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Types of Agricultural Innovations and the Design of Extension Programs

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Geoff Kaine, Megan Hill and Ben Rowbottom
Department of Primary Industries, Victoria

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Table of Contents

List of Figures

List of Tables

Introduction

The Australian wine industry is constantly responding to environmental, business and market challenges, while striving to improve productivity and the management of natural resources (GWRDC 2007). To meet these challenges, growers and wineries adapt their businesses by adopting innovations or using existing technologies and practices in innovative ways (Invest Australia 2005). Through research and extension, public sector agencies and industry bodies play a critical role in supporting growers to adapt their businesses. Therefore effective extension to inform growers about these research findings, and to enhance their adoption, becomes crucial in terms of justifying the investment in research and extension.

While there is extensive literature on agricultural extension, it provides little guidance for systematically identifying which of those extension methods would be best employed to accelerate the adoption of any particular innovation. The extension literature on learning styles (Kilpatrick et al. 1999; Trompf and Sale 2001; Fulton et al. 2003; Kilpatrick and Johns 2003; Andrew et al. 2005; Coutts et al. 2005) suggests different types of extension methods are needed to deliver knowledge to people with different styles of learning. Although this literature draws on a variety of theories of learning such as action learning, adult learning, experiential learning, social learning and double loop learning (Argyris 1976; Bandura 1977; Kolb 1984), this literature does not suggest, in a systematic way, how different extension methods might suit the promotion of different innovations.

The extension literature on participatory approaches to research (Biggs and Clay 1981; Byerlee et al. 1982; Roling 1996; Black 2000; Norman 2002; Dorward et al. 2003; Sumberg and Reece 2003) highlights the importance of producer participation in refining research directions so that the innovations developed suit their needs. However, this literature is largely silent on the issue of the role of extension in promoting the resulting innovations among the wider population of producers (Douthwaite et al. 2002; Dorward et al. 2003).

The literature on the diffusion of innovations (Rogers 1995) provides criteria (based on the characteristics of innovations) for assessing the relative rates with which different innovations may be expected to diffuse through a population of potential adopters. While recognising that the differing characteristics of the innovations influence the ease of their adoption, this literature does not provide a systematic method for using these characteristics to identify which extension activities might be the most appropriate for promoting adoption.

Farming systems research (Norman 1980; Ruthenberg 1980; Byerlee et al. 1982; Norman 2002) focuses on identifying innovations to overcome critical constraints in selected farming systems. The issue of choosing methods to promote the dissemination of these solutions among producers with the selected farming systems is largely ignored (Dorward et al. 2003; Reece et al. 2004).

Kaine (2004) provides a method for identifying the population of potential adopters of an agricultural innovation and, in doing so, provides information on the benefits producers seek from innovations. While this information is necessary to design extension programs that will attract the attention of producers, this information provides only limited guidance on the extension methods to include in an extension program.

Hence, there is a need for a framework for classifying agricultural innovations in a way that provides guidance on the qualitative differences in the extent and nature of learning necessary to adopt them. Such a framework would assist in identifying the extension activities that would most effectively support that learning.

In this paper we describe Henderson and Clark's (1990) framework for classifying innovations. We then describe the adaptation of their framework so as to classify innovations in agricultural systems into the four generic types described by Henderson and Clark (1990). The application of the framework with implications for the design of extension programs is then illustrated using examples drawn from viticulture.

Conceptual Framework

Henderson and Clark (1990) argue that a product can be conceived of as a system – that is, a collection of components that are linked together. Henderson and Clark (1990) define the components of a product as the physically distinct parts of a product. Components embody a core design concept and perform a particular function. The architecture of the product describes how the components are linked together to enable the product to function as a whole.

Henderson and Clark (1990) describe how the creation, maintenance and management of a system requires knowledge in regard to the components of the system and the design concepts embodied in them. Architectural knowledge is also required, in regard to how components are linked together, the design concepts embodied in the architecture of those linkages and an understanding of how the components and linkages combine to influence the way in which the system functions and behaves in different environments (Baldwin and Clark 2000). This means, any change to the components of a system or the linkages between them involves, to some degree, the acquisition of new knowledge and the development of plans and procedures to implement the change. Consequently, the four types of innovations they identify present a continuum of change for organisations in regard to competencies, roles, responsibilities processes, policies, organisational structure and culture (Abernathy and Clark 1985; Kaine et al. 2006).

