGB of Vegetable Oil vs. Solvent-Based Inks.

	Vegetable Oil			Solvent based			Color
Color(s)	L* Color 1 n = 278	a*	b*	L* Color 2 n = 278	a*	b*	Difference ΔE
Yellow	91.56	-4.84	46.23	91.23	-2.01	39.15	7.63
Red	70.43	27.88	26.95	72.17	27.63	22.97	4.35
Magenta	73.45	30.8	-4.38	72.80	33.17	-4.27	2.46
Blue	63.77	13.22	-18.68	63.03	12.52	-20.75	2.31
Cyan	74.38	-14.21	-19.23	78.69	-15.01	-20.88	4.68
Green	76.86	-21.99	-22.78	75.86	-21.58	15.00	7.85
Black	65.09	0.51	0.64	69.34	0.89	1.11	4.29

high density and sharp printing to maintain the shadow details. Shadow details with higher print contrast were noticeably better than in the lower print contrast image. This visual result is in agreement with the print contrast values of the two inks. The largest print contrast was found in VO magenta color: 35.31% and 31.17 % for SB ink. In addition, the magenta color of the VO ink image and the black color of the SB ink image had the smallest standard deviation when compared to the other colors (see Table 4). Due to the mechanical deviation, it is possible that not all the colors have the same pattern of print contrast between the VO and the SB inks.

Color Variation in the Print Contrast (75% dot) Area of Vegetable Oil vs. Solvent-Based Inks

The CIE L* a* b* values associated with the CMYKRGB colors in shadow (75% dot area) color area of VO vs. SB inks are compiled in Table 5. Numerical and visually noticeable color differences (DE) were found when comparing the VO inks (color) with SB inks in the midtone area of the printed image on all seven colors (CMYKRGB). VO inks produced higher L* a* b* values in yellow, red, and green inks (bigger gamut) compared to SB inks. In contrast, both inks did not produce the same/similar color gamut in the midtone areas (see Figure 6) except on the printed proof, which consists of the same colors in magenta, cyan, and blue. The 2D color gamut comparison (see Figure 6) reveals a significant difference in color between the two inks.

Color Variation in the Print Contrast (75% dot) Area of Vegetable Oil vs. Solvent-Based Inks

The CIE L* a* b* values associated with the CMYKRGB colors in shadow (75% dot area) color area of VO vs. SB inks are compiled in Table 5. Numerical and visually noticeable color differences (ΔE) were found when comparing the VO inks (color) with SB inks in the midtone area of the printed image on all seven colors (CMYKRGB). VO inks produced higher L* a* b* values in yellow, red, and green inks (bigger gamut) compared to SB inks. In contrast, both inks did not produce the same/similar color gamut in the midtone areas (see Figure 6) except on the printed proof, which consists of the same colors in magenta, cyan, and blue. The 2D color gamut comparison (see Figure 6) reveals a significant difference in color between the two inks.

Table 4. Comparison of Mean Scores (Vegetable oil vs. Solvent-Based Inks) of CMYK Print Contrast at 75% Tint.

	Vegetable Oil		Solvent		
	n = 278		n = 278		
Process Ink	M (%)	SD (%)	M (%)	SD (%)	t-value
Cyan	33.06	2.98	9.72	3.77	4.23*
Magenta	35.33	1.88	30.39	4.07	2.26*
Yellow	22.78	3.42	27.94	3.13	17.79*
Black	28.61	2.20	31.17	2.28	3.37*

*t 0.05 (554 df) = 1.648

Table 5. Color Variation in the Print Contrast (75% Dot) area of CMYKRGB of Vegetable Oil vs. Solvent-Based Inks.

	Vegetable Oil			Solvent based			Color
	L*	a*	b*	L*	a*	b*	Difference
Color(s)	Color 1			Color 2			ΔE
	n = 278			n = 278			
Yellow	90.39	-5.75	65.61	89.86	-3.5	58.77	7.22
Red	61.62	42.29	22	61.6	36.17	18.79	6.91
Magenta	61.67	44.00	-3.73	63.69	47.78	-3.41	4.30
Blue	51.94	17.65	-26.04	52.39	18.29	-28.36	2.45
Cyan	71.07	-21.49	-28.22	72.00	-21.69	-29.77	1.82
Green	68.38	-33.93	29.02	67.24	-33.64	21.33	7.78
Black	57.13	0.68	1.43	56.46	0.97	1.98	0.92

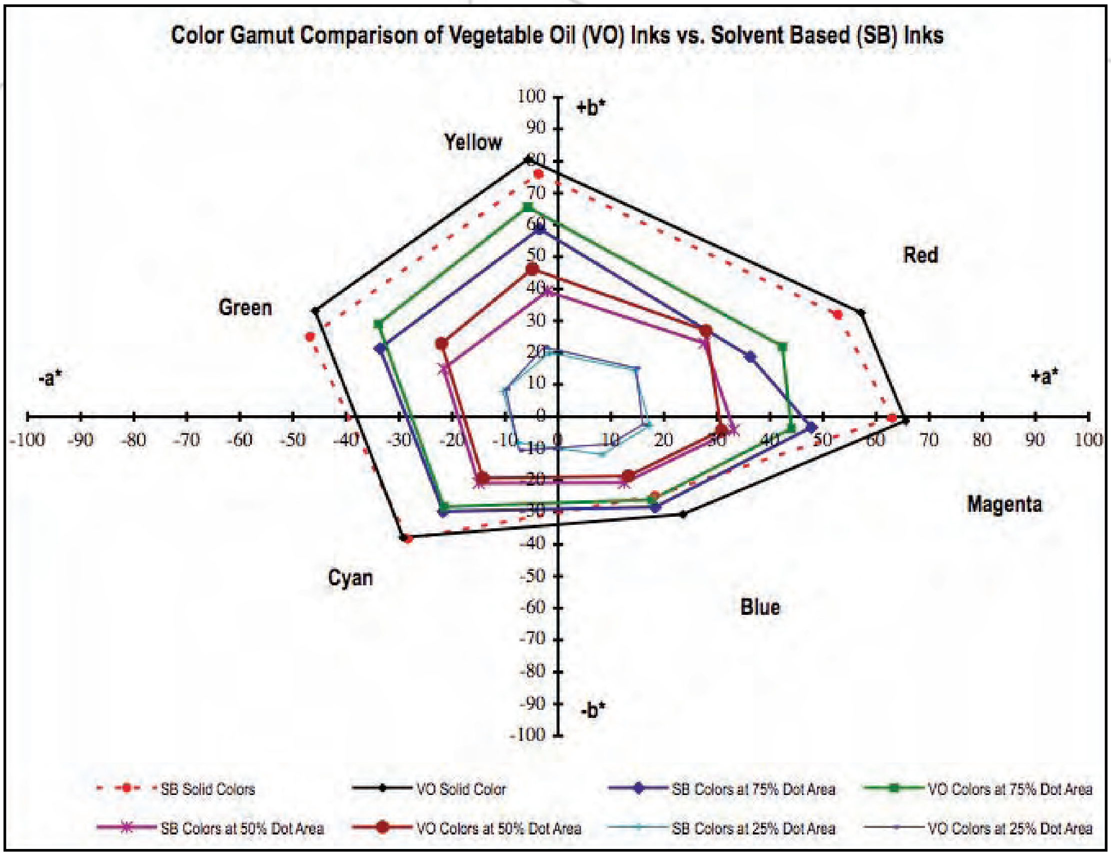

Figure 6. CIE L* a* b* 2D-model for VO Inks vs. SB inks CMYK color gamut comparison.

The measured L* a* b* data was not reported for the highlight and solid colors of VO inks vs. SB inks. The values were used to construct the major color gamut (see Figure 6). The visual comparison of the gamut reveals that only the colors from the 25% dot area of the inks have the same gamut (similar or identical colors). As the dot area increases (50%, 75%, and 100%), the color shift is occurring, mostly with yellow, green, and red. In comparison, VO inks produced better colors (green, red, and yellow) than did the SB inks.

Conclusions and Recommendations

The conclusions of this study are based on results of the data analysis. The findings of this study represent specific printing or testing conditions. The screening technologies, paper, ink, dampening solution, film and plate imaging system, and printing process that were used are important factors to consider when evaluating the results. The findings of this study may not be generalized to other printing conditions. However, the findings of this research suggest that VO inks provide greater print contrast than do SB inks under specific printing conditions. This provides greater detail in the shadow areas (CM) of printed images. The black and yellow inks' print contrast ran counter to this conclusion, which suggests the need to explore other factors or variables that may have contributed to this result. Variables to explore include print order or printing unit: ink color interaction.

SB inks had statistically significant higher levels of dot gain for three of the four ink colors. A lower dot gain in VO ink resulted in a better color gamut in the midtones and shadow areas. Again, further study is needed to attempt greater control of variables. A more deliberate process of press calibration would also be recommended in a future study. The margin for error is much smaller with SB inks, requiring a carefully calibrated and controlled press platform. Qualitative analysis is also something to be pursued. A panel of experts could provide qualitative analysis regarding their preference for one ink or the other.

In comparing the color gamut of both types of inks from highlight color areas to solid color areas, VO inks produced better visual colors than the SB inks. This suggests that the VO inks are environmentally friendlier and can be used for better color reproduction. This experiment revealed that the VO inks produce better colors than do SB inks. Green printing is an environmentally friendlier, healthier, and safer approach to printing that requires only a small amount of energy. The question is, how many printers are going green? Additionally, if printers are not doing so, why not? Answers to these questions would require additional study to determine the status of using VO inks in the printing industry.

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References

Alternatives to petroleum- and solvent-based inks. (1997). Retrieved September 14, 2009, from The Massachusetts Toxics Use Reduction Institute Website:http://www.p2pays.org/ref/11/10142.htm

Argent, David (2009). *How to become a green printer.* Retrieved March 16, 2010, from Penton Media website: http://pffc-online.com/print/become_green_printer_0109/

Brehm, P. V. (1992). I*ntroduction to densitometry: A user's guide to print production measurement using densitometry.* Alexandria, VA: Graphic Communications Association.

Christensen, L. B. (1990). *Experimental methodology.* Boston, MA: Allyn and Bacon.

Committee for Graphic Arts Technologies Standards [CGATS]. (1993, Reaffirmed 1998).

Graphic technology – graphic arts reflection densitometry measurements – terminology, equations, image elements, and procedures. (ANSI/CGATS.4-1993). Reston, VA: NPES, The Association for Suppliers of Printing and Publishing Technologies.

Committee for Graphic Arts Technologies Standards [CGATS]. (2003). Graphic technology – spectral measurement and colorimetric computation for graphic arts image. (ANSI/CGATS.5-2003). Reston, VA: NPES, The Association for Suppliers of Printing and Publishing Technologies.

Eco- and mild solvent products help provide more options for output providers. (2009). Retrieved September 23, 2009, from Wide-Format Imaging Website: http://www.wideformatimaging.com/publication/article.jsp?pubId=2&id=260&pageNum=1

Evans, P. (1997). *The complete guide to eco-friendly design.* Cincinnati: North Light Books. Comparing inks. (2009). Retrieved October 10, 2009, from Executive Summary Website: www.pages.drexel.edu
A new test method based on CIELAB Colorimetry for evaluating the permanence of pictorial images. (2003). Retrieved January 20, 2006, from Goodhard, M. M., & Wilhelm, H. Website:http://www.wilhelm-research.com.

Hsieh, Y. C. (1997). Factors affecting dot gain on sheetfed offset presses. *Journal of Visual Communications, 1*(1), 37-39.

Lustig, T. (2001). Sheetfed specs proposed. *Graphic Arts Monthly, 73*(7), 64-65.

Lychock, G. (1995). *Dot area, dot gain, and n-factor* [Brochure]. X-Rite, Incorporated.

X-Rite, Incorporated. (2003). *A guide to understanding graphic arts densitometry* [Brochure]. Grandville, MI: Author.

Pedagogical Content Knowledge and Industrial Design Education

Kenneth R. Phillips, Michael A. De Miranda, and Jinseup "Ted" Shin

Abstract

Pedagogical content knowledge (PCK) has been embraced by many of the recent educational reform documents as a way of describing the knowledge possessed by expert teachers. These reform documents have also served as guides for educators to develop models of teacher development. However, in the United States, few if any of the current models accurately address the role of PCK in the development of industrial design educators. This article introduces the concept of PCK and how a taxonomy of essential industrial design subject matter can be organized to serve as a content guide. The PCK model presented could serve as a catalyst for the field of industrial design education to produce a conceptual framework and taxonomy for the teaching of industrial design upon which future PCK studies in industrial design education can be based. These conceptual frameworks (or taxonomies) help within a field to articulate the core knowledge, skills, and dispositions that define practice. The interaction of teacher content knowledge in industrial design, pedagogical knowledge, and context of industrial design is framed within a PCK taxonomy.

