CERIAS Tech Report 2007-88

Preparing IAS Graduates to Recognize and Manage Complexity

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ABSTRACT
Graduates entering the field of Information Assurance and Security (IAS) will be faced with many complex, ill-defined challenges. To be successful, IAS professionals will need to be able to solve complex, ill-defined problems that reflect the nature of the security risks, threats, and vulnerabilities that await them. Hence, a significant challenge facing educators is how to prepare professionals to recognize and manage complexity. Frequently, class assignments and problem activities are selected without complete understanding regarding the efficacy of the activities to increase students' understanding of the principles being taught. This paper will examine attributes of complex problems in the context of information assurance and security and proceed to analysis of how to teach complexity in IAS.

Categories and Subject Descriptors
K.3.2 [Computers and Education]: Computer and Information Science Education –Curriculum.

General Terms
Security

Keywords
IAS Education

1. INTRODUCTION
Our society has seen a dramatic increase in the number of security threats, risks, and vulnerabilities to our nation's computer systems, data, and infrastructure. This rise of security risks and threats to our society may necessitate a change in the way we prepare IAS graduates. Graduates entering the IAS field will be constantly faced with new threats, vulnerabilities, and risks to their organizations that will require creative and new solutions. These solutions will depend upon the graduate's ability to deal with complexity and ambiguity. IAS professionals will be faced with many problems that are complex, ill-defined, and multi-disciplinary in nature. But how do we, as educators, prepare these professionals to be successful? Are traditional approaches sufficient to prepare them to recognize and manage the complexity they will face? Traditional lectures with exercises that results in correct or incorrect answers may not produce the skills necessary to solve today's security issues. Research has shown that the problem-solving skills used to solve traditional, well-structured problems (those typically found at the end of textbooks and traditionally used in class assignments) do not help when solving ill-structured problems [3] and especially those ill-structured problems found in the field of IAS. The demand for professionals being able to solve IAS problems is steadily increasing and academia is now faced with the challenge of preparing these professionals for the complex ill-defined problems that await them.

Many institutions are experimenting with case-study approaches to teach problem solving, while others are developing laboratory exercises to develop troubleshooting skills, however; we may need to reevaluate how we think about IAS instruction and the nature of thinking skills. There are many important factors to consider when designing and/or selecting activities for instruction. Some of these factors include:

- Selecting essential items (principles, big ideas) followed by in depth student examination.
- Making the activity "real" and "authentic" to students.
- Active "doing" rather than passively learning, "engaging" the students.
- Encouraging representational fluency (Modeling cycles, multiple solution pathways, multiple design iterations).
- Promoting "higher order thinking" through complexity and ill-structuredness.
- Helping pull out principles (abstraction) so that they can apply these principles to new situations (transfer).
- Using learning outcomes as the driver for selecting problem types.

It is not the intent of this paper to address all of the factors of designing instructional activities, rather to examine research findings with an eye toward the application of such theory to teaching students to recognize and manage complexity. In order to create activities that encourage the development of ill-structured problem solving skills, one must understand how problem types differ.

2. THE NATURE OF PROBLEM SOLVING

Understanding the theory behind problem-solving provides important insights when creating problems activities for students. Jonassen [5] has focused his research on creating better design models to help instructors think through the different characteristics of problem types. According to Jonassen, problem-solving skill is a function of three factors: the nature of the problem, the way the problem is represented to the solver, and individual differences as shown in Figure 1.

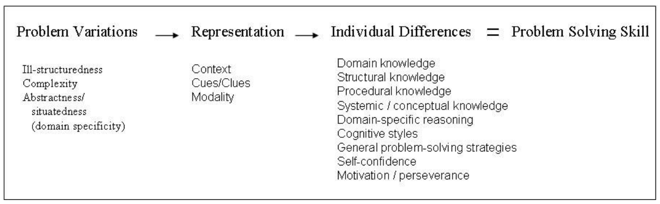

Figure 1. Problem Solving Skill

Problem types vary along three dimensions: structure, form and process [5]. A starting point is the classification of problems into two different categories: well-structured and ill-structured. Well structured problems are where the problem has well-defined parameters and are the type often found at the end of textbooks [5]. Characteristics of well-structured problems include a) all elements of the problem are presented, b) rules and principles are presented in a predictive way, and c) solutions are known and the relationship between solution and possible outcomes are probabilistic [5].