Henderson and Clark (1990) provide the example of a fan to illustrate these concepts. The components of a fan include blades, electric motor, stand and a fan guard. The motor embodies a core design concept which is the use of electricity to power the fan blades. Henderson and Clark (1990) describe how the components of the fan are linked together to create a system for moving air in a room. For example, the blades are secured to an axle which is linked to the motor. The motor and fan assembly are fixed to a stand. The linking of the blades, engine and stand is underpinned by a series of architectural principles resulting in a mobile room fan (Henderson and Clark 1990).

Consequently, product innovation can be conceptualised as changes to components, the linkages between them, or both. They then suggest that innovations can be categorised into four types: incremental, modular, architectural or radical, depending on the degree of change introduced into the components and the linkages between them (see Table 1 and Figure 1). The distinctions between these types of innovations are a matter of degree (Henderson and Clark 1990).

Incremental Innovations

Incremental innovations introduce relatively modest changes to existing products by refining and improving design concepts that exploit the potential of an established design (Henderson and Clark 1990). This is usually achieved by altering relatively few components and leaving the links between components, that is, the product architecture, largely unchanged (Henderson and Clark 1990). These incremental innovations increase the functional capacity of the product through small-scale, continuous improvements in product attributes such as performance, safety, quality and cost (Olofsson 2003). A change in the shape of the blades used in a fan might be an example of an incremental innovation.

Henderson and Clark (1990) suggest that incremental innovation may require new component knowledge and skills. However, incremental innovations are described as competence enhancing because they tend to build on, and extend existing skills, reinforcing the applicability of existing knowledge. Christensen and Overdorf (2000) suggest that incremental change also confirms that organisational processes and priorities are valid, entrenching them in the organisation's culture.

Modular Innovations

A modular innovation contains components that supersede the components they replace because they embody a new core design concept. Existing components become obsolete because the new components are based on novel design concepts rather than simply being improvements on established design concepts. The architecture linking the components of the product together remains largely unchanged with modular innovation (Henderson and Clark 1990).

Modular innovation may be competence enhancing or destroying, depending on the history of the specific organisation (Gatignon et al. 2002). Because the new modules are based on entirely new design concepts, the skills and practices that were required in the design and manufacture of the obsolete components may no longer be required. Entirely new skills, competencies and processes may be required to manufacture and install the new components. Some organisations purchase the expertise needed to deal with the demands for new knowledge and skills (Kaine and Higson 2006).

Since modular innovations may test or displace organisational competencies and knowledge that are specific to the components that are replaced, modular innovation may have disruptive effects across an organisation (Tushman and Anderson 1986) and require changes in roles and responsibilities within organisations (Kaine and Higson 2006).

A change in the materials used in the blades of a fan, such as the replacement of metal blades with plastic blades, might be an example of a modular innovation. The change from metal to plastic represents a new core design concept yet there is little or no change in the other components of the fan, or in the way the components are linked together.

Table 1: The characteristics of different types of innovation, adapted from Henderson and Clark (1990)

Type of innovation	Core design concept	Components	Architecture
Incremental	No change	Changed	No, or minor change
Modular	New	Major change or new	No, or minor change
Architectural	No change	No, or minor change	Major change or new
Radical	New	Major change or new	Major change or new