Introduction and Background

Theoretical Framework

The notion of pedagogical content knowledge (PCK) was first introduced to the field of education by Lee Shulman in 1986 and a group of research colleagues collaborating on the Knowledge Growth in Teaching (KGT) project. The focus of the project was to study a broader perspective model for understanding teaching and learning (Shulman & Grossman, 1988). Members of the KGT project studied both how novice teachers gained new understandings of their content and how these new understandings interacted with their teaching. The researchers of the KGT project described PCK as the intersection of three knowledge bases coming together to inform teacher practice: subject matter knowledge, pedagogical knowledge, and knowledge of context. PCK is described as knowledge that is unique to teachers and separates, for example, an industrial design (ID) teacher/professor from a practicing industrial designer. Along the same lines, Cochran, King, and DeRuiter (1991) differentiated between a teacher and a content specialist in the following manner:

> Teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field (p. 5).

Geddis (1993) described PCK as a set of attributes that helped someone transfer the knowledge of content to others. According to Shulman, it includes "most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1987, p. 9).

In addition, Shulman (1987) suggested that PCK is made up of the attributes a teacher possess that help her/him guide students towards an understanding of specific content, such as industrial design, in a manner that is meaningful. Shulman argued that PCK included "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8). In light of what industrial design educators should know and be able to do, Shulman (1987) might assert that PCK is the best knowledge base of teaching and suggested:

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are

pedagogically powerful and yet adaptive to the variations in ability and background presented by the students (p. 15).

Therefore, the intersection of industrial design content knowledge and the pedagogical knowledge of industrial design instructors, depends on the ability of design educators to transform this knowledge into a design rich adaptive instruction that unifies these elements of PCK into successful instruction (Mishra & Koehler, 2006). Figure 1 helps to capture this complex relationship between content knowledge, knowledge of teaching, professional design context, and their interaction in an instructional setting.

Figure 1 helps to conceptualize the complex relationship between a teacher's content knowledge in industrial design in addition to knowledge required to infuse these concepts into classroom instruction. This knowledge combined with an instructor's general knowledge of pedagogy helps to contribute to a specialized form of pedagogical knowledge in industrial design education. In addition, the specialized knowledge of industrial design is often highly contextualized in the form of authentic application to design problems that are relevant to professional practice.

While content *knowledge* refers to one's understanding of the subject matter, and *pedagogical knowledge* refers to one's understanding of teaching and learning processes independent of subject matter, *pedagogical content knowledge* refers to knowledge about the teaching and learning of particular subject matter, taking into account its contextual learning demands. The rationale for doing this is appropriately suggested by Geddis (1993):

> The outstanding teacher is not simply a 'teacher,' but rather a 'history teacher,' a 'chemistry teacher,' or an 'English teacher.' While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach,' but rather 'how to teach electricity,' how to teach world history,' or 'how to teach fractions.' (p. 675)

Additionally, one could add, 'how to teach concept visualization skills,' or 'how to teach manufacturing processes,' or 'how to teach computer aided design.' Obviously, the demands of learning about concept visualization skills are different from the demands of learning about manufacturing processes. Good teachers are able to carefully analyze the various sorts of content-specific demands in each of these areas related to teaching industrial design.

Each industrial design educator has a unique knowledge of specific domains spanning multiple content areas based on his/her industrial experience. This professional experience is what informs quality instruction when

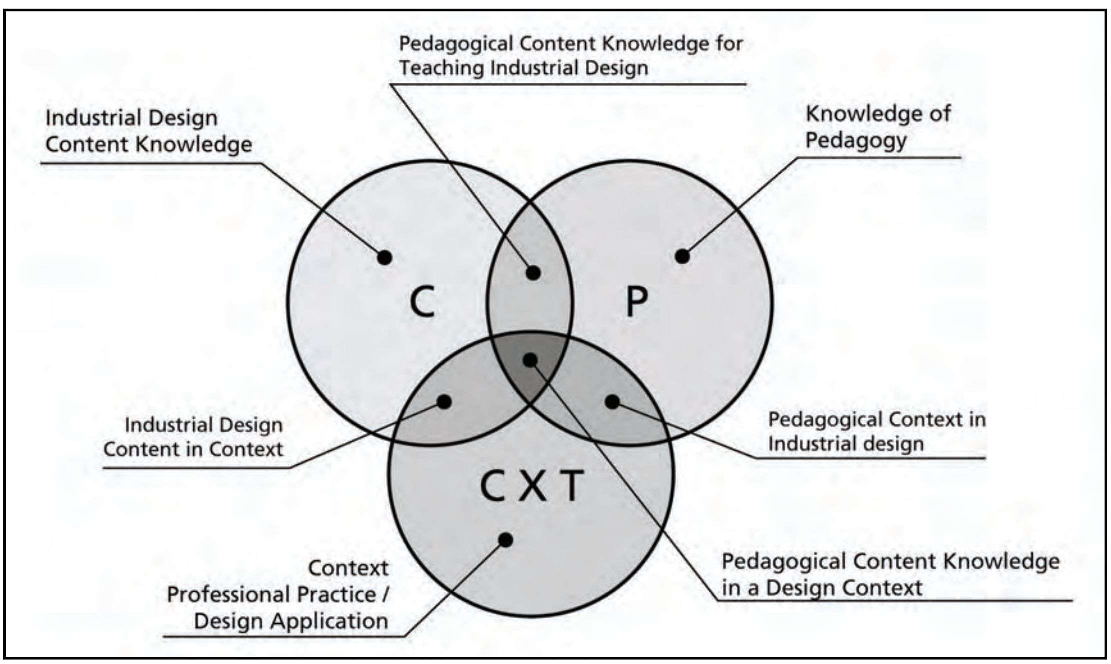

Figure 1. Model of content knowledge, pedagogy, and context in industrial design education.

combined with overall content knowledge and pedagogy. Quality design educators have come to know the subject matter in industrial design, not only for the content itself, but also in terms of its "teachability" and "learnability." Shulman (1986, p.9) conceptualized these as the "transformation of subject-matter knowledge into forms accessible to the students." The implications for this in terms of quality industrial design instruction will require this blending of content knowledge, professional design context, and knowledge of pedagogy. Geddis (1993) informed us that "in order to be able to transform subject matter content knowledge into a form accessible to students, teachers need to know a multitude of particular things about the content that are relevant to its teachability" (p. 676). Developing ways to do this is indeed the creation of new knowledge of a type that characterizes the good teacher, and it is part of her/his professional skill. The design education community must recognize the requirement for teachers to invent this new integrated knowledge.

The continued interest in PCK as an epistemological perspective in the preparation of industrial design educators may provide an opportunity to frame and guide the transition of industrial design professionals to becoming industrial design educators. The PCK model could serve as a catalyst for the field of industrial design education to produce a conceptual framework and taxonomy for the teaching of industrial design upon which future PCK studies in industrial design education can be based. These conceptual frameworks (or taxonomies) help within a field to articulate the core knowledge, skills, and dispositions that define practice (Travers, 1980).

PCK and the Training of Industrial Design Educators

Pedagogical content knowledge research and its implications for design education have important messages for the teaching and learning of industrial design and the infusion of design concepts into the curriculum. Commenting on criteria used for evaluation of teaching in the 1980s, Shulman (1986, p.5) asked, "Where did the subject matter go? What happened to the content?" Of course we should attempt to advance educational theory, in the same way that any other discipline does "pure research."

But surely advances in theory of a discipline have only one purpose: to reflect back on, and improve, the practice of that discipline. Perhaps a productive path to travel is to examine more critically the concept of PCK and what it means or could mean to the preparation of future industrial design educators. In addition, examining the notion of PCK can inform an understanding of what is required to teach and infuse critical design concepts in the industrial design classroom. This will require those in the field of industrial design to move ahead of many technical fields in articulating a conceptual framework that supports a taxonomy of industrial design content knowledge; a task that may be close at hand.

Why Taxonomies and Conceptual Frameworks Matter in a PCK Model

Many have specific taxonomies to aid the understanding of PCK within the content area. For example, two explicit taxonomies are available in science education literature, and there is a framework in technology education literature that can help guide the emerging field of engineering and technology education in understanding the PCK required to deliver meaningful engineering content (McCormick & Yager, 1989; Neale & Smith, 1989, Lewis & Zuga, 2005). Shulman (2002) advanced a taxonomy of learning one can liken to the original work of Benjamin Bloom (1956) to extend a deeper understanding of learning. In each case, a taxonomy designed to organize content or concepts in a field helped to stir discourse and clarify learning and outcomes. Likewise there is a good base of research literature on the categories that should be taught in industrial design, yet there is no current taxonomy or framework developed to facilitate understanding the PCK required to prepare industrial design professionals to succeed as educators (Croston, 1998; NASAD, 2008; Yeh, 1999). The development of such a framework to guide what should be taught in industrial design education could provide a basis for informing a quality industrial design educator. The industrial design content literature and accreditation requirements like standards and content schemes in other fields may provide a starting point for the development of such a conceptual framework and essential knowledge hierarchy to benefit the field (Koehler & Mishra, 2008).

Accreditation and Guidelines for Industrial Design Education

The accrediting body in the United States for industrial design programs is the National Association of Schools of Art and Design (NASAD). NASAD is the only accrediting agency covering the field of art and design recognized by the U.S. Department of Education. NASAD provides basic criteria for member institutions, general standards and guidelines for all undergraduate degree programs in the visual arts and design, and standards and guidelines for specific professional degree programs, such as industrial design. Industrial design education involves a combination of the visual arts disciplines and technology, utilizing problem-solving and communication skills.

Specific NASAD standards and guidelines for industrial design programs include the following.

Curricular structure. Curricular structure, content, and time requirements shall enable students to develop the range of knowledge, skills, and competencies expected of those holding a professional baccalaureate degree in industrial design. Curricula to accomplish this purpose normally adhere to the following guidelines: studies in industrial design comprise 30-35% of the total program; supportive course in design, related technologies, and the visual arts, 25-30%; studies in art and design history, 10-15%; and general studies and electives, 25-30%. Studies in industrial design; supportive courses in design, related technologies, and the visual arts; and studies in art and design histories normally total at least 65% of the curriculum.

General studies. The NASAD standards provide guidelines for a well-rounded general education for industrial design education programs. Concepts and courses from the physical and natural sciences, the social sciences, and the arts and humanities are important for industrial designers. These guidelines provide the freedom for institutions to strengthen industrial design education by integrating courses and creating innovative interdisciplinary programs.

Essential competencies. The NASAD standards provide guidance in the essential or core knowledge competencies for industrial design education. This is perhaps the most informative component of the NASAD standards that can inform a framework that defines the content knowledge component of the PCK model. The knowledge competencies include the following:

(a.) A foundational understanding of how products work; how products can be made to work better for people; what makes products useful, usable, and desirable; how products are manufactured; and how ideas can be presented using state-of-the-art tools.

(b.) Knowledge of computer-aided drafting (CAD), computer-aided industrial designs (CAID), and appropriate two-dimensional and three-dimensional graphic software.

(c.) Functional knowledge of basic business practices, professional practice, and the history of industrial design.

(d.) The ability to investigate and synthesize the needs of marketing, sales, engineering, manufacturing, servicing, and ecological responsibilities and to reconcile these needs with those of the user in terms of satisfaction, value, aesthetics, and safety. Industrial designers thus must be able to define problems, variables, and requirements; conceptualize and evaluate alternatives; and test and refine solutions.

(e.) The ability to communicate concepts and requirements to other designers and colleagues; to clients and employers; and to prospective clients and employers. These communication skills include verbal and written forms, 2-D and 3-D media, and levels of detailing ranging from sketch or abstract to detailed and specific.

(f.) Studies related to end-user psychology, human factors, and user interfaces.

These essential competencies could serve the field as a catalyst for articulating the content knowledge that defines the core body of knowledge that interacts with pedagogy and context in the PCK model of understanding industrial design learning and instruction.

Essential opportunities and experiences. A unique feature of the NASAD standards guide is the inclusion of essential opportunities to learn and professional experiences. These areas are often neglected in other fields of study and could serve as a model for other technical fields. The essential opportunities to learn and experience include the following:

(a.) Opportunities for advanced undergraduate study in areas that intensify already-developed skills and concepts and that broaden knowledge of the profession of industrial design. Studies might be drawn from engineering, business, the practice and history of visual art, design, and technology, or interdisciplinary programs related to industrial design.

(b.) Easy access to computer facilities; woodworking, metalworking, and plastics laboratories; libraries with relevant industrial design materials; and other appropriate work facilities related to the major.

(c.) Internships, collaborative programs, and other field experiences with industry groups are strongly recommended whenever possible.

(d.) Participation in multidisciplinary team projects. (NASAD, 2008).