Ill-structured problems are those more likely to be encountered in real life and professional practice. The solutions for ill-structured problems may require knowledge from many different content domains with the solution not being predictable. For example, having students determine the SHA-1 hash of a file is a simple well-structured problem as compared to deciding upon a strategy for intrusion detection with no way to verify the correctness of the solution. Jonassen [5] presents the following as attributes of ill-structured problems: a) possess problem elements that are unknown or not known with any degree of confidence., b) possess multiple solutions, solution paths, or no solutions at all, c) possess multiple criteria for evaluating solutions, so there is uncertainty about which concepts, rules, and principles are necessary for the solution and how they are organized, and d) often require learners to make judgments and express personal opinions or beliefs about the problem, so ill-structured problems are uniquely human interpersonal activities.

Problems also vary by complexity and abstractness as shown in Figure 2. Complexity refers to how many issues, variables, and functions are enmeshed into problems, and this complexity constitutes the problem difficulty. With a more difficult problem, more cognitive operations must be used to process all of the information. Jonassen [5] notes that ill-structured problems tend to be more complex and well-structured problems tend to be simpler. However, it is important to note that well-structured problems *can* be very complex. For example, a programming assignment may be a complex, well-structured problem and deciding which finger to use on a biometric device may be a simple, ill-structured problem [5].

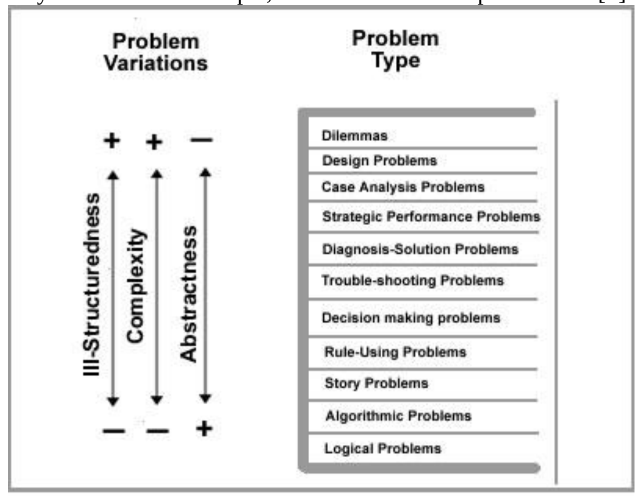

Figure 2. Problem Variations by Type

Complexity does not only refer to the number of variables, but also to the nature of the interactions among variables. Von Aufschnaiter and Von Aufschnaiter [13] studied the relationship between complexity and situated meaning and found four distinct levels of conceptual development with regard to complex ideas and complex thinking (see table 1). Area I represents the least complexity and area IV the most complexity. According to von Aufschnaiter and von Aufschnaiter [13] complexity increases not only as more variables and relationships are added, but as the nature of those relationships becomes more theoretical and less concrete.

Table 1. Levels of Complexity

Area	Description of Levels
Area IV: covariations of variable classes of situations and objects	Systems: Construction of stable networks of variable principles Networks: Systematic variation of a principle according to other principles Connections: Links between several principles with the same or different variable properties
Area III: variable classes of situations and objects	Principles: Construction of stable covariations of pairs of properties Programs: Systematic variation of a property according to other stable properties
Area II: invariant classes of situations and objects	Events: Links between some stable properties of the same or of different class(es) of objects Properties: Construction of classes of objects on the basis of common or different aspects
Area I: situations and objects	Operations: Systematic variation of objects according to their aspects Aspects: Links between objects and/or identification of specific features Objects: Construction of stable figure-ground distinction

Jonassen [5] offers eleven problem types that lie on a continuum from those considered well-structured and abstract to those considered ill-structured and situated. Logical problems are the most well-structured, abstract problems in Jonassen's taxonomy with dilemmas being the most ill-structured situated problem type (see figure 2).