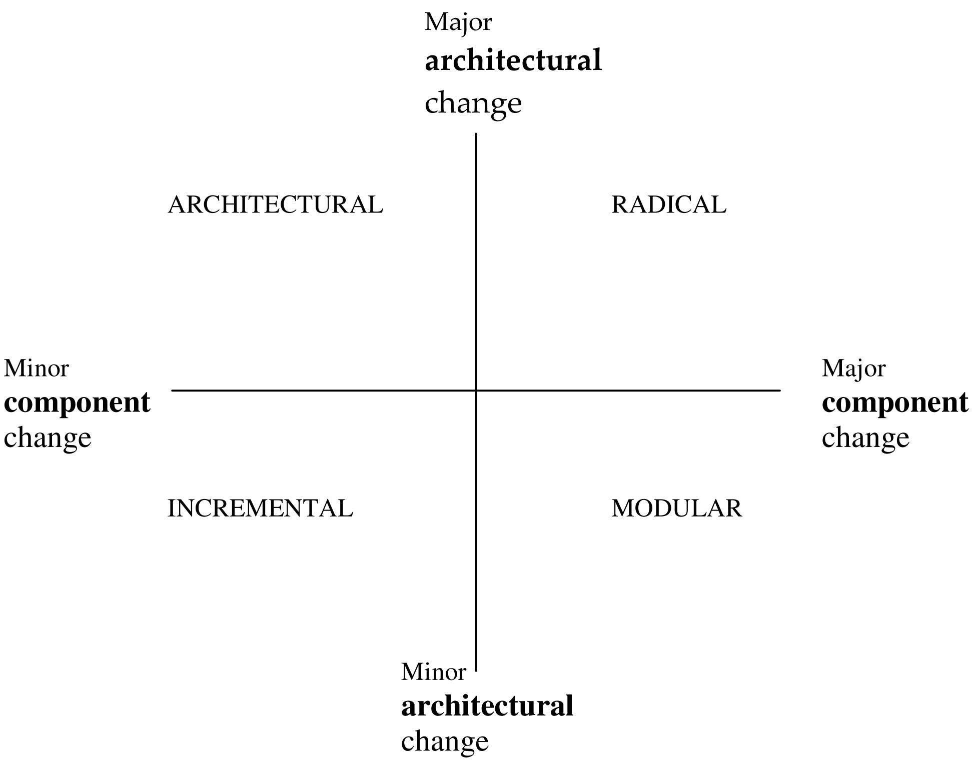

Figure 1: A classification of innovations, adapted from Henderson and Clark (1990)

Architectural Innovations

Henderson and Clark (1990) define an architectural innovation as "the reconfiguration of an established system to link together existing components in a new way". Generally speaking, architectural innovations entail relatively minor changes in the components. Abernathy and Clark (1985) suggest that architectural innovations are often triggered by changes in the size or design of component size that create new interactions and linkages between components in the established product. In short, the core design concepts that underpin the components in the system remain unchanged by architectural innovation, it is the changes to the linkages between components that characterises architectural innovation.

Architectural innovations may be difficult to identify because most of the components in the system and the core design concept that underpin them, remain the same. Yet architectural innovations have been shown to create serious disruptions in organisations because areas of architectural knowledge are superseded, rendering the associated skills and competencies obsolete, even though much component knowledge remains useful (Henderson and Clark 1990; Kaine and Higson 2006). This is particularly disruptive for the organisation as architectural knowledge becomes embedded in the organisational procedures, processes and structures over time (Henderson and Clark 1990). Hence, architectural innovations in products not only require the acquisition of new skills and competencies, they may also require changes in the operating procedures, processes and structures of the organisations that manufacture them.

A change in the architecture of a fan, such as the development of the design for a ceiling fan from a design for a free-standing, portable fan, might be an example of an architectural innovation. A ceiling fan is manufactured from largely the same components as a portable, free-standing fan however the components are linked together in different ways using a different architecture based on fundamentally different design principles.

Radical Innovations

Radical innovations involve a new set of core design concepts embodied in new components that are linked together using a new architecture (Henderson and Clark 1990). Radical innovations are based on completely different scientific and engineering principles to the principles that were used in the products they supersede.

The magnitude of change entailed in radical innovations means that many areas of organisational knowledge and competence are rendered irrelevant, destroying the value of existing resources by making existing technologies, production systems and organisational structures obsolete (Henderson and Clark 1990; Gatignon et al. 2002; Kaine and Higson 2006). Consequently, to adopt a radical product innovation an organisation must acquire completely new component and architectural knowledge, develop new organisational processes and procedures, implement new organisational structures and may even have to consider new ways of thinking that may challenge organisational values (Smith 2000). In short, radical innovations are the most disruptive type of innovations.