These essential competencies could serve the field as a catalyst for articulating the context or professional practice that define how the core body of knowledge is applied. This has a direct influence on the pedagogy and content in the PCK model of understanding industrial design, learning, and instruction. The essential core competencies, the essential opportunities to learn, and the experiences position the field of industrial design well ahead of many other technical fields in building a PCK model for learning and instruction.

Connecting Research and Defining Critical Content to Inform PCK

Robert Croston from Drexel University conducted a survey in 1997-1998 on the growth of the industrial design profession and what practicing designers expected in an industrial design curriculum. Employers of industrial designers rated subject area categories as "very important," "needed," or "unimportant." The categories that were selected for the research may lend themselves to the creation of a taxonomy for PCK research in industrial design. Movement toward a taxonomy of knowledge within a field has often been elusive in technical fields of study. Examining what the core content is through research and polling of experts adds external validity to the content component of a PCK model. Croston's (1998) categories that resulted from his research are listed in the following paragraph, and they parallel many of the accreditation areas. The critical content expressed by practicing professionals in the industrial design field include the following:

> Creative problem solving, 2-D concept sketching, verbal and written communication, materials and manufacturing process, computer-aided industrial design, multi-disciplinary interaction, concept model making, internship or co-op experience, design theory, mathematics and science, graphic design, engineering technologies, cognitive and consumer psychology, research and documentation, marketing and business practice, history of art and design, and arts and humanities.

Although the information about what practicing professionals viewed as important in these categories is interesting and speaks to PCK, the more relevant information for this discussion is the categories that were selected. Croston's (1998) own conclusions stress the importance of teaching students through experimenting, model making, prototyping, and testing. These allow design students to understand the tangible nature of the products they design for people to use, and they address the concept of ID context and its relevance to PCK (Croston, 1998).

Wen-Deh Yeh from the University of Wisconsin – Madison (1999), conducted another informative piece of survey research searching for strengths and weaknesses in industrial design curriculums. Yeh identified seven critical competence categories made up of 69 specific competencies for industrial design graduates. Yeh surveyed industrial design educators, graduates, and employers of industrial designers regarding the importance of the individual competencies. The top five competencies reported for industrial designers were: creativity, knowledge of three-dimensional form, ability in problem solving, ability in visualizing design, and critical thinking. Specifically, Yeh's study concluded that the central competencies of industrial designers should include the following:

- Problem-solving abilities
- Creative thinking and conceptualization
- Communication skills, visual, oral, and written
- Knowledge of human factors
- Knowledge and hand-on experience of manufacturing technology
- Form-developing skills
- Model-making skills
- Technical-drafting ability

In addition, the ability to use computer/technology to aid in the design processes and the knowledge of business practices should be integrated into industrial design education. Finally, Yeh recommended that being a continual learner is critical to an industrial designer who wants to keep himself/herself up-to-date. In light of PCK and the role content taxonomies play in defining teacher content knowledge, these findings reflect some of the knowledge, skills, and dispositions required of industrial designers.

The organization of domains of appropriate industrial design content, principles, and classroom practice within a taxonomy or hierarchy of essential content knowledge can help industrial design educators define what students both *need to know* and *be able to do* to become practicing professionals in the field. A taxonomy of hierarchical domains in the study of industrial design as opposed to the practice of design, could serve as a catalyst in helping design educators negotiate the inherent overlap between general design content knowledge, professional practice and design application context, and pedagogical knowledge. The development of an explicit teaching and learning taxonomy for the study of industrial design would alleviate the diffusion of a curriculum that claims to teach design while providing clear guidance for curriculum development. A well-understood taxonomy would also facilitate meaningful communication and cooperation among industrial design educators (Wiley, 2001). Conversation and efforts could turn to more significant work on *how to teach* rather than expend resources on *what to teach*. A well-designed taxonomy can guide the design education community and would set the stage for pedagogically powerful and yet adaptive ways that teachers could respond to varying student ability and background ; such a tool could lead to powerful teaching.

Challenges to Developing Industrial Design Educators

There are several professional complexities that interact to challenge the conceptualization of PCK for design education. Of significant challenge is the transitional phase that prevents industrial design practicing professionals from becoming industrial design educators. These professional “border crossings” between professional practice and education are not easily facilitated. Perhaps the foremost issue here is the discrepancy between compensation for successful industrial design practitioners and the design educator. Based on a salary survey conducted by a popular design website, http://www.Coroflot.com in 2007, the average salary of U.S. industrial design educators was $51,833 (an average high salary was $74,500). Professional practitioners’ average salary was $79,198 (an average high salary was $175,000). Considering the significant salary gap and the additional years spent to earn the required Master’s Degree to teach at the college or university level, industrial design educator salaries are even lower in terms of real earnings compared to the practicing industrial design professional. The 2000 compensation study conducted by the Industrial Designers Society of America reported sharp salary increases at all experience levels of practicing industrial designers; however, the salaries of educators with equal years of experience appeared unchanged and substantially lower than the salaries of professionals. Although this case can be made for many technical fields, smaller fields of study (like industrial design education) perhaps are affected more than larger fields.

Another key element here is the broad range of essential competencies knowledge that is required to teach industrial design effectively. A significant question remains: what level of knowledge across each of these interacting subjects does a teacher need master to effectively achieve a level of PCK in order to teach industrial design in an integrated manner? This issue represents the tension raised by Shulman (1986, 1987) on how teachers and practicing professional arrange, use, and access (or think about) knowledge within a field differently. Professionals in industrial design are constantly changing, moving, growing, and learning; they must remain current to stay competitive in an evolving market. To these professionals, nothing is more excruciating than the prospect of becoming stagnant. As a result, they may change jobs more frequently. In contrast, it appears that the "senior faculty members" or industrial design educators that have remained with a single university for an entire career make fewer job changes and repeatedly teach fundamental or core content; they have few opportunities to innovate through leading-edge contemporary design problems. Novak (2003) went as far as to assert that, many of these faculty appear to be somewhat inept in their design abilities, which may suggest that they have somehow found a place to hide.

Another issue in the quality of teaching in industrial design is the lack of training in instructional techniques and pedagogical methods for most design educators. Even if the best-facilitated border crossing could be made by bringing a practicing professional into the ranks of industrial design educator, the pedagogical component of the PCK model of instruction would be deficient. Practicing professionals can use their own instincts for teaching coupled with the teaching models that they encountered as they received their own design education. An educator who graduated from a small program would have a particularly limited frame of reference for appropriate pedagogy. This issue could perhaps be addressed by the professional organizations, like the Industrial Designers Society of America (IDSA), that offer workshops for design educators at annual conferences to increase their pedagogical knowledge. Prospective design educators also could consult the resources available to learn pedagogical techniques in technical fields (e.g., the classic, *Instructors and their Jobs* by Miller and Miller (2008). The benefit of looking at the challenges of industrial design education through the PCK concept is to allow the creation of an organizational framework for design education. This should allow an investigation into what knowledge and skills are consistently taught in the essential categories discussed in the prior taxonomy section, and the pedagogical techniques typically utilized. This research in design education should provide a means to improve overall design instruction.

Implications for Industrial Design Programs and Teaching

Why do offer PCK as an essential part of thinking about industrial design education? PCK can help educators to move on to consider the problems they face by the bifurcation of content and pedagogy implicit in standards and explicit in university practices. And finally educators can begin to examine the assumptions of industrial design, the industrial design education community, and the roles that PCK plays in this community. The general PCK interrelationships and the potential creation of a taxonomy of PCK for industrial design attributes can provide a relatively comprehensive categorization scheme for future studies of PCK development in design education (Koehler & Mishra, 2008). An interest in PCK as an epistemological perspective and as a knowledge base for design educators has produced a need for a conceptual framework upon which future PCK studies can be based. The need for taxonomies and frameworks suggested in this article provide some insight into where additional thought is necessary in industrial design education as members of the field grapple with the infusion of an ever-changing technological evolution. First, the general taxonomy of PCK will allow researchers and industrial design education programs to more accurately identify and address distinctions among knowledge bases of various industrial design disciplines, technological subjects, and topics regarding professional practice. Thus, it can provide a classification scheme for implementing unique instructional methods in the industrial design education classroom. Second, the taxonomy of PCK attributes can help researchers who study knowledge development in industrial design teachers to identify and characterize different attributes of industrial design teaching; these include content domain knowledge, pedagogy, and context to form a rich and flexible knowledge base for industrial design educators. In addition, these authors recognize the relative importance that researchers and educators have given to the different components of PCK. The need for organizational frameworks and taxonomies in industrial design education provides an opportunity to organize and integrate research efforts centered on PCK and its application in design education.

The use of taxonomies and frameworks as a foundation for future research also can provide a model for industrial design educator preparation. For example, conference and workshop programs could focus on developing topic-specific PCK for prospective design educators. Many potential industrial design educators know their content well, but they may not have learned how to transform or translate that knowledge into meaningful instruction that students can access.

What is necessary is the effective use of exemplary models of design education within topics that can later be transferred to another topic or domain. They can then apply these strategies to other topics and domains based upon their content backgrounds (Darling-Hammond, 1991).

Directly or indirectly, industrial design education programs could benefit from further PCK research. One obvious area is to identify and classify the various types of PCK employed in the industrial design classroom that appropriately infuse content knowledge and professional practice context into instruction. The importance of sponsored projects and input from current professionals outside of the faculty are also concepts that should be explored. It is our hope that the development of taxonomies will provide a foundation for future research and further discussion concerning the preparation of highly qualified industrial design educators. It is vital that all educators, develop an understanding about how to teach integrated domains in a manner that reflects the knowledge of today's industrial design content, the benefits of professional experience, and knowledge of pedagogical methods.

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References

Bloom, B. S. (1956). *The Taxonomy of Educational Objectives: Cognitive Domain.* New York: David McKay

Cochran, K. F., King, R. A., & DeRuiter, J. A. (1991). *Pedagogical content knowledge: A tentative model for teacher preparation.* East Lansing, MI: National Center for Research on Teacher Learning.

Coroflot Design Salary Survey. (2007). Retrieved October 10, 2009, from http://www.coroflot.com.

Croston, R. (1998). Industrial design employment and education survey. *Why design? IDSA National Education Conference Proceedings.* CD-Rom Dulles, V. Industrial Designers Society of America

Darling-Hammond, L. (1991). Are our teachers ready to teach? *Quality Teaching, 1*(1), 6-7.

Geddis, A. N. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 15*(6), 673-683.

Industrial Designers Society of America. (2000). *Salary compensation survey results.* Dulles, VA: IDSA

Koehler, M. J., & Mishra, P. (2008). Introducing TPACK. In AACTE Committee on Innovation & Technology (Eds.). *Handbook of technological pedagogical content knowledge for educators* (pp. 3-29). New York: Routledge.

Lewis, T., & Zuga, K. F. (2005). *A conceptual framework of ideas and issues in technology education.* Retrieved October 10, 2009, from http://teched.vt.edu/ctte/HTML/Research1.html.

McCormack, A. J., & Yager, R. E. (1989). A new taxonomy of science education. *Science Teacher, 56*(2), 47-48.

Miller, W.R., & Miller, M. F. (2008). *Instructors and their jobs.* (4th ed.). Orland Park, IL: American Technical Publishers

Mishra, P., Koehler, M. J. (June, 2006). Technological pedagogical content knowledge: A Framework for teacher knowledge. *Teachers College Record 108(6)*, 1017-1054.

National Association of Schools of Art and Design (ed.) (2008). *National association of schools and art design handbook.* Reston, VA: NASAD.

Neale, D., & Smith, D. (1989). Configurations checklist for evaluating a teaching performance. *Teaching and Teacher Education, 5*(1), 1-20.

Novak, J. (2003). Identifying causes for the shortage of high-quality industrial design education. Retrieved October 6, 2009, from www.idsa.org/ webmodules/Articles/articlefiles/ John_Novak_Paper_2.pdf

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. Harvard *Educational Review, 57*(1), 1-22.

Shulman, L., & Grossman, P. (1988). *The intern teacher casebook.* San Francisco: Far West Laboratory for Educational Research and Development.

Shulman, L. (2002). *Making differences: A table of learning Change.* Retrieved October 6, 2009, from http://www.carnegiefoundation.org/elibrary/docs/making_differences.htm

Travers, R. M. W. (1980). Taxonomies of educational objectives and theories of classification. *Educational Evaluation & Policy Analysis, 2*(2), 5-23.

Wiley, D. A. (2001). Connecting learning objects to instructional design theory: A definition a metaphor, and a taxonomy. In D. A. Wiley (Ed.), *The Instructional use of learning objects.* Bloomington, IN: Association for Educational Communications and Technology. Retrieved October 6, 2009, from http://reusability.org/read/chapters/wiley.doc

Yeh, W. D. (1999). *Critical competencies for baccalaureate industrial designers.* Symposium at the Chicago 99 – Design Education Conference Industrial Design Society of America, Chicago, IL.