While not the focus of this paper, it is important to note that problem-solving skill also depends upon representation and individual differences. Problem representation involves deciding upon how to construct the problem space for the learners. Will there be clues and other prompts? Will problems be presented in a classroom setting with students working in teams, or will problems be individual assignments that can be solved outside of class?

Returning to figure 1, individual differences are the capabilities of the student to solve the problem. This includes how familiar the students are with the problem type used, and their previous experiences solving problems that are similar. Domain knowledge is also an important individual difference. Domain knowledge includes the amount of declarative, conceptual, procedural, and principle knowledge the students have acquired and structural knowledge is how well students can create relationships between concepts. Metacognition is the problem solvers' ability to monitor their learning and create plans on how they will go about solving the problem. To summarize Jonassen's [5] design theory of problem solving, problem-solving skill is dependent upon problem types which differ by variations (structuredness, complexity, and situatedness), representation, and individual differences.

3. COMPLEXITY IN IAS: IMPLICATIONS FOR INSTRUCTION

The field and knowledge domain of information assurance and security are inherently about systems of systems and the interaction therein. Systems of systems (SoS) are made up of multiple systems that are complex in and of themselves. These multiple systems are integrated at multiple levels and across multiple domains, including geographical domains. Because the systems are inherently complex, the thinking required of professionals who design, develop, deploy, and maintain these systems is necessarily complex. In order to more meaningfully discuss considerations for teaching complexity, we begin with a brief discussion about the nature of complex systems with a focus on IAS.

According to Sage and Cuppan [12] and DeLaurentis [2], System-of-Systems problems possess the following characteristics: operational independence of the individual systems, managerial independence of the systems, geographical distribution, emergent behavior, evolutionary development,, networks, heterogeneity, and trans-domain knowledge. We define these characteristics briefly in table 2 below in order to discuss how IAS possesses these traits.

Table 2. Characteristics of Systems-of-Systems

Characteristic	Description
Operational Independence	Constituent systems are useful in their own right and generally operate independent of other systems.
Managerial Independence	No one is completely in charge. Unique intent can be provided by the owner/operator. A Systems of Systems (SoS) will most likely represent a federation, perhaps formed ad hoc.
Geographical Distribution	Constituent systems are not physically co-located; but, they are in communication.
Emergent Behavior	Properties appear in the SoS that are not apparent (or predicted) from the constituent systems.
Evolutionary Development	The SoS is never completely, finally formed. It constantly, changes and has a "porous" problem boundary; i.e. is a living system. Behavior is time varying.
Networks	Networks define the connectivity between independent systems in the SoS through rules of interaction.
Heterogeneity	Constituent systems are of significantly different nature, with different elementary dynamics that operate on different time scales.
Trans-domain	Effective study of SoS requires unifying knowledge across fields of study.

In information assurance and security, the systems include technical/mechanistic systems, as well as human/societal systems including, for example, government (federal, state, local), organizations (for profit, non-profit, etc.), and social groups (nation states, terrorists, organized crime, etc.), to name a few. A systems of systems approach to IAS would consider integration interfaces of the various heterogeneous systems and at multiple levels. A systems of systems approach will explore trans-domain interactions and cooperation among independent systems, which aligns to area IV of the von Aufschnaiter and von Aufschnaiter model of complexity where covariations of variable classes of situations and objects are at issue.