The switch from producing a ceiling fan to an air conditioner is an example of a radical innovation. Both products are used to change the temperature of air in a room. While a ceiling fan achieves this by using rotating blades to circulate air, an air conditioner changes air temperature by refrigeration. The air conditioner is composed of many components that are based on design principles that are fundamentally different from those used in a fan. Furthermore, the components in an air conditioner are linked together using a different architecture based on fundamentally different design principles to the architectural principles used to create fans.

Types of Agricultural Innovations

Henderson and Clark (1990) developed their framework to identify different types of product innovation and argued that each of these types of innovation had different consequences for the manufacturing organisation in relation to organisational skills, competencies, procedures, structures and culture. In essence their framework identifies different generic types of system innovations. Given that agricultural enterprises are systems, we should be able to adapt and use their framework to classify agricultural innovations into these generic types.

Henderson and Clark (1990) argued that changes (innovations) in the components or architecture of a system require, to some degree, the acquisition of new knowledge and the development of plans for implementation. The greater the degree of change in the components and architecture of the system an innovation poses, the greater the effort involved in learning the knowledge, skills and competencies necessary to adopt the innovation. So, if agricultural innovations can be classified into the generic types proposed by Henderson and Clark (1990), there should be qualitatively important differences in the learning required to implement each type.

We expected that, as a result of these differences in learning, different kinds of extension activities would be required to support the adoption of each type of innovation. Given this purpose, we were interested in identifying different types of innovations in the production system rather than the output of the system. In other words, unlike Henderson and Clark (1990), we wished to identify different types of innovations in the organisation producing the product, rather than the product itself.

As our purpose was to classify agricultural innovations into types so that there were important differences in the learning involved in implementing each type, we chose farm sub-systems as the unit of analysis for applying the concepts used by Henderson and Clark (1990). We found that if the farm as a whole was treated as the unit for analysis, then this would mean that radical innovations would be restricted to those innovations where the design concept underpinning most of the components and the architecture of the farm were replaced by fundamentally different design concepts. In other words, radical innovation would be restricted to instances where the farm system itself was completely transformed. The analysis of such transformations, such as conversion of a beef enterprise from an extensive grazing system to an intensive feedlot system, was not our intent. Consequently, we chose farm sub-systems as the unit of analysis for this paper. This choice is consistent with the systems theory which recognises that the boundaries of any systems or subsystems of interest must be established depending on the topic of interest and are rarely clear cut (Weinberg 2001; Packham et al. 2007).

Fundamental Elements

Having selected farm sub-systems as the unit of analysis, innovations to sub-systems can be categorised into types on the basis of the extent to which the design concept or design principles underpinning the components and architecture of a sub-system are changed by an innovation (see Table 2).

A 'sub-system concept' is a generic description of the function of the sub-system and the way that the sub-system performs this function. Different sub-systems are designed to perform fundamentally different functions in specific ways. For example, a pressurised irrigation system is a generic description of a sub-system that distributes water to plants using mechanical energy. In contrast, integrated pest management is a generic description of a sub-system for managing pests and diseases based on the use of beneficial insects and species-specific chemicals. Therefore, pressure irrigation and integrated pest management are examples of two sub-system concepts; other sub-system concepts include animal health, feed management and breeding management.

Table 2 Fundamental elements of a farm sub-system

Sub-system Concept	A generic description of the function of a sub-system and the way this function is performed
Components	The individual technologies, techniques, practices and procedures that form the sub-system
Component Principles	The fundamental principles that guide the design and functioning of a component
Architecture	The way that the components are arranged or integrated to form the sub-system
Architectural Principles	The fundamental principles that underpin the arrangement and combined functioning of the components that form the sub-system

Adapting Henderson and Clark's 1990 framework, we defined the 'components' of a farm sub-system as physically distinct elements of the sub-system that perform a particular function. The components of a farm sub-system may include technology, techniques and practices. They embody a core design concept which consists of one or more component principles.