Epistemological Beliefs of Engineering Students

Bethany A. King and Susan Magun-Jackson

Abstract

This study examined undergraduate and graduate engineering students' epistemological beliefs as a function of their educational level. Schommer's (1998) Epistemological Questionnaire was used to assess the beliefs in quick learning, certain knowledge, fixed ability, and simple knowledge of 396 students attending two universities in Western Tennessee. Additional analyses examined the effects of background characteristics, such as gender, ethnicity, and high school grade point average. Results indicated that freshmen and sophomores were more likely than juniors and seniors to have beliefs in quick learning and certain knowledge above and beyond the effects of the background characteristics. There were no significant differences in graduate students' and undergraduate students' beliefs. The results of this study also indicate that engineering students' beliefs are related to their advancement in problem-solving processes in an undergraduate engineering curriculum.

Keywords: college students, engineering education, epistemological beliefs

Epistemological Beliefs of Engineering Students

For the past years, there have been reports that address the concern that the United States is globally losing its competitive edge in the fields of Science, Technology, Engineering, and Mathematics (STEM) (Committee on Science, Engineering, and Public Policy [COSEPUP], 2007). The United States' competitive edge in STEM fields is important to maintain because science and technology perpetuate growth in the economy and contribute to national security. Furthermore, there is a concern that as American science and engineering workers approach retirement, the number of scientists and engineers to replace them will constantly decline (COSEPUP, 2007). As a result, the engineering community has started a reform in engineering education (National Academy of Engineering [NAE], 2005). A primary step in implementing this reform is to understand what constitutes the nature of engineering knowledge ("The Research Agenda," 2006).

What is Epistemology?

Epistemology is a branch of "philosophy concerned with the nature and justification of human knowledge" (Hofer & Pintrich, 1997, p. 88). First influenced by the genetic epistemology research of Jean Piaget, educational psychologists study epistemological development and beliefs to determine how students come to know what beliefs they have about knowledge and how epistemological beliefs affect cognitive processes (Hofer & Pintrich, 1997). For example, William G. Perry, Jr. is credited for being the first educational psychologist to study the educational experiences of college students (Perry, 1970). Since then, Perry's research has served as a framework for epistemological development studies (Culver & Hackos, 1982; Fedler & Brent, 2004; Hofer & Pintrich, 1997; Schommer, 1990).

Perry's Model

Perry is considered by many as the pioneer of epistemological development studies of college students (Hofer & Pintrich, 1997; Muis, 2004). Using open-ended questions, Perry (1970, 1988) conducted two longitudinal studies in which he interviewed male college students about their perceptions of what influenced their college experience. He noticed changes in the students' thinking processes (Perry, 1970), and these changes occurred in patterns as they progressed through college (Perry, 1988). Using these patterns, Perry (1988) mapped the students' college experiences and developed the foundation of his epistemological development theory. His theory consisted of four broad classifications that represent the students' overall views: in dualism, knowledge was based on one right answer from an authority figure, in multiplicity, knowledge was based on differing opinions, in relativism, knowledge was dependent on a given scenario, and in commitment, knowledge was a decision based on known information. Research studies have shown that most engineering undergraduates complete college in the lower classifications of either dualism or multiplicity (Culver & Hackos, 1982; Felder & Brent, 2004; Fitch & Culver, 1984; Marra & Palmer, 2004; Pavelich & Moore, 1996).

Compared to other epistemological theories, Perry's theory has been the one most applied to engineering education (Fedler & Brent, 2005).

Schommer's Model

Being the first to develop a quantitative measure of epistemological beliefs, Schommer's (1990) research was different from other epistemological beliefs models in that she suggested that epistemological beliefs were not unidimensional, but multidimensional and independent (Schommer 1990, 1993, 1997; Schommer & Walker,1995). She suggested that the epistemological beliefs system consisted of five dimensions; however, as her research continued, only four dimensions consistently appeared in factor analysis results. These four dimensions each had a dichotomous relationship of either a naïve belief or a sophisticated belief. The dimensions were structure of knowledge (knowledge was either simple and consisted of isolated pieces of information or complex and consisted of interdependent pieces of information), certainty of knowledge (knowledge was either absolute and not changing or continuously evolving), control of knowledge (knowledge was fixed or incrementally increased and improved), and speed of knowledge (knowledge was quickly obtained or perceived as a gradual process) (Hofer & Pintrich, 1997; Schommer 1993, 1997; Schommer & Walker, 1995). Although not used as often as Perry's (1970) framework, Schommer's (1990) questionnaire has served as a framework for several epistemological studies that evaluated engineering students (Jehng, Johnson, & Anderson, 1993; Paulsen & Wells, 1998; Schommer, 1990; Schommer, 1993; Trautwein & Ludtke, 2007).

Epistemological Beliefs Studies of Engineering Students

Perry framework. In 1996, Pavelich and Moore used Perry's epistemological development model to rate undergraduate engineering students on their perceptions of knowledge and found significant differences in the ratings between freshmen and seniors, between freshmen and sophomores, and between sophomores and seniors. In another study, Wise and colleagues (2004) found that educational level also had a significant effect on engineering students' Perry ratings; there were significant differences between students' freshman and senior years and between their junior and senior years. Although Marra, Palmer, and Litzinger (2000) did not consider educational level, their study examined the effects of a first-year design course on engineering students' epistemological beliefs. They found that students who took the course had significantly higher Perry ratings, which were above and beyond the effects of math and verbal SAT scores and GPA, than students who had not taken the course. In addition, Marra and Palmer (2004) found that engineering students' Perry ratings were correlated with the use of engineering design principles in solving ill-structured problems. Students who were skilled in solving ill-structured problems were more likely to have higher Perry ratings than students who were not skilled in solving ill-structured problems. In this same vein, Palmer and Marra's (2004) study found that engineering students who were exposed to open-ended problem solving within a science domain were more likely to have higher Perry ratings in epistemological beliefs related to the science domain than their Perry ratings in the beliefs related to the humanities/social sciences domain.

Schommer Framework. After the initial and trailblazing development of the Schommer Epistemological Questionnaire (SEQ) (Schommer, 1990), Schommer (1993) conducted a study with community college students and university students and found that community college students were more likely to believe that knowledge was simple, certain, and quick, whereas university students were more likely to believe that knowledge was innate. In another study, Jehng, Johnson, and Anderson (1993) conducted a cross-sectional investigation and found that graduate students were less likely than undergraduate students to have beliefs in certain and simple knowledge. In addition, upper level undergraduate students were less likely than lower level undergraduate students to have certainty beliefs. Jehng and colleagues (1993) also found that engineering students were the most likely of students in all fields to believe that knowledge was certain. In a similar study, Paulsen and Wells (1998) found that students' epistemological beliefs became more sophisticated as they progressed in their levels of education. Also, engineering students were more likely than those students in humanities/arts, social sciences, and education to believe that knowledge was certain, simple, and acquired quickly beyond the effects of age, gender, education level, and GPA. In a study that only examined certainty beliefs, Trautwein and Ludtke (2007) found that engineering students were more likely to have naïve certainty beliefs than students in other academic majors (e.g., humanities/arts, mathematics/natural sciences, business, social sciences, medicine, and law). In addition, engineering students were the only group to show an increase, although slight, in their certainty scores during the period of the study.

Statement of the Problem

Epistemological beliefs of college students have been examined by both qualitative and quantitative research methods. Studies that have used both of these methods provide support that epistemological beliefs become more sophisticated as students' educational level advances (Jehng, et al., 1993; Paulsen & Wells, 1998; Pavelich & Moore, 1996; Schommer, 1993; Wise et al., 2004). Although qualitative research methods have been used to solely examine engineering students, a gap in the literature exists in that quantitative studies have not been conducted to solely examine the relationship between epistemological beliefs (in each of the four dimensions) and educational level of engineering students. Hence, the purpose of this study is to use Schommer's Epistemological Questionnaire (Schommer, 1990, 1998) to measure engineering students' epistemological beliefs at five educational levels and to answer the primary research questions: Do epistemological belief dimensions (certainty, structure, control, and speed) of engineering students significantly differ across educational levels (freshman, sophomore, junior, senior, and graduate)? If the beliefs significantly differ by educational level, do these differences still exist when background variables are controlled?

Method

Participants

A total of 396 undergraduate and graduate engineering students from two universities in Western Tennessee voluntarily participated in this study during the fall semester of 2008. Students were surveyed in 25 classes within the engineering disciplines of civil, biomedical, chemical, electrical, engineering management, and mechanical.

Materials

Schommer Epistemological Questionnaire. The Schommer Epistemological Questionnaire (Schommer, 1990, 1998) was used to assess the students' epistemological beliefs within four dimensions: certainty of knowledge (e.g., knowledge was either absolute and not changing or continuously evolving); structure of knowledge (e.g., knowledge was either simple and consisted of isolated pieces of information or complex and consisted of interdependent pieces of information); control of knowledge ability (e.g., knowledge was fixed or incrementally increased and improved); and speed of knowledge (e.g., knowledge was quickly obtained or perceived as a gradual process). Participants were presented 63 statements about knowledge and learning, and they were asked to rate the statements, such as "The only thing that is certain is uncertainty itself," using a Likert scale which ranged from 1 = strongly disagree to 5 = strongly agree.

Background information form. The students were surveyed to determine their personal and pre-college characteristics using Barker's (1998) background information form. As a result, the students' self-reported their gender, ethnicity, high school grade point average, educational level, and engineering discipline.

Procedure

Engineering students were recruited from two Western Tennessee universities to voluntarily participate in the study. They were told that the objective of the study was to gather data on engineering students' beliefs and views toward various topics. Participants were given the epistemological questionnaire and background information questionnaire during their regularly scheduled class time.

Participants were divided into three groups according to their classification (lowerclassmen: freshmen and sophomores; upperclassmen: juniors and seniors; graduate: master and doctoral). High school grade point average was divided into three groups (below average, average, and above average), and ethnicity was divided into three groups (European American, African American, and Other ethnicity). Subsequently, dummy-coded variables were created whereas lowerclassmen, European American, and above average were the primary reference groups for their respective measurements.

Results

After reviewing the returned surveys for errors, 370 surveys were included in the analyses. There were 304 students who identified themselves as males and 62 students identified themselves as females. In addition, 182 students identified themselves as lowerclassmen and 167 students identified themselves as upperclassmen. The majority of the students reported that they were European American (68%). The remainder of the students reported their ethnicity as African American (15%), Asian American (6%), Hispanic (2%), Multi-ethnic/racial (2%), Native American (1%), and Other (6%). Students' major fields of study consisted of seven categories: civil, mechanical, electrical, biomedical, chemical, engineering management, and other.

The first research question, "Do engineering students' epistemological beliefs in each dimension (e.g., fixed ability, simple knowledge, quick learning, and certain knowledge) significantly differ across educational levels (e.g., freshman, sophomore, junior, senior, and graduate)?" was answered by using one-way analysis of variance (ANOVA). Two of the four epistemological belief factors were found to be significantly different across the educational levels at the $p < .05$ level: quick learning F (2, 301) = 3.06, $p < .05$, $\eta_p^2 = .02$ and certain knowledge F (2, 301) = 3.95, $p < .05$, $\eta_p^2 = .02$.

Since the test of homogeneity of variances for beliefs in quick learning was violated, the Robust Tests of Equality of Means was also evaluated. Based on the Welch test, the belief in quick learning for the three educational levels closely approached statistical significance at the $p < .05$ level: F (2, 49.208) = 3.07, $p = .056$. Beliefs in fixed ability and simple knowledge did not vary across educational levels.

Post hoc pair-wise comparisons that were based on Tukey's HSD tests for unequal samples were used to identify the specific pairs of educational level groups that differed significantly in quick learning and certain knowledge beliefs. However, the variances for the belief in quick learning were not equal; therefore, the Games-Howell test was also used to identify the specific pairs of educational level groups that differed significantly in quick learning beliefs. Lowerclassmen were significantly more likely to have naïve beliefs in quick learning than did upperclassmen ($p < .05$). Moreover, lowerclassmen were significantly more likely to have naïve beliefs in certain knowledge than did upperclassmen ($p < .05$).

The second question, "Do these differences still exist when background characteristics (i.e., gender, ethnicity, high school grade point average) are controlled?" was answered using hierarchical regression analyses to examine the relationships between each epistemological belief factor and educational level while controlling for the influence of the background measures of gender, high school grade point average (GPA), and ethnicity. Since gender was the only dichotomous variable, dummy-coding was used for the remaining three variables: educational level, high school GPA, and ethnicity. Two groups of educational level (i.e., upperclassmen graduate) were included in the analysis; the largest group (lowerclassmen) was used as the primary reference group. In addition, two groups of high school GPA (i.e., above average and below average) were included in the analysis, and average was used as the primary reference group. Moreover, two groups of ethnicity (i.e., African American, Other ethnicity) were included in the analysis, and the largest group, European American was the primary reference group.