As Neumann [10] notes with regard to the security of information systems…"system compositions at present are typically ad hoc, based on the intersection of potentially incompatible component properties, and dependent on untrustworthy components that were not designed for interoperability— often resulting in unexpected results and risks". This brief quote about information systems security exemplifies the systems of systems characteristics.

Operational independence of each component of an IAS system necessitates policies, procedures and constant diligence by those managing the systems. Each component selected within an IAS system usually works independent of other systems with specific purposes in mind. For example, a perimeter firewall independent of the anti-virus server, however each is needed in order to achieve the purpose of IAS. Another example of operational independence within the IAS systems of systems is Public Key Infrastructure (PKI). PKI is used to provide confidentiality for online transactions and also ensures integrity and non-repudiation. Although these IAS technical systems are independent from each other, effective coupling of these systems together requires integration, as well as supporting policies among management and personnel. While the management of the systems is independent, the interdependence of each system in achieving a larger whole must be addressed so that the federation serves collective and individual needs. IAS systems can vary over a wide geographic distances. Corporate security systems can span states and even countries as employees travel to customer's locations and employees work from home. With each employee laptop connecting back to a company network through a virtual private network (vpn), the company's IAS system has been expanded and extended to all of the endpoints. These endpoints include datacenters, disaster recovery sites, and remote locations that extend the IAS systems geographically. Information sharing, policies, and technical reviews should be an ongoing process in order to manage the complexity of these far-distant systems. Having systems located in different locations complicates the span of control. Learners need to work from the concrete to the abstract and from the abstract to the concrete - an upward and downward dialectic if you will – in order to motivate the need for abstraction on the part of the learner as well as to provide sufficient meaning at a concrete level to enable abstraction to occur.

Emergent behavior of IAS systems renders the ability to abstract in order to predict and respond to covariant behavior essential. Emergent behavior describes how new ways to utilize the system emerge that were not previously foreseen. IAS systems are not a steady state system; they are constantly evolving, changing, and being updated to adjust to the new threats as they become apparent. Each week as new threats are discovered, IAS systems will need to be patched and updated to mitigate threats. In addition to ongoing maintenance, the IAS system is always expanding or contracting through devices and systems being added to or subtracted from the environment.

Technical systems are made for and created by human systems. Technical systems are also attacked by human systems. Humans have created non-technical systems (management and policy) to manage and mitigate threats to technical systems from other human systems (individual groups, organized crime, subcultures, etc). In short, IAS is as much about human and societal systems as it is about technical systems; without humans and societies we would not need information assurance and security. Information assets are tied to individuals, organizations, agencies, societies, geopolitical entities, etc. The actions, or lack thereof, of human beings as they interact with information systems and information security systems can be threats, vulnerabilities and countermeasures. From an offensive perspective, human threats to information assurance and security can be both accidental, as well as intentional. Accidental threats can be due to negligence, ignorance, and simple error. Intentional human threats can range from hacking to virus writers and beyond; intentional threats are often classified according to motivation, capabilities, and resources. From a defensive perspective, humans need to be a part of the security solution, whether it is in detecting social engineering, auditing security policies, monitoring logs, or protecting passwords. Gaps or inadequacies can create vulnerabilities. When human beings/societal systems fail to take action, it can be vulnerability; conversely, when they act, they function as countermeasures.

Information systems are comprised of subsystems and these subsystems are often built/implemented by different organizations with conflicting or competing goals. Furthermore, these subsystems are often designed under different assumptions and/or built to different quality standards. The policies intended to support any one entity (be it one organization or an entire industry sector) are often plagued by operational independence. We can assume that the policy applies to all sub-entities within the entity (all people within an organization or all organizations within a country, however, these policies are often not consonant with the policies of other organizations or other countries. In this way, we can see the operational and managerial independence of the human/societal systems and the manifest discord when the respective policies compete or conflict. Understanding these differences is no small feat. It requires students to have multiple perspectives (e.g., computing, psychology, sociology, political science and law, to name a few).