'Component principles' are the fundamental principles that guide the design and functioning of a component. For example, the design of irrigation bays in a flood irrigation sub-system is governed by principles in relation to controlling the direction and rate of flow of water. Other components of an irrigation sub-system might include dams for storing water and devices for monitoring water flow (see Table 3).

The 'architecture' of the sub-system describes how the components are arranged or linked together to enable the sub-system to function and consist of one or more architectural principles that describe how two or more components link together. Architectural principles are the fundamental principles that underpin the arrangement and combined functioning of the components that form the sub-system. For example, in a flood irrigation sub-system the layout of channels, bays and dams is governed by the principle that water moves from higher to lower areas. Similarly, the scheduling of irrigations is governed by principles including plant physiology.

Different sub-system concepts have different architectures and so are underpinned by different architectural principles. For example, the principle that water moves downhill under the influence of gravity underpins the arrangement and combined functioning of the components (bays, channels, gates) that form a flood irrigation sub-system. In contrast, the principle that water moves from an area of high to low pressure underpins the arrangement and combined functioning of the components (pumps, pipes, valves) that form a sprinkler irrigation sub-system.

These fundamental elements provide a basis for classifying innovations in farm sub-systems into four types of innovation: incremental, modular, architectural and radical. These four types of innovation are distinguished by the dimensions of change the innovation introduces to the component principles and architectural principles of the original sub-system.

Given that farms consist of hierarchies of inter-related sub-sub-systems (Packham et al. 2007) farm managers require procedures, policies and strategies to co-ordinate the behaviour of these sub-systems and manage the interactions between them. Hence, implementation of changes to a farm sub-system (such as the incorporation of an innovation) may require not only the acquisition of knowledge about the change to the sub-system, but also the acquisition of knowledge about how to realign sub-systems to accommodate any changes in the behaviour of sub-system that has been changed.

Different types of innovation are expected to have differential effects on the linkages between sub-systems and their interactions, with architectural and radical innovations having greater effects than incremental or modular innovations (Henderson and Clark 1990; Gatignon et al. 2002).

Therefore, if innovation in farm sub-systems can be classified into the generic types proposed by Henderson and Clark (1990), then the adoption of each type could be expected to differ in:

- the new skills and competencies needed with respect to the sub-system itself,
- the skills and competencies needed to manage changes in the interactions between sub-systems
- the skills and competencies needed to plan the implementation of the innovation.

In the next section we explore the application of the Henderson and Clark (1990) framework using illustrative applications from viticulture.

Table 3 Fundamental elements of overhead sprinkler irrigation

Overhead sprinkler irrigation	
Component	**Component Principles**
Pump	A mechanism for compressing water
Valve	A mechanism to control the flow of water through a pipe
Timer	A mechanism to open or close valves at a pre-set time
Sprinkler	Water outlet that emits water at relatively high volume
Pipe	Round, sealed receptacle used to store and transport water
Dam	Installation for storing water
Tensiometer	Mechanism for measuring water content of soil
Architecture	**Architectural Principles**
Sprinkler irrigation	Irrigation system is a fixed structure
	Water moves through system from high to low pressure
	Irrigation scheduling based on satisfying physiological requirement of plants for water optimises plant growth and crop production

Illustrative Applications

To demonstrate the application of the Henderson and Clark (1990) framework to a vineyard system, we considered the adoption of four different types of irrigation system innovations.

Kaine and Bewsell (2001a; 2001b; 2002) conducted a study on the adoption of irrigation systems in Southern Australia. They created market segments to describe the irrigation systems adopted and the benefits sought from adoption. Kaine and Bewsell (2001a; 2001b; 2002) found that the growers they sampled in Victoria and New South Wales were either:

- using either conventional gravity fed, pipe and riser irrigation systems or laser graded furrow irrigation systems
- installing pressurised irrigation on new vineyard sites
- removing furrow irrigation and installing pressurised irrigation systems when redeveloping the vineyard
- replacing outdated with new pressurised irrigation systems.

Some of the following examples represent changes made by grape growers when adopting the irrigation systems described in the Kaine and Bewsell (2001a; 2001b; 2002) study. Supporting information was obtained from a range of personal communication and technical information (Cornish et al. 1990).