The five background variables (i.e., gender, above average GPA, below average GPA, African American, and Other ethnicity) were entered at Step 1 into each equation prior to the educational level variables (i.e., upperclassmen, graduate) that were entered at Step 2. F-tests for each regression showed that the R^2 was significant for the beliefs in fixed ability and quick learning.

Step 1 explained 5.2% of the variance in the belief in fixed ability. After entry of the upperclassmen and graduate students at Step 2, the total variance explained by the model as a whole was 5.4%, F (7, 280) = 2.28, $p < .05$. The two control measures explained an additional .02% of the variance in fixed ability, after controlling for gender, above average GPA, below average GPA, African American, and Other ethnicity, R squared change = .002, F change (2, 280) = .25, $p = .779$. In the final model, neither upperclassmen nor graduates were statistically significant predictors offixed ability (see Table 1 for details).

Step 1 explained 8.4% of the variance in the belief in quick learning. After entry of the upperclassmen and graduate students at Step 2, the total variance explained by the model as a whole was 10.5%, F (7, 280) = 4.69, $p < .001$. The two control measures explained the additional 2.1% of the variance in quick learning, after controlling for gender, above average GPA, below average GPA, African American, and Other ethnicity, R squared change = .021, F change (2, 280) = 3.32, $p < .05$. In the final model, upperclassmen, as compared to the lowerclassmen reference group, was the only educational level that was statistically significant (beta = -.150, $p < .01$). These results suggest that upperclassmen, which are the same gender, have the same high school GPA, and are the same ethnicity, are less likely to have naïve beliefs in quick learning than the reference group lowerclassmen (see Table 1 for details).

Step 1 explained 1.2% of the variance in the belief in certain knowledge. After entry of the upperclassmen and graduate students at Step 2, the total variance explained by the model as a whole was 3.7%, F (7, 280) = 1.55. However, this model as a whole was not statistically significant. The two control measures explained 2.6% of the variance in certain knowledge, after controlling for gender, above average GPA, below average GPA, African American, and Other ethnicity, R squared change = .026, F change (2, 280) = 3.76, $p < .05$. In the final model, upperclassmen, as compared to the lowerclassmen reference group, was the only educational level that was statistically significant (beta = -.138, $p < .05$). Although the overall model was not significant, these results suggest that upperclassmen, which are of the same gender, have the same high school GPA, and are the same ethnicity, are less likely to have naïve beliefs in certain knowledge than the reference group lowerclassmen (see Table 1 for details).

Results for the background variables indicate that females were less likely than males to have naïve beliefs in fixed ability (beta = -.203, $p < .05$) and quick learning (beta = -.274, $p < .05$). Students with above average high school GPA's were more likely to have naïve beliefs in fixed ability than students with average high school GPA's (beta = .129, $p < .05$). Finally, African American students were more likely to have naïve beliefs in simple knowledge than did European Americans (beta = .151, $p < .05$).

Discussion

The results of this study suggest that there are some differences in engineering students' epistemological belief dimensions across educational levels. In fact, three conclusions about engineering students can be tentatively drawn. First, upperclassmen are less likely than lowerclassmen to have beliefs in two dimensions: quick learning and certain knowledge. Second, educational level still predicts beliefs in quick learning and certain knowledge when background characteristics of students are the same. Third, epistemological beliefs differ according to gender, high school GPA, and ethnicity. In the following sections, each of these conclusions will be discussed further.

Conclusions

Upperclassmen vs. Lowerclassmen. This study supports several epistemological studies in that there are findings that college students' beliefs become more sophisticated as they progress through school (Jehng, et al., 1993; Paulsen & Wells, 1998; Pavelich & Moore, 1996; Schommer, 1993; Wise et al., 2004). However, this study's findings are only present for engineering students' beliefs in quick learning and certain knowledge. More specifically,

Table 1 Hierarchical Multiple Regression Analyses for Variables Predicting Engineering Students' Epistemological Beliefs in Fixed Ability, Quick Learning, Certain Knowledge, and Simple Knowledge.

	Fixed		Quick		Certain		Simple	
Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1	.052**		.084***		.012		.022	
Control variables[a]								
Step 2	.002		.021*		.026*		.003	
Upper classmen		-.04		-.150*		-.138*		.02
Graduate		.005		-.04		.06		.05
Total R^2	.054*		.105***		.037		.025	
n	304		304		304		304	

Note. Reference group for high school GPA is average GPA, the reference group for ethnicity is European American, and the reference group for educational level is Lower classmen.

[a]Control variables included above average GPA, below average GPA, gender, African American, and other ethnicity.

*$p < .05$. **$p < .01$. ***$p < .001$.

the beliefs became more sophisticated as students progressed from lowerclassmen (i.e., freshmen and sophomores) to upperclassmen (i.e., juniors and seniors). Like these authors, Jehng and colleagues (1993) found support that upperclassmen are less likely to have beliefs in certain knowledge. This is more than likely because upperclassmen have had exposure to ill-structured problem solving in design courses; therefore, they have learned that knowledge changes and is not absolute (Marra & Palmer, 2004; Marra et al., 2000).

Although other studies (Paulsen & Wells, 1998; Schommer, 1993) found that engineering students are more likely than other majors to have naïve beliefs in quick learning and certain knowledge, it is noteworthy that these studies are similar to the current study in that they found the students' beliefs in these dimensions became more sophisticated in their junior and senior years. Ironically, this progression in students' knowledge (from naïve to sophisticated thinking) is in line with the engineering education reform to increase students' engineering knowledge and prepare them for professional practice (Accreditation Board for Engineering & Technology, 2007; NAE, 2005; "The Research Agenda," 2006).

Based on the epistemological beliefs literature, it was expected that this study would have supported differences between undergraduate and graduate engineering students' beliefs. However, this study found no differences in beliefs between undergraduate and graduate students. This finding is similar to Jehng and colleagues' (1993) finding that graduate students did not differ from undergraduate students in their beliefs in fixed ability and quick learning. In contrast, Jehng and colleagues (1993) did find that graduate students were less likely to have beliefs in simple knowledge and certain knowledge.

Educational level predicts beliefs regardless of background characteristics. Students enter college with various backgrounds and experiences; therefore, it is important to consider these characteristics as confounding variables when evaluating educational outcomes. It was interesting to find that upperclassmen were less likely than the lowerclassmen to have beliefs in quick learning and certain knowledge above and beyond the effects of gender, high school GPA and ethnicity. Other studies of college students (Marra et al., 2000; Paulsen & Wells, 1998; Schommer, 1993) also found epistemological belief differences remained over and beyond the effects of background characteristics. For example, Marra et al. (2000) found that a change in the engineering curriculum affected epistemological beliefs of students over a period of four years regardless of their background characteristics. In another study, Paulsen and Wells (1998) found that engineering students were more likely than other majors to have beliefs in simple knowledge, quick learning, and certain knowledge when gender, GPA, and educational level were the same. However, Schommer (1993) found that lowerclassmen engineering students' beliefs in quick learning disappeared when background characteristics were controlled. With all of this in mind, one cannot assume that background variables will not ever influence the epistemological beliefs of engineering students.

Background characteristics predict beliefs. Not only did this study find that educational level predicts engineering students' beliefs beyond background characteristics, but the background characteristics also predict the students' epistemological beliefs. For example, females were less likely than the males to have beliefs in fixed ability (beta = -.203, $p < .05$) and quick learning (beta = -.274, $p < .05$). Although Paulsen and Wells (1998) and Schommer (1993) did not limit their studies to engineering students, they also found that college females were less likely than college males to have beliefs in quick learning and fixed ability.

An additional finding in this study is that engineering students with above average high school GPAs were more likely to have beliefs in fixed ability as compared to engineering students with average high school GPAs. In contrast, Schommer (1993)found that the less likely high school students, although not identified as future engineering students, believed in fixed ability, the more likely they were to have higher high school GPAs. Furthermore, Marra and colleagues (2000) did not find a relationship between high school GPA and first-year engineering students' epistemological beliefs.

Finally, the finding that being African American, as compared to being European American, is more likely to predict beliefs in simple knowledge was unexpected. This is because significant results for ethnicity have not been reported in any other epistemological beliefs studies. Consequently, Hofer and Pintrich's (1997) review expressed a need for studies that examine epistemological beliefs across cultures and ethnic groups. This research would also be useful in the field of engineering education in that there is a need in the United States to attract more minorities to study engineering.

Limitations and Future Research

As with all studies, the current study is not perfect and has its limitations. These limitations include generalizability, low reliability, and small effect sizes. For example, the generalizability of this study is only applicable to engineering students with similar characteristics and to students in Western Tennessee universities.

The lack of differences between graduate and undergraduate students beliefs can be attributed to the small and limited sample of graduate students ($n = 19$). It is reasonable to believe that the expected differences between graduate and undergraduate students might have been realized if the sample of graduate students was larger. More research is needed that examines epistemological belief differences between graduate and undergraduate engineering students in order to understand how curriculum and the classroom environment influence or correlate with their academic achievement and behavior in terms of epistemological beliefs.

Ethnicity was also a limitation that affects the generalizability of this study. The largest ethnic groups in this study were European American and African American, respectively. The other groups were less than half the size of both groups. As a result, one cannot assume that the findings of this study would be consistent cross-culturally. In agreement with Hofer and Pintrich (1997), there is a need to study epistemological beliefs among cultures and ethnicities because most epistemological beliefs studies are conducted with white males. In the same vein, there is a need for more epistemological beliefs research that studies engineering students of different cultures and ethnicities.

The low reliability values, which ranged from -.084 to .521, and small effect sizes for this study can be explained by Wood and Kardash's (2002) findings that the design of an epistemological beliefs study may affect reliability values and effect sizes. For example, they found studies that evaluated samples with wide ranges were more likely to have higher internal consistencies than studies with samples that had narrow ranges. This study's sample had a narrow range in that it only assessed students in one field of study (e.g., engineering). Wood and Kardash (2002) also warned researchers that low reliability should not prevent them from identifying differences between groups. As a probable solution to improve reliability, Wood and Kardash (2002) suggested that researchers increase items that represent a construct of a measure. Their rationale for this solution was that the reasoning and vocabulary of epistemological research was complex, and more items must be loaded on a participant's score. Furthermore, Hofer and Pintrich (1997) mentioned that Schommer's (1990) questionnaire has construct validity issues in content. As a result, Hofer and Pintrich (1997) believed there was a possibility that Schommer's (1990) questionnaire would not have accurate indicators of beliefs about knowledge and would have high construct-irrelevant variance.

Finally, SAT scores and high school GPA were self-reported by the students; therefore, it is reasonable to question the accuracy of this data. Some students could not remember this information and left the items blank on their answer sheets. As a result, their data was eliminated from some of the data analyses. In addition, some students probably guessed their scores and GPA. Guessing would also result in inaccurate findings in the study. In future research, it would be preferable to obtain examination scores and GPA data directly from the records office of the university.

Implications

Currently, there are many initiatives underway to increase student enrollment in the fields of science, technology, engineering, and mathematics (STEM). Engineering education researchers are contributing to these initiatives by focusing their research on five major areas; one area of interest is engineering epistemologies. Hence, engineering education researchers are investigating what constitutes the nature of engineering knowledge and ways of engineering thinking ("The Research Agenda," 2006). This study contributes to the engineering epistemologies research in that its findings support the idea that the epistemological beliefs (i.e., certain knowledge, quick learning) of engineering students become more sophisticated as the students advance in their undergraduate engineering curriculum.

These findings are important to engineering education because they can be used to identify the specific parts of the curriculum that influence sophisticated, or advanced, cognitive processes (e.g., engineering thinking) in engineering students. For example, engineering education researchers could examine the curricula and classroom environments to identify whether they correlate to the differences in the epistemological beliefs between lowerclassmen (i.e., freshmen, sophomores) and upperclassmen (i.e., juniors, seniors). However, that type of investigation would not provide a complete context for acquiring engineering knowledge as it would only identify external influences on engineering students' cognitive processes.

In order to develop an effective engineering curriculum that supports the overall development of sophisticated engineering thinking, engineering education researchers might also identify internal influences on cognitive processes as they relate to the changes in the students' epistemological beliefs. Understanding students' internal influences is important, because they might work in conjunction with the external influences (e.g., teacher, peers, curriculum, classroom environment) to facilitate learning and the acquisition of engineering knowledge.

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References

Accreditation Board for Engineering and Technology. (2007). *Criteria for accrediting engineering programs.* Retrieved on November 12, 2007, from http://www.abet.org/ Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20Criteria%2011-30-07.pdf

Barker, S. A. (1998). *The domain-generality of epistemological beliefs.* Unpublished master's thesis, Wichita State University, Wichita, Kansas.