At more concrete levels, IAS students should be able to identify the relevant agents and even to describe classes of objects, e.g., hacker taxonomies do this. However, educators should also be interested in cultivating in learners the ability to conceive the complexity of covariation across multiple domains, (e.g.., technical, social, political). The nature of this grounding should be deep enough to allow students to consider that organizations are complex, nonlinear systems whose members (agents) can shape their present and future behavior. IT is enabling the creation and development of new federations, including ad hoc networks. An obvious and timely example is that of globalization. The growth in inexpensive, yet relatively sophisticated communication modes is contributing to changes in political, financial, trade and production globally. These ad hoc networks, or federations, are changing the environment to a more global one. This implies, as a minimum, A competing in B's country, B competing in A's country, and A and B competing in C, D, and E. This co-evolution impacts values, business practices, cultural and ethical parameters. Understanding these trends and the factors that are involved is important to IAS students as they consider how changes in organizational and human behavior impacts the nature and value of information assets, threats, vulnerabilities and counter-measures.

4. USING MEAS TO TEACH COMPLEXITY

We turn now to a few principles for teaching IAS to recognize and manage complexity. Students need to be repeatedly exposed to authentic life situations. Examples of situations that hold great potential for teaching complex thinking skills are ambiguities, challenges, dilemmas, discrepancies, paradoxes, puzzles, etc. Problem situations that are particularly fruitful are multi-categorical and not domain specific [4]. In other words, multi-categorical situations span multiple problem types at once; these problems are challenges, dilemmas, discrepancies, etc., at the same time. A multi-categorical problem also involves learners across a spectrum of thinking activities: problem finding, trouble shooting, detecting inequities and contradictions, making choices, and creating new ideas and objects. And finally, a multi-categorical problem is one that targets varying levels of complexity, i.e., level one - situations and objects, level two invariant classes of situations and objects, level three – variable classes of situations and objects, and level four – covariations of variable classes of situations and objects. A problem is not domain specific when it crosses disciplinary bounds (e.g., psychology, computing, sociology) and requires use of skills from these multiple dimensions to find the problem, trouble shoot, detect the contradiction, etc. Many of these principles are found in a teaching approach called Model Eliciting Activities (MEAs). We turn now to a discussion of the features of MEAs with an emphasis on how MEAs can be useful for teaching complex thinking in IAS. Our intent is not to focus on MEAs as a silver bullet instructional method. The salient point for readers should be the features of MEAs and how those features are useful for teaching complex thinking so that the principles can be applied to other instructional strategies.

Model eliciting activities (MEAs) are ill-defined problem activities where the students are engaged in constructing a model that reflects their thought processes, which is externalized and evaluated for purposes of refining and improving the model. A main goal of MEAs is not to derive an answer for the problem; rather, the goal is the coming up with the process itself [6]. These thought revealing activities are based upon a modeling perspective of helping the students find ways to adapt, modify, and refine ideas rather than identifying relevant ways of thinking when they have none. However, an ultimate goal of MEAs is to have students develop mental models that are robust and accurate.

When doing MEAs, learners create conceptual tools that may include diagrams, spoken language, metaphors, symbols, and other representational media. These tools are used to document the learner’s current mental representations and help explore how they are interconnected. This is an evolutionary process referred to as “modeling cycles” and the learner will progressively refine and test these representations [7]. The process of shifting back and forth among a variety of relevant representations helps learners refine their understanding until a solution is possible. This process allows the learner to see underlying patterns that may require the learner to question their current representations, or relationships between representations, so that their model is continually evolving until “the match between the model and the modeled is experienced as being sufficiently close and sufficiently powerful to produce the desired results without any further adaptations” ([7] p.16).