These examples assume that service providers will be employed to plan, design and install the irrigation systems, as these tasks require specialised skills and technology.

Incremental Innovation

The conversion of an irrigation sub-system from overhead sprinkler to drip irrigation is an example of an incremental innovation. The key components, component principles and architectural principles for overhead sprinkler irrigation are reported in Table 4. The components and component principles that are changed by the conversion to drip irrigation are also reported in the table. Table 4 reveals that most of the components in the irrigation sub-system, except for the sprinkler heads which are replaced by drippers, are unchanged. The architectural principles of the sub-system are unaffected by the conversion. Hence, as a type of innovation, the conversion from sprinkler to drip irrigation is incremental.

The innovation requires the acquisition of some new knowledge about the components in the sub-system. For instance, drippers emit water through holes of 0.5-1.0 mm in diameter and, as a consequence, a 150 mesh water filtration system is required to prevent impurities in the water blocking these holes (Cornish et al. 1990). However, for the most part, the components in the system and the design principles that underpin them are unchanged. This means the knowledge the grower has accumulated about these components remains relevant and useful.

The architectural principles underpinning the linkages between the components in sprinkler and drip irrigation systems are largely the same. Consequently, the majority of the grower's knowledge associated with the management of the sprinkler system will apply to the management of the drip system. Some experimentation may be required to adjust irrigation schedules that were designed for relatively high volume system to suit a low volume system. In short, most of the knowledge, competencies and skills the grower already possesses from operating spray irrigation remains useful and relatively little additional knowledge is needed to install and operate drip irrigation.

These considerations suggest that the adoption of drip irrigation is, at least in this instance, competency enhancing. Nieuwenhuis (2002) suggests that reading journals and talking to other growers would be sufficient for most growers to obtain straight-forward technical information. Hence, the role for extension may be limited to the provision of technical information on the new components and guidelines on irrigation scheduling (Rogers 1995; Czinkota et al. 2000).

Table 4 Incremental innovation – conversion from overhead sprinkler irrigation to drip irrigation

Overhead sprinkler irrigation		**Drip irrigation**	
Component	**Component Principle**	**Component**	**Component Principle**
Pump	A mechanism for compressing water		Unchanged
Valve	A mechanism to control the flow of water through a pipe		Unchanged
Timer	A mechanism to open or close valves at a pre-set time		Unchanged
Sprinklers	Water outlet that emits water at relatively high volume	Drippers	Water outlet that emits water at particularly low volume
Pipes	Round, sealed receptacle used to contain water		Unchanged
		Filter	Mechanism for removing impurities from water
Tensiometer	Mechanism for measuring water content of soil		Unchanged
Architecture	**Architectural Principle**	**Architecture**	**Architectural Principle**
Sprinkler irrigation	Irrigation system is a fixed structure		Unchanged
	Water moves through system from high to low pressure		Unchanged
	Irrigation scheduling based on satisfying physiological requirement of plants for water optimises plant growth and crop production		Unchanged

Modular Innovation

The replacement of a travelling irrigator with mini-sprinkler irrigation is an example of a modular innovation. A travelling irrigator has relatively high volume sprinklers mounted on a carriage that is pulled along a cable by hydraulic pressure, the traveller irrigates a crop as the carriage moves along the cable. Mini-sprinkler irrigation is a system with many low volume sprinklers that are attached to pipes which are fixed to vineyard trellises. Both are pressurised methods of irrigation. The key components, component principles and architectural principles for travelling irrigators are reported in Table 5. The components and component principles that are changed by the replacement with mini-sprinkler irrigation are also reported in the table.

Table 5 reveals that many of the components in the irrigation sub-system and the principles underpinning them, are changed. However, only one of the architectural principles of the sub-system is affected by the innovation. Hence, as a type of innovation, the conversion from travel irrigation to mini-sprinkler irrigation is modular.

The replacement of many of the components of the travelling irrigator with new components underpinned by different principles or core design concepts means that much of the knowledge accumulated by growers about the operation of travelling irrigation would not be relevant to the operation of mini-sprinkler irrigation. Hence, much of the component knowledge growers with travel irrigators possess would be obsolete. Consequently, the replacement of travel irrigation with mini-sprinkler irrigation is competence destroying.