Committee on Science, Engineering, and Public Policy [COSEPUP]. (2007). Rising above the gathering storm: Energizing and employing America for a brighter *economic future.* Retrieved on June 25, 2007 from http://books.nap.edu/catalog.php?record_id=11463#orgs

Culver, R. S., & Hackos, J. T. (1982). Perry's model of intellectual development. Engineering Education, 73, 221-226.

Fedler, R. M., & Brent, R. (2004). The intellectual development of science and engineering students. Part 1: Models and challenges. *Journal of Engineering Education, 93*, 269-277.

Fedler, R. M., & Brent, R. (2005). Understanding student differences. *Journal of Engineering Education, 94,* 57-72.

Fitch, P., & Culver, R. S. (1984). Educational activities to stimulate intellectual development in Perry's scheme. *Proceedings ASEE Annual Conference, 2,* 712-717.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs abut knowledge and knowing and their relation to learning. *Review of Educational Research, 67*, 88-140. doi: 10.3102/00346543067001088

Jehng, J. J., Johnson, S. D., & Anderson, R. C. (1993). Schooling and students' epistemological beliefs about learning. *Contemporary Educational Psychology, 18*, 23-35.

Marra, R., and Palmer, B. (2004). Encouraging intellectual growth: Senior college student profiles. *Journal of Adult Development, 11*, 111-122. doi: 10.1023/B:JADE.0000024544.50818.1f

Marra, R. M., Palmer, B., & Litzinger, T. A. (2000). The effects of a first-year engineering design course on student intellectual development as measured by the Perry scheme. *Journal of Engineering Education, 89*, 39-46.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74*, 317-377. doi: 10.3102/00346543074003317

National Academy of Engineering (NAE). (2005). *Educating the engineer of 2020: Adapting engineering education to the new century.* Retrieved on June 25, 2007 from http://books.nap.edu/catalog.php?record_id=11338#orgs

Palmer, B., & Marra, R. M. (2004). College student epistemological perspectives across knowledge domains: A proposed grounded theory. *Higher Education, 47*, 311-335.

Paulsen, M. B., & Wells, C. T. (1998). Domain differences in the epistemological beliefs of college students. Research in *Higher Education, 39*, 365-384.

Pavelich, M. J., & Moore, W. S. (1996). Measuring the effect of experiential education using the Perry model. *Journal of Engineering Education, 85*, 287-292.

Perry, W. G., Jr. (1970). *Forms of intellectual and ethical development in college years: A scheme.* New York: Holt, Rinehart and Winston.

Perry, W. G., Jr. (1988). Cognitive and ethical growth: The making of meaning. In A. W. Chickering (Ed.), *The modern American college* (pp. 76-116). San Francisco, CA: Jossey-Bass Publishers. The research agenda for the discipline of engineering education. (2006, October). *Journal of Engineering Education, 95*, 259-261.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498-504.

Schommer, M. (1993). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education, 34*, 355-370. doi: 10.1007/BF00991849

Schommer, M. (1997). The development of epistemological beliefs among secondary students: A longitudinal study. *Journal of Educational Psychology, 89*, 37-40.

Schommer, M. (1998). The influence of age and education on epistemological beliefs. *British Journal of Educational Psychology, 68*, 551-562.

Schommer, M., & Walker, K. (1995). Are epistemological beliefs similar across domains? *Journal of Educational Psychology, 87*, 424-432.

Trautwein, U., & Ludtke, O. (2007). Epistemological beliefs, school achievement, and college major: A large-scale longitudinal study on the impact of certainty beliefs. *Contemporary Educational Psychology, 32*, 348-366. doi: 10.1016/j.cedpsych.2005.11.003

Wise, J. C., Lee, S. H., Litzinger, T., Marra, R. M., & Palmer, B. (2004). A report on a four-year longitudinal study of intellectual development of engineering undergraduates. *Journal of Adult Development, 11*, 103-110. doi: 10.1023/B:JADE.0000024543.83578.59

Wood, P. K., & Kardash, C. A. (2002). Critical elements in the design and analysis of studies of epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 231-260). Mahwah, NJ: Erlbaum.

Course Modules on Structural Health Monitoring with Smart Materials

Hui-Ru Shih, Wilbur L. Walters, Wei Zheng, and Jessica Everett

Abstract

Structural Health Monitoring (SHM) is an emerging technology that has multiple applications. SHM emerged from the wide field of smart structures, and it also encompasses disciplines such as structural dynamics, materials and structures, nondestructive testing, sensors and actuators, data acquisition, signal processing, and possibly much more. To stimulate students' desire for pursuing advanced technologies and to ensure that they are well prepared for their future careers, technology educators need to dedicate their efforts to educate the students with this emerging technology. At Jackson State University (JSU), three course modules (Smart Materials and Structures, Data Acquisition Systems, and Lamb Waves Generation & Detection) were added to the existing course to help undergraduate students develop hands-on experience for understanding this technology. The course modules did not require prior knowledge of software and hardware, and they all followed an applied, hands-on approach. These three course modules allowed students to gain insight into the SHM as well as to become knowledgeable users of the instrumentation.

Introduction

Structural Health Monitoring (SHM) is fast becoming a highlight of both research and applications to ensure the safe operation of various structures, such as bridges, ships, pipelines, and aircrafts (Giurgiutiu, 2008; Staszewski, Boller, & Tomlinson, 2004). The structure under investigation is energized using actuators. The response to the excitation is sensed at various locations throughout the structure. The response signals are collected and processed. Based on the processed data, the state of the structure is diagnosed.

A successful understanding and application of structural health monitoring depends on an in-depth appreciation of structural modeling, smart materials, signal processing, data acquisition techniques, and more. JSU's Department of Technology has developed significant teaching capabilities and the experimental facilities for structural control and health monitoring. Three course modules have been developed to introduce structural health monitoring concepts to undergraduates. The field of SHM is vast. These teaching modules are not designed to give an encyclopedic coverage of all the SHM techniques. Instead, the primary objective of these efforts is to provide students with background information and knowledge of principal technologies involved in SHM using smart materials and Lamb waves. Lamb waves are guided elastic waves. Lamb wave techniques have been emerging as one of the most effective methods to detect structural damage.

From these modules, students can learn to use software, hardware, and instrumentation properly both theoretically and in the context of real-world applications. All three modules were offered together for the first time during the spring semester of 2009. Results of these new modules are very encouraging. Being able to see, touch, and interact with entities that demonstrate complex behavior is exciting and appealing to students. Students become very motivated by the diversity and creativity of the course content.

Course Modules Development

Three new course modules (Smart Materials & Structures, Data Acquisition Systems, and Lamb Waves Generation & Detection) were added to the existing Technology course. This addition is intended to present students with a comprehensive view of SHM with smart materials. The new course modules have helped students understand the concept of a smart structural system; it also has helped them to understand its application to performance monitoring of structural systems.

Course Module 1: Smart Materials and Structures

Smart structures utilize active (smart) materials as sensors and actuators to sense and respond to their environment (Gabbert & Tzou, 2001; Srinivasan & McFarland, 2000). Smart materials (e.g., electrostrictives, shape memory alloys, and piezoelectrics) are now used in numerous applications. However, most of today's technology students are not aware of the remarkable properties of smart materials or the applications of smart-structure technology. Therefore, it is desirable to prepare future technologists for the cutting-edge technologies in smart structures, which they will see in broad application during their careers. This proposed course module aims to prepare technologists to meet this demand.

This module demonstrates the properties of piezoelectric materials, and it reveals the basic principles of intelligent structures and structure control. The electromechanical property of piezoelectric materials has both a direct and a converse effect (Shih, 1999). The direct effect is described as the generation of an electric charge in a material when it is subjected to a mechanical stress. The converse effect is described as generation of a mechanical strain in a material in response to an applied electric field. Piezoelectrics are available in polymer (polyvinylidene fluoride or PVDF) or ceramic (lead zirconate titanate or PZT) form. Piezoceramics are stiff and brittle, whereas piezopolymers are compliant and soft. There are two possible ways to utilize piezoelectric materials. First, piezoelectric materials can be used as sensors (direct effect). Second, piezoelectric materials can be used as actuators (converse effect). Because piezoelectric materials are applicable to both sensors and actuators, their use is very popular in smart structures and systems.

This module consists of lectures and laboratory experiments. The laboratories are developed first; the lectures then support the laboratories. The lectures introduce students to the piezoelectric effects and the fundamental mechanism behind the extraordinary ability for piezoelectric materials to behave as both a sensor and as an actuator. Materials delivered in the lectures also cover the analysis and design of a control system, as well as MatLab, Simulink, and dSpace. The experimental setup is depicted in Figure 1. The test apparatus consists of an aluminum cantilever beam 24.75 inches long, 1.5 inches wide, and 0.075 inch thick. The commercially available PZT patches (QP15W and QP20W from Midé Technology) are used. QP15W works as a sensor and QP20W acts as an actuator. A PZT patch is bonded near the clamped end on each side of the beam. This position was chosen because the greatest strains occur at the fixed end of the beam. The controller is implemented on a dSpace 1104 controller board using MatLab and Simulink software. The Model 7500 power amplifier from Krohn-Hite Instruments is used in the test.

Once the cantilever beam is forced to vibrate, the piezoelectric sensor will continue to generate the signal. When the controller to the actuator patch is on, the sensor signal will be preceded by a control algorithm, and then the control signal will be amplified and fed back to the actuator to suppress the vibration. This cantilevered beam system is a simple form of a smart structure since both the sensor and actuator are integrated parts of the structure. This smart beam has the ability to sense and to respond to vibrations.

A laser vibrometer (VibroMet 500) is also used to measure the tip displacement and obtain the frequency response of the beam's vibration.

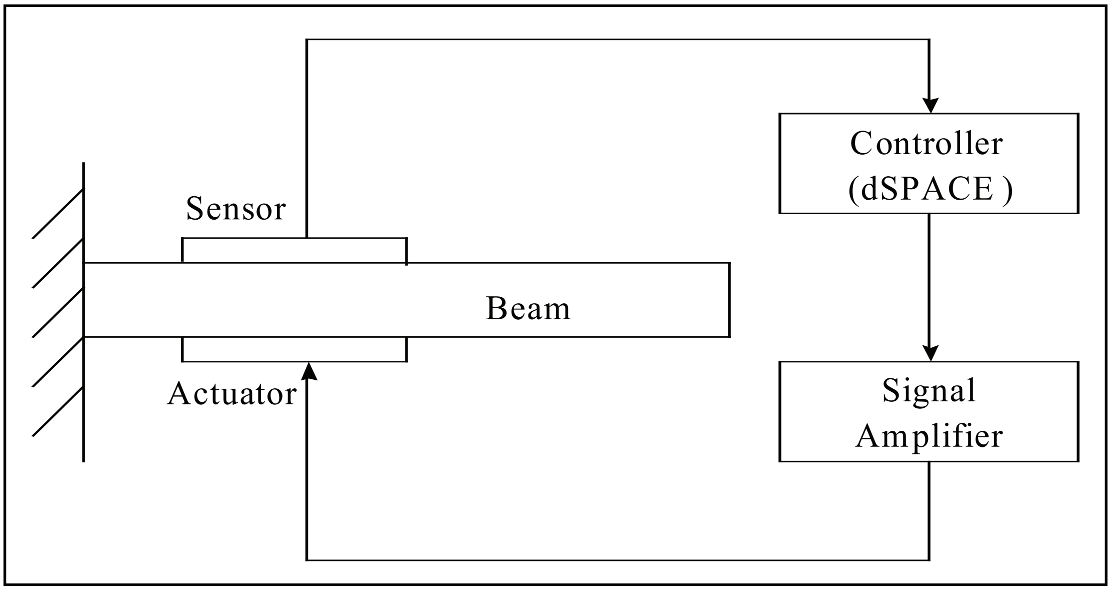

Figure 1. Experimental setup.