MEAs are similar to case studies in the fact that both include analysis of situations; however the goal of MEAs is to consistently go beyond discussions and short answers. MEAs are simulations of real-life problems where the learners develop models and conceptual tools for making sense of complex systems. These conceptual tools are created during an MEA activity where students make significant modifications to their own current ways of thinking as they revise and refine their models. So while case studies are looking backward at events that took place, MEAs are relying on students to look forward using their existing ideas and putting them down on paper using diagrams, symbols and words and then through discussions, modify their ideas until a solution presents itself. This process reveals important aspects about how students are thinking. The goal is to have students add to their existing understandings rather than trying to introduce new ideas with no connections to previous experiences.

5. AN ANALYSIS OF MEAS TO LEARNING AND TRANSFER

The National Research Council [9] published findings that suggest the following key characteristics of learning and transfer are important for educators to consider as they develop activities to help students understand knowledge domains that are complex:

- Initial Learning / Knowledge
- Multiple Contexts (Representational Fluency)
- Active Learning
- Metacognition
- Motivation
- Abstract representations
- Previous Learning
- Transfer between school and everyday life

Although there are varying degrees of each characteristic, Table 3 shows a viewpoint of how MEAs for complex concepts correspond to the principles that are important for learning and transfer. This is not to say that a learning activity must include all of these principles, rather these principles can be used as a lens to view where a learning activity may or may not fall short.

Table 3. A comparison of MEAs and transfer.

National Research Council's Findings on Learning & Transfer	Initial Learning/knowledge	Multiple Contexts (Representational Fluency)	Active Learning	Metacognition	Motivation	Learning from Previous Experience	Abstract Representations	Previous Learning	Transfer between school and everyday life
Model Eliciting Activities		✓	✓	✓	✓	✓	✓	✓	✓

These learning principles are non-discipline dependent suggesting that all learning can benefit from these principles. Seven of the nine characteristics of learning and transfer can be mapped directly to the theory behind MEAs. To further explore how each principle relates to MEAs, a discussion of each of these principles and how they relate to MEAs will be provided.

5.1 Initial Learning Knowledge

Initial learning is a key factor for transfer that many times is overlooked. Initial learning is mastery over a particular topic or subject matter and "without an adequate level of initial learning, transfer cannot be expected ([9], p53). In a study to see the effects of transfer when using the programming language LOGO, it was found that there were no benefits of transfer unless a significant degree of knowledge was gained during the learning process [9]. Further studies have shown that other characteristics of initial learning that affect transfer are understanding rather than memorizing and the time required for students to "process" complex subject matter [9]. Additionally, it is important to understand the amount of time initial learning takes to move into long term memory, for example to become a chess master requires around 100,000 hours of playing in order to reach world class expertise [9]. Much of the time spent on initial learning is developing patterns of recognition that can be recalled and applied to new experiences [9].

MEAs are based upon a modeling perspective of helping students find ways to adapt, modify, and refine ideas to come up with solutions. Currently, MEAs have been used to help students create solutions based off of mathematical concepts and students use their previous mathematical learning to adapt, modify, and refine their ideas. This suggests that some experience and initial learning of the underlying concepts is important for students performing MEAs. This would also suggest that MEAs that are based off of complex concepts may require additional initial learning and experience to elicit solutions.

5.2 Multiple Contexts

The context in which initial learning occurred is also important for transfer. If the initial learning was tied to one context it may be difficult for students to see how this knowledge transfers to novel contexts. For example, it was shown that Orange County homemakers were able to make shopping calculations, but not be able to perform equally on a school-like, paper test [9]. Brown Collins and Duguid [1] suggest much of learning is situated, meaning that what is learned is closely tied to the context in which it is learned. Another potential limitation to transfer is when discussions and examples are used to facilitate retrieval for later use will also make it more difficult to retrieve knowledge in other contexts. This can be seen in case-based and problem-based activities where knowledge is overly contextualized [9].

An important characteristic of MEAs is the students are repeatedly revising, refining, and extending their thinking. They are continuously going through sequences of induction and deduction cycles as they think about possible solution paths. This allows their current interpretations to be evolving through team discussions. Each student may have specific contexts attached to their previous learning and through discussions will be able to see how others have understood this knowledge in different contexts, thus helping students to see how knowledge can be used in multiple situations.