In short, modular innovations require new component knowledge and may make existing competencies obsolete (Tushman and Anderson 1986; Kaine and Higson 2006). These considerations suggest that the adoption of mini-sprinkler irrigation would, at least in this instance, require learning a relatively large body of technical knowledge. Furthermore, the process of replacing travelling irrigators with mini-sprinklers may involve some degree of problem solving and planning to fit the particular circumstances of growers, and experimentation with irrigation scheduling. This suggests that some experiential learning may be involved (Nieuwenhuis 2002).

Hence, the role for extension may be to provide technical information on the new components and guidelines on irrigation scheduling, support for experiential learning and experimentation through farm demonstrations, and maybe support for business and development planning possibly through formal training (Kilpatrick and Johns 2003). Hence, a mix of printed information and personally conveyed information using formal or informal, group or individual processes may be appropriate (Rogers 1995; Czinkota et al. 2000; Shields et al. 2003).

Architectural Innovation

The adoption of Reduced Deficit Irrigation (RDI) is an example of an architectural innovation. Conventional irrigation is based on the principle of meeting any shortfall between the water available to plants from the soil and their requirements for growth, as any shortfall will create physiological stress in plants and reduce plant growth (Goodwin 2000). RDI is based on the principle that limited water stress induces a hormonal response in plants that results in an increased yield (Goodwin 2000). Hence, RDI involves under-watering compared to standard irrigation practice and its adoption entails changing the principles that underpin the timing and duration of irrigations. RDI may be employed with all types of irrigation sub-systems and does not require any change to the components of irrigation sub-systems.

In Table 6 the key components, component principles and architectural principles for mini-sprinkler irrigation are reported together with the architectural principles that are changed by the adoption of RDI. Table 6 reveals that only the architectural principles of the sub-system are affected by the innovation. In other words, adopting RDI does not involve changing the irrigation sub-system as such, it involves changing the way the irrigation sub-system is managed. Hence, as a type of innovation, the adoption of RDI is architectural.

Table 5 Modular innovation – conversion from travelling irrigator to mini-sprinkler irrigation

Travelling irrigator		Mini-sprinkler irrigation	
Component	**Component Principles**	**Component**	**Component Principles**
Pump	A mechanism for compressing water		Unchanged
Valve	A mechanism to control the flow of water through a pipe		Unchanged
Timer	A mechanism to open or close valves at a pre-set time		Unchanged
Sprinklers	Water outlet that emits water at relatively high volume	Mini-sprinklers	Water outlet that emits water at relatively low volume
Carriage	Travelling structure with wheels and a rotating pipe		Not required
Hose	Flexible, round, sealed receptacle used to contain water that attaches to carriage	Pipes	Fixed, round, sealed receptacle used to contain water
Cable	A strong wire rope that guides the carriage		Not required
		Filter	Mechanism for removing impurities from water
Tensiometer	Mechanism for measuring water content of soil		Unchanged
Architecture	**Architectural Principles**	**Architecture**	**Architectural Principles**
Mobile sprinkler irrigation	Irrigation system is a moveable structure	Fixed sprinkler irrigation	Irrigation system is a fixed structure
	Water moves through system from high to low pressure		Unchanged
	Irrigation scheduling based on satisfying physiological requirement of plants for water optimises plant growth and crop production		Unchanged

Architectural innovations such as RDI can appear misleadingly simple to adopt because the differences between them and the practices they supersede can be subtle. Yet they can create unexpectedly disruptive consequences (Henderson and Clark 1990). The adoption of RDI illustrates this proposition. A comparison of Tables 5 and 6 reveals that, at first glance, the extent of change associated with the adoption of a modular innovation is greater than for the adoption of an architectural innovation. However, the differences in the tables are deceptive. The replacement of travelling irrigators with mini-sprinklers involves learning new technical knowledge, experimentation with irrigation scheduling and some degree of planning and problem solving. The adoption of RDI involves all this and much more.