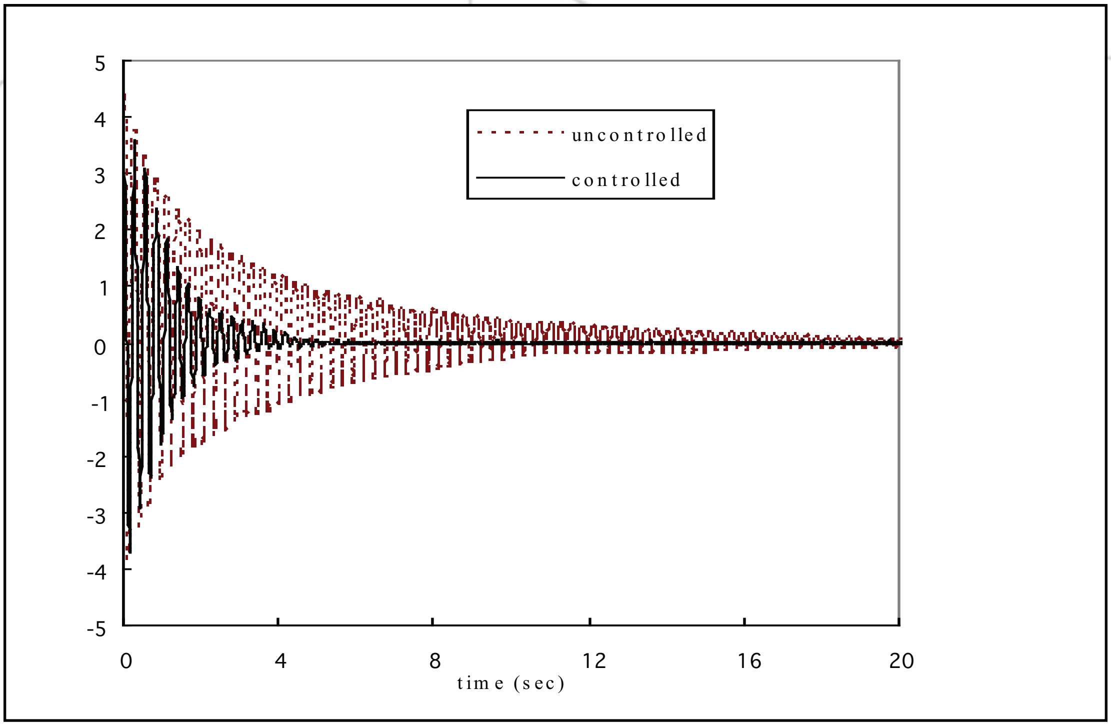

Figure 2. Responses of the beam after an initial disturbance at the tip.

Thus, important parameters of the beam, such as fundamental modal frequencies can be obtained and then used to design the controller. The open-loop response can be validated with analytical results. The dotted line in Figure 2 shows the free vibration of the beam in an open loop after an initial disturbance to its tip. The damping ratio ζ can be determined from the observation of this decay.

In the next step, a control method is needed to dampen the vibration of the beam (Song, Qiao, Binienda, & Zou, 2002). The proper control method can be chosen with help of computer simulations. Students usually choose the positive position feedback (PPF) algorithm. PPF is applied by sending the structural position coordinate directly to the controller. Next, the product of the controller output and a scalar gain are fed back to the actuator. Students can adjust the gain to optimize the control performance. As mentioned previously, the controller is implemented on a dSpace 1104 controller board using MatLab and Simulink software, illustrated in Figure 3. Simulink is a graphical extension to MatLab for modeling and simulation of systems.

In Figure 3, the block "ADC" which is the analog-to-digital converter, receives the input signals from sensor. The block "DAC" is the digital-to-analog converter. The controller output is sent to the amplifier through DAC. The behavior of a cantilever beam can be represented by a second-order linear transfer function. The fundamental frequency and damping ratio can be obtained from the experiment as previously described. Next, these parameters can yield the transfer function. In Figure 3, the block "Transfer Fcn1" represents the beam's transfer function.

Flexible structures consist of a large number of highly resonant modes. In general, PPF can offer quick damping for a particular mode. The input value of the PPF controller can be considered as the modal displacement. The resonant frequency of a controller is set to the designated modal frequency of the structure to be controlled. Around the resonant frequency, the phase lag of the controller is about 90 degrees. The output of the controller is the modal velocity feedback signal. Thus, the controller can reduce resonant responses of the structure by increasing the system damping at that modal frequency.

An important issue in designing a controller for a flexible structure is whether the developed closed-loop system will have sufficient robustness to deal with uncertainties in the structure. One more advantage of the PPF algorithm is that the controller can function as a special bandpass filter. Frequencies that are lower or higher than the frequency of the filter will be

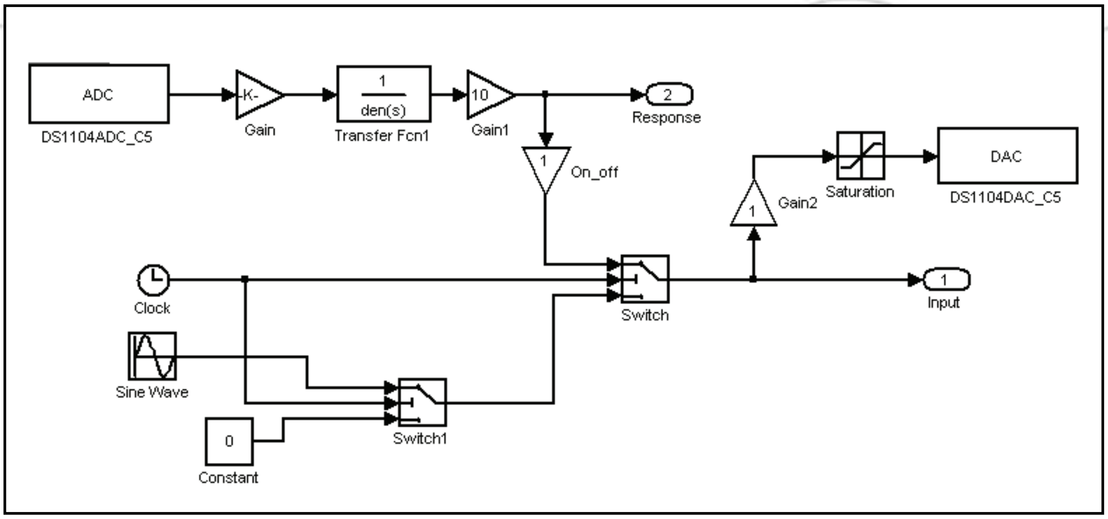

Figure 3. PPF controller.

depressed. Thus, the controller can guarantee closed-loop stability in the presence of uncontrolled modes.

The control performance has been observed in the time domain by monitoring the transient behaviors of the beam. The decaying behaviors are presented in Figure 2 for both the controlled and uncontrolled cases. From this figure, the effectiveness of the present vibration control can be clearly understood.

Smart material systems exhibit very complex coupled physical behavior. From this experiment it can be seen that, in piezoelectrics, the coupling is in between mechanical stresses and electrical potentials. Smart materials and structures are a rapidly growing interdisciplinary technology embracing the fields of materials and structures, sensor and actuator systems, and information processing and control. Study of smart materials can increase the interdisciplinary experiences of the students.

Course Module 2: Data Acquisition Systems

The broad field of SHM encompasses many advanced technologies that, when integrated, provide a system that can potentially identify and characterize the performance and/or possible deterioration of a structural system. For a SHM system, a data acquisition subsystem is required to record a structure's response to ambient and external loads.

A course module has been developed to allow students to gain a basic knowledge of data acquisition with hands-on experiences. The focus of this module is to give students a starting point for developing the data-acquisition system. In recent years, LabVIEW has been widely used in applications where engineers, scientists, and technologists want to acquire, analyze, and present data. LabVIEW is a graphical programming language developed by National Instruments (NI). LabVIEW is used in this class to write programs for the acquisition, processing, and presentation of data. Thus, the additional benefit is that students are also introduced to programming concepts. The graphical programming environment of LabVIEW has proven to be a suitable teaching mechanism for students to use to learn the basic concepts of loops, case structures, etc. in a short period of time and to generate working programs (Bishop, 2007; King, 2009; Strachan, Oldroyd, & Stickland, 2000; Sumali, 2002; Zhao, 2006).

The LabVIEW environment consists of two main windows: the block diagram (Figure 4) and the front panel (Figure 5). The front panel is where the developer can build the user interface through the use of various GUI objects. Students build the front panel with controls and indicators, which are the interactive input and output terminals, respectively. Controls are knobs, push buttons, dials, and other input devices. Indicators are graphs, LEDs, and other displays.

When a front panel item is dropped on the screen, a terminal is also created on the block diagram automatically. The block diagram is where the functionality of the LabVIEW program (known as a virtual instrument or VI) is defined. A wide variety of function blocks (also referred to as VIs) are available to allow the user to define any functionality that they want. In addition, the VIs that allow the user to build

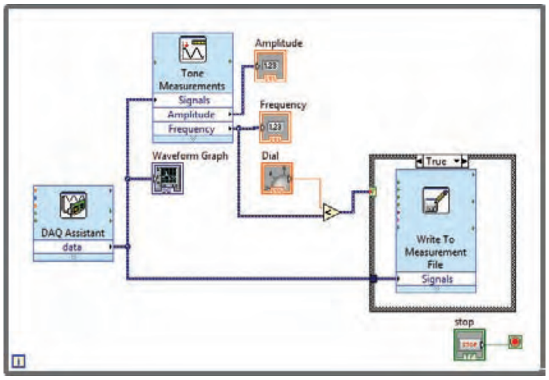

Figure 4. Block diagram of a LabVIEW program.

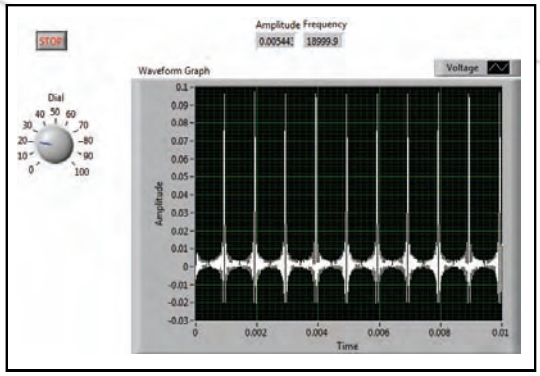

Figure 5. Front panel of a LabVIEW program.

his/her program, such as while loops, for loops, and case structures, are also available as in any programming language.

This module is designed so that the knowledge and techniques that are introduced can later be used in further studies and applied in SHM. The module is a mixture of lectures and practical works. In lectures, the basic features of LabVIEW are first covered along with the data-acquisition hardware. The procedures of LabVIEW data flow programming are introduced. The comparison between LabVIEW and the traditional programming languages is presented. The block diagram and front panel for a LabVIEW program are discussed. In addition, the editing features of functions palette and controls palette are introduced. A brief discussion of the hierarchy of the organization of various panels on those palettes is also presented. Due to the limited time available, LabVIEW is not be covered in detail.

In the laboratory sessions, students are instructed to perform the tutorial from the LabVIEW Hands-On Course Manual (2005), the manual that is also used by NI in its training courses. For all of the exercises, the instructor provides common electronic tools and components (e.g., multimeters, oscilloscopes, breadboards, function generators, and data-acquisition systems). A data-acquisition system includes a computer, a LabVIEW, an NI PCI 6251 data-acquisition (DAQ) board, and an NI BNC 2110 connector block. Through these practices, students should gain an understanding of the capabilities and structure of a computer-based data-acquisition system as well as the ability to write simple programs to acquire, process, and store data.

Course Module 3: Lamb Waves Generation and Detection

SHM techniques are being developed to reduce operations and support costs, increase availability, and maintain the safety of various structures, such as bridges and aircraft. Conventional ultrasonic methods, such as pulse-echo techniques, have been used successfully to inspect structural integrity. However, the application of these traditional techniques has been limited to testing relatively simple geometries or inspecting the region in the vicinity of the transducer (Yang & Qiao, 2005). A new ultrasonic methodology which uses Lamb waves to examine the structural components has been developed. Lamb waves are guided elastic waves, which can travel relatively large distances with very little amplitude loss; they offer the advantage of large-area coverage with a minimum of installed sensors (Giurgiutiu, 2003a). Thus, in contrast to the conventional methods, the guided-wave technology can be used to inspect the entire structure in a single measurement, and it can also inspect inaccessible regions of complex components. This module is designed to provide students with the foundational knowledge for understanding SHM using Lamb waves.

For Lamb waves, at a given frequency, at least two modes (one symmetric and one anti-symmetric) are generated. As frequency increases, the number of simultaneously existing waveforms also increases. Lamb wave propagation is usually highly dispersive. Therefore, how to choose the best frequency is a major issue. In Lamb wave inspection, mostly the S_o (symmetric) and A_o (anti-symmetric) modes are used. So and A_o are referred to as the fundamental modes. These two modes are the most important because they exist at all frequencies, and they carry more energy than the higher order modes in most situations.