5.3 Active Learning

The National Research Council [9] states "it is important to view transfer as a dynamic process that requires learners to actively choose and evaluate strategies, consider resources, and receive feedback" (p. 66). Learning and transfer should be an active dynamic process where learners are engaged. Prompting and discussions can aid in this process.

The model development sequence puts the learners into teams where they conceptualize, build, discuss, test, revise, refine, and retest possible solutions and question ideas as they are presented. The continuous revising and discussing ideas would be considered a very active approach to learning.

5.4 Metacognition

Metacognition is the ability of learners to be aware of themselves and their thought processes. This occurs when learners can identify when their current knowledge is inadequate and then take appropriate steps to fill in their missing knowledge. Teaching metacognition approaches to learners has also been beneficial for increasing learning transfer. Teaching learners how to monitor themselves, their thinking, learning strategies, resources and assessing readiness, will provide a lifelong strategy for staying on the path to expertise [9]. This monitoring includes learners seeking feedback from others to correct and progress current understandings.

One of the main goals of MEA exercises is for the students to be self-monitoring. This means that the students, not the instructors, monitor their own thought processes to identify errors of logic and continue to make adjustments to their own ways of thinking. A key characteristic of a model is eliciting activity is that it evoke self-assessment, which means that to be effective, the MEA will require students to judge for themselves when ideas and responses need refinement. These processes takes place throughout the entire MEA and requires continuous assessment of students' own work.

5.5 Motivation

Motivation has been identified as one of the most influential aspects to learning. When students are motivated they will invest more time and energy into learning of new material. It is also important that the difficulty level should be considered to keep students motivated. If the activity is too difficult, students will disengage, and if they activity is too easy they will become bored. The NRC [9] also identifies social opportunities as an important component of motivation. "Learners of all ages are more motivated when they can see the usefulness of what they are learning and when they can use that information to do something that has an impact on others—especially their local community" (p. 61). This suggests that students will be more motivated if they feel like the activity they are engaged in is useful and a benefit to others.

MEAs are problem activities that have been developed to provide real-life examples that engage students. When designing MEAs one of the guiding principles is to make the MEA realistic enough so that students feel the activity is authentic and would be the type of problems students will face when they enter the workplace.

5.6 Abstract Representations

Abstract representations are another important requirement for transfer. This involves students being able to generalize their solution strategies so that they can be used in different contexts.

For example, students who were trained on performing specific tasks without identifying the underlying principles were less likely to apply their new learning to new problems while those who were both trained on specific tasks and provided abstract training were able to transfer their knowledge to new problems [9].

MEAs are part of a sequence of activities where the goal for the students is to be able to create an abstract problem solving tool that can be applied to new problems. The sequence involves a warm up activity, MEA, presentations and discussions, reflection, Model-Exploration Activity, follow-up activities, and a Model-Adaptation activity. These sequences of activities are designed to help students develop deeper, higher-order and abstract thinking.

5.7 Previous Experiences

The NRC [9]) suggests that all learning is based on transfer from previous experiences. This includes initial learning because even when new information is presented for the first time, students will use their previous understandings and experience in order to make sense of the new information. This becomes important for instructors trying to introduce new learning to students because misunderstandings may occur due to students' previous experiences, which may cause the student to not realize he/she is failing to understand correctly [9].

The use of MEAs is not focused on solving problems rather assisting students in eliciting ideas from their previous experiences to create conceptual models. The MEA activity consists of students discussing ideas surrounding their previous experiences that may apply to this situation and through discussions and peer questions, students will be able to revise their thoughts and build upon others' ideas. MEAs are strongly dependent upon the idea that all learning involves transfer from previous experience.