The adoption of RDI requires learning and applying new knowledge in relation to:

- the response of vines to water stress
- the growth cycle of vines and stages of berry development through the season
- the water requirements of vines water through the season
- experimenting with the timing and rate of application of irrigations
- changing exposure to climatic risk.

This knowledge challenges and may even supersede long-held beliefs about best practice in irrigation management and associated competencies. This means that to adopt RDI, the grower may have to acquire new analytical, evaluation and monitoring skills in order to accurately assess the state of their soil and vines, draw appropriate conclusions about the need for management intervention and make appropriate decisions about when and how much to irrigate.

This suggests that the adoption of RDI may entail considerable problem solving and experiential learning as well as learning new technical information (Nieuwenhuis 2002; Shields et al. 2003). Hence, the adoption of RDI is competence destroying and therefore requires learning and practising new skills and competences.

Hence, the role for extension may be to provide technical information on principles of RDI and guidelines on irrigation scheduling, support for acquisition of analytical, evaluative and monitoring skills, and support for experiential learning and experimentation (Rogers 1995; Czinkota et al. 2000; Nieuwenhuis 2002). This may involve growers attending courses and demonstrations, visiting other growers and employing agronomic consultants. Hence, a mix of printed information and personally conveyed information using formal or informal, group or individual processes may be appropriate (Rogers 1995; Czinkota et al. 2000; Shields et al. 2003).

The adoption of RDI irrigation also highlights that architectural innovations can have profound implications for the operation of other farm-sub-systems. The higher degree of stress placed on vines may increase the susceptibility of vines to pests, requiring changes in pest and disease management. In addition, the adoption of RDI also requires growers have the capacity to source and deliver irrigation water quickly to vines in response to unexpectedly high temperatures. This may require additional investments in plant and infrastructure to ensure reliable water supplies.

These considerations increase the likelihood that producers may need to make a substantial investment in anticipating and evaluating the benefits and costs of architectural innovations, and planning their implementation. This reinforces the conclusion that the adoption of RDI is likely to entail considerable problem solving and experiential learning as well as learning new technical information.

Radical Innovation

Conversion from furrow irrigation to mini-sprinkler irrigation is an example of a radical innovation. Furrow irrigation involves the watering of plants using a series of narrow channels dug into soil to distribute water. Differences in the elevation of the furrows enable water to flow through the channels under the influence of gravity. Mini-sprinkler irrigation is a system with many low volume sprinklers that are attached to pipes which are fixed to vineyard trellises.

Table 6 Architectural innovation – adoption of Reduced Deficit Irrigation (RDI)

Conventional irrigation with mini-sprinklers		Reduced Deficit Irrigation with mini-sprinklers	
Component	**Component Principles**	**Component**	**Component Principles**
Pump	A mechanism for compressing water		Unchanged
Valve	A mechanism to control the flow of water through a pipe		Unchanged
Timer	A mechanism to open or close valves at a pre-set time		Unchanged
Mini-sprinklers	Water outlet that emits water at relatively low volume		Unchanged
Pipes	Fixed, round, sealed receptacle used to contain water		Unchanged
Filter	Mechanism for removing impurities from water		Unchanged
Tensiometer	Mechanism for measuring water content of soil		Unchanged
Architecture	**Architectural Principles**	**Architecture**	**Architectural Principles**
Conventional irrigation	Irrigation system is a fixed structure	Reduced deficit irrigation	Unchanged
	Water moves through system from high to low pressure		Unchanged
	Irrigation scheduling based on satisfying physiological requirement of plants for water optimises plant growth and crop production		By limiting water during specific stages of crop development the physiological processes of the vine can be influenced to modify crop characteristics

A pump creates pressure and the difference in water pressure between the pump and the sprinklers forces water to flow through the pipes. The key components, component principles and architectural principles for furrow and mini-sprinkler irrigation are reported in Table 7.

Table 7 reveals that many of the components in the irrigation sub-system and the principles underpinning them are changed. In addition, the architectural principles of the sub-system are also changed. Hence, as a type of innovation, the conversion from furrow to mini-sprinkler irrigation is radical.

The replacement of all of the components of furrow irrigation with new components underpinned by different principles or core design concepts means that much of the knowledge accumulated