So and A_o modes are often called the extensional mode and flexural mode, respectively. The A_o Lamb mode has a much lower wave speed than the S_o Lamb mode, and therefore it has a smaller wavelength, making it more sensitive to smaller levels of damage. However, the symmetric waveform has a substantially greater group velocity and would therefore arrive at a sensor well before the anti-symmetric waveform. Kessler, Spearing, Atalla, Cesnik, & Soutis (2001) recommended use of the A_o mode because of lower attenuation. Alternatively, selective excitation of the S_o mode has also been reported (Giurgiutiu, 2003b). At low frequencies, below 1 MHz, only A_o and S_o Lamb modes are present. Frequency excitation ranges above 1.5 MHz would produce other modes that will make Lamb mode selection more difficult. In order to generate only a few Lamb wave modes, narrowband techniques are necessary. Thus, a frequency range of up to 500 kHz is usually chosen. Giurgiutiu (2005) has also shown that, by adjusting the excitation frequency, it is possible to tune certain transducers to excite a single mode (either S_o or A_o) dominantly.

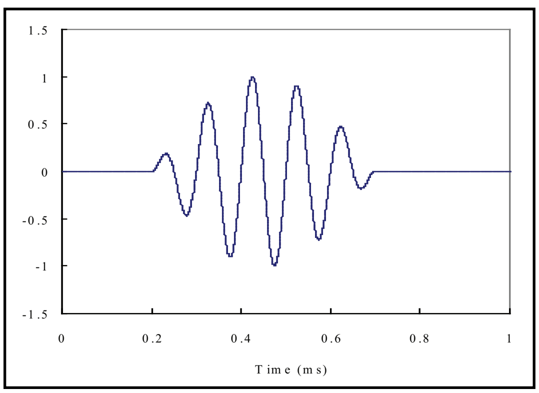

Figure 6. Excited waveform.

According to four studies (Giurgiutiu, 2003a; Hong, Sun, & Kim, 2005; Ullate, Saletes, & Espinosa, 2006; Yang & Qiao, 2005), using the tone burst smoothed pulses can improve the feedback signals and enhance the reliability of damage detection. In the experiment, the excited transient signal is made up of a windowed five-cycle sine tone burst (shown in the Figure 6). The center frequency is varied. This signal is windowed in order to get a single wave traveling at the desired driving frequency. Because the pulse has a finite duration, a range of frequencies is excited rather than a single frequency, and dispersion distorts the shape of the pulse as different frequency components travel at different velocities.

Among the various transducers available for damage detection, piezoelectric materials are particularly attractive because they can act simultaneously as transmitters and receivers. These transducers can be bonded or embedded on the structure to be analyzed. Their reduced thickness, low weight, and low cost make them very useful when designing an integrated damage monitoring system (Hong, et al., 2005). In the experiments, piezoelectric transducers (APC-850, 8 mm x 8 mm x 0.3 mm in size) are used to generate and receive the wave.

Students have learned how to operate a function generator and DAQ board, as well as write the LabVIEW program. This module is designed so that it can integrate the knowledge they gained and tools they acquired from the first two modules. The experiment in this module enables students to test their abilities in using a data-acquisition system to acquire data.

This module is also laboratory intensive. An aluminum beam (or plate) was used in the experimental measurements. Several square piezoceramic elements were bonded on the structure surface at the different positions. One can serve as the actuator to generate the Lamb waves. The others perform as sensors to detect the waves. Figure 7 shows the test setup, which includes an arbitrary function generator, a digital oscilloscope, and a computer. The piezoceramic actuator was excited by a signal constructed and transferred to an arbitrary function generator (Agilent 33220A). This function generator could read the digital signal and output the corresponding analog signal to the actuator. The measured signals were obtained with a digital oscilloscope or recorded in a computer with a LabVIEW program.

In experiments, both extensional and flexural modes can be excited and detected. Figure 8 shows the wave signals received at the sensor for the 150 kHz, 250 kHz and 350 kHz excitation, respectively. The wave excitation used is a 5-count tone burst. From the first row of wave in Figure 8, it can clearly be seen that A_o is dominant at 150 kHz. When the tone burst is tuned to 250 kHz, both S_o mode and A_o mode can be excited. This can be seen from the second row of the wave. At 350 kHz (the third row), S_o mode is maximized, whereas A_o mode is still slightly excited.

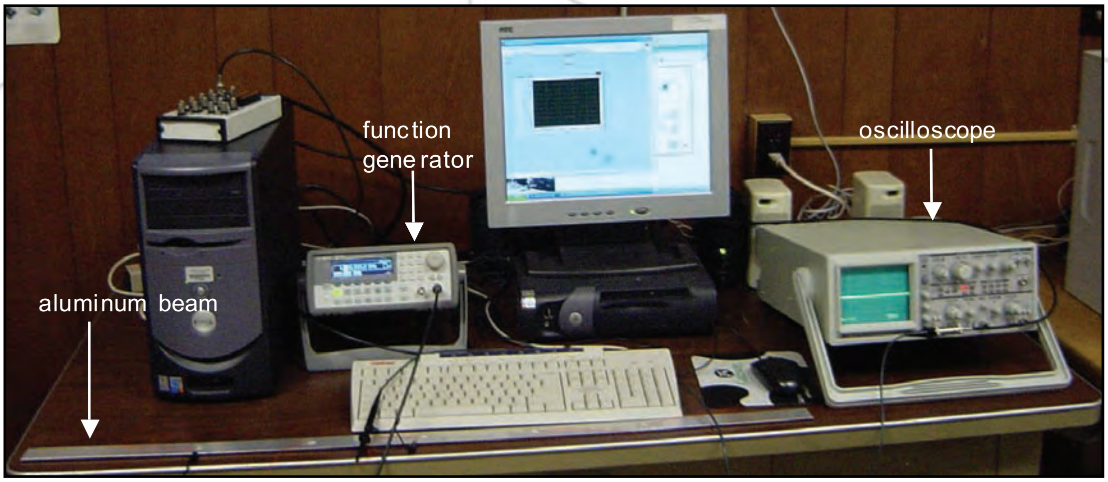

Figure 7. Experimental setup for Lamb wave propagation.

This experiment can show students that the transmission and reception of Lamb waves in thin structures can be effectively implemented using small-size surface-bonded piezoelectric sensors and actuators. The Lamb waves can be used to scan the structures and are capable of detecting internal damage through ultrasonic techniques (Yang & Qiao, 2005). The piezoelectric transducers are inexpensive and unobtrusive. They can be deployed over large structural areas to create active sensor arrays.

The learning exercises described above aim to equip students with the knowledge, skills, and understanding necessary for tackling problems in SHM-related professional fields. The lecture materials cover the core concepts. The laboratory experiments expose students to the hands-on techniques. The three teaching modules presented in this article can easily and seamlessly be integrated to existing technology courses.

Student Feedback

These three course modules were delivered for the first time during the spring 2009 semester. An important outcome of any course is what students think about various aspects of the class. The initial outcome for these modules has been assessed. All students who took the course modules outlined previously were asked whether they thought the structure of the course gave them a good introduction to the basics of smart materials, data acquisition, structural monitoring, and in particular, laboratory and experimental works.

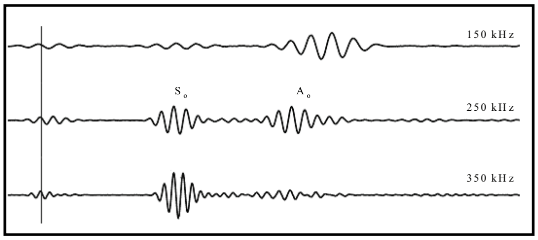

Figure 8. Wave signals received.

The ratings, relative to a maximum rating of 10.0 on key categories pertaining to the course content, are presented in Table 1. The responses of the evaluation showed highly supportive evidence toward the intended course outcomes. In order to gain additional insight regarding students' perceptions of the modules, students were also submitted written comments. According to the comments, students increased their perception of the value of technology, and their self-efficacy in performing SHM and DAQ tasks. Although a few students complained about too much time involved with the laboratory assignments, most of the students agreed that the amount of time and work required to complete the assignments was reasonable. The majority of students enjoyed working in the lab. Several students indicated that having additional opportunities to "play with the technology" would greatly enhance their learning. Some students also expressed an interest in being provided with additional information regarding the smart materials themselves, such as where they can be purchased and how much they cost. Overall, most students commented positively about the knowledge they gained. They agreed that these modules were a valuable learning experience.

The student feedback provides valuable information to the instructors for further improving the modules. Even though student learning and perception were positively affected by the developed teaching materials, there are challenges in future development. Because the laboratory experiments were custom-made, the major challenge is preparing enough experimental systems

Table 1. Survey results.

Organizes and plans course effectively.	8.2
I found the course intellectually stimulating.	8.5
I learned a great deal in this course.	9.2
Rate overall value of this course.	8.9

at a low cost to support a larger student population.

Conclusions

Keeping curricula and lab resources current with respect to the fast pace of technological advances is a challenge. A module-based approach is a new learning paradigm that offers an effective way to address the challenge of emerging technologies. Smart structures and SHM have become increasingly important technologies to ensure the safe operation of various structures. In this work, we advocate a module-based approach for teaching and learning. Three course modules were designed to provide students with a firm grasp of the smart structures and integrated health-monitoring techniques. The modules balance theory and application, classroom lectures and laboratory experiments. These modules also were designed to enable students to gain a competence with tools they can use in their future jobs. These teaching modules have been successfully tested in the three-credit Capstone course offered in the senior year to all the Industrial Technology majors. Extending this learning concept to other practical courses could broaden the students' practical and advanced skills, which are much desired by industry leaders.

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References

Bishop, R. H. (2007). *LabVIEW 8* (Student edition). Upper Saddle River, NJ: Prentice Hall.

Gabbert, U., & Tzou, H. S. (2001). *Smart structures and structronic system.* London: Kluwer Academic Publishers.

Giurgiutiu, V. (2003a). Embedded NDE with piezoelectric wafer-active sensors in aerospace applications, *Journal of Materials (JOM-e), Special Issue on NDE, 55* (1), http://www.tms.org/pubs/journals/JOM/0301/Giurgiutiu/Giurgiutiu-0301.html.

Giurgiutiu, V. (2003b). Lamb wave generation with piezoelectric wafer active sensors for structural health monitoring. *Proceedings of the SPIE's 10th Annual International Symposium on Smart Structures and Materials and 8th Annual International Symposium on NDE for Health Monitoring and Diagnostics,* paper # 5056-17.

Giurgiutiu, V. (2005). Tuned Lamb wave excitation and detection with piezoelectric wafer active sensors for structural health monitoring, *Journal of Intelligent Material Systems and Structures, 16*(4), 291-305.

Giurgiutiu, V. (2008). *Structural health monitoring with piezoelectric wafer active sensors.* Boston: Academic Press.

Hong, J. C., Sun, K. H., & Kim, Y. Y. (2005). The matching pursuit approach based on the modulated Gaussian Pulse for efficient guided-wave damage inspection, *Journal of Smart materials and Structures, 14*, 548-560.

Introduction to LabVIEW 3-Hour Hands-On, (2005). Austin: National Instruments.

Kessler, S. S., Spearing, S. M., Atalla, M. J., Cesnik, C. E. S. & Soutis, C. (2001). Damage detection in composite materials using frequency response methods. *Proceedings of the SPIE's 8th International Symposium on Smart Structures and Materials.*

King, R. H. (2009). *Introduction to data acquisition with LabVIEW*. New York: McGraw Hill.

Shih, H. R. (1999). Damping control of a piezoelectric laminated structure, *Journal of Engineering Technology, 16*(2), 54-58.

Song, G., Qiao, P. Z., Binienda, W. K. & Zou, G. P. (2002). Active vibration damping of composite beam using smart sensors and actuators, *Journal of Aerospace Engineering, 15*(3), 97-103.

Srinivasan, A. V., & McFarland, D. M. (2000). *Smart structures, analysis and design.* Cambridge: Cambridge University Press.

Staszewski, W., Boller, C. & Tomlinson, G. R. (2004). *Health monitoring of aerospace structures: Smart sensor technologies and signal processing.* New York: John Wiley & Sons.

Strachan, P., Oldroyd, A. & Stickland, M. (2000). "Introducing instrumentation and data acquisition to mechanical engineers using LabVIEW," *International Journal of Engineering Education, 16* (4), 315-326.

Sumali, H. (2002). An instrumentation and data acquisition course at Purdue University, *Proceedings of the 2002 ASEE Annual Conference & Exposition,* Session 2208. Montréal, Quebec, Canada.

Ullate, Y. G., Saletes, I., & Espinosa, F. M. D. (2006). Lamb waves generation in plates using glued piezoceramics, *Boletin de la Sociedad Espanola de Cerámica y Vidrio, 45*(3), 188-191.

Yang, M., & Qiao, P. (2005). Modeling and experimental detection of damage in barious materials using the pulse-echo method and piezoelectric sensors/actuators, *Journal of Smart Materials and Structures, 14,* 1083-1100.

Zhao, J. (2006). Introducing LabVIEW in undergraduate measurements and instrumentation course, *Proceedings of the ASEE 2006 Illinois-Indiana and North Central Joint Section Conference,* Indiana University Purdue University Fort Wayne (IPFW).

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