5.8 Transfer between School and Everyday Life

The NRC 10] suggests that the goal of learning is to help students transfer what they have learned in school to everyday life. This includes home, community and the workplace. One of the limitations placed on students during school is the focus on individual work. When students enter the workplace they will need to be able to work collaboratively and share their knowledge. People have to work together in order to succeed in most any discipline, whether it is piloting a ship, running a business, or defending a network.

Teamwork is an essential part of MEAs as peer learning is the vehicle through which models and ideas are generated. This involves students planning, monitoring, assessing, and communicating their ideas to each other. This process more closely resembles real-life situations that students will find in everyday life.

6. INSTRUCTIONAL USE OF MEAS

For educators wishing to develop model eliciting activities for instruction, there are six instructional design principles of an effective MEA.

1. The Personal Meaningfulness Principle
2. The Model Construction Principle
3. The Self-Evaluation Principle
4. The Model-Externalization Principle
5. The Simple Prototype Principle
6. The Model Generalization Principle

The personal meaningfulness principle is used to engage the learner by helping the learner to see the usefulness and real life application of the exercise and to help the student understand that they will use their existing experiences and knowledge without any constraints for how to think about the problem [6]. Questions for analyzing how well the personal meaningfulness principle is being incorporated into the MEA are: a) did the MEA require students to reveal explicitly how they are thinking about the situation, b) are the students revealing possible solution paths they took, c) is there an audit trail to determine what the students were thinking about, and d) does the products students produce disclose their thought processes?

The model construction principle is used to help the learner understand the need for a model and what depth the task involves [6]. Questions regarding the model construction principle include: a) is the model that is developed shareable, and b) is the model easily modifiable?

The self-evaluation principle is used to help students recognize which representations are useful and whether their model is sufficient for the specific exercise [6]. Questions that may be asked to assess if the MEA meets the self-evaluation principle are: a) can the students' judge when their responses need improved, refined or extended, b) will the students know when they are finished? Or will they continually ask "is this good enough, and c) can students detect deficiencies in their current ways of thinking?

The model-externalization principle is used to help ensure the learners model explicitly and appropriately represents the learner's views [6].This can be seen by asking: a) did the MEA require students to reveal explicitly how they are thinking about the situation, b) are the students revealing possible solution paths they took, c) is there an audit trail to determine what the students were thinking about, and d) does the products students produce disclose their thought processes?

The simple prototype principle is used to help the learners understand that the model should be as simple as possible without losing any explanatory power for the current problem or similar problems [6]. Simple prototype questions are: a) do the solutions produce a useful prototype for interrupting other situations, and b) is the solution as simple as possible?

The model generalization principle helps the students understand that the desired model should be modifiable and extendable for different situations [6]. These principles were also used to assess and improve activities that were already being used or found in other resources. Questions include: a) is the model that is developed shareable, and b) is the model easily modifiable?

Using these six principles, MEAs can be an effective way to help students learn how to approach complex problems.

The form of the MEA can take many shapes. Some universities have used the “memo” type MEA, which is given to a group of students (usually 3 or 4) who are then allotted 45-60 minutes to work on a solution.

7. CONCLUSION

We believe that teaching students how to recognize and manage complexity is in itself a difficult and complex task. If educators seek to develop this type of expertise in their students, it is necessary for them (educators) to have well-formed definitions of complexity with regard to the nature of complex problems and the nature of complex thinking. Once this theory base is sufficiently established, then educators can move in a purposeful manner toward instructional strategies that will more effectively elicit complex representations of systems.

By way of example, this paper presented the idea of MEAs and discussed the characteristics of MEAs that are essential in helping students recognize and manage complexity. We are not trying to suggest that MEAs are the only instructional approach; there are likely many instructional methods that would be efficacious for developing complex thinking in students. Future work is needed to examine other instructional methods in general. Future work is also needed on MEAs in particular to better understand which attributes of MEAs most contribute to students’ ability to recognize and manage complexity in the field of IAS.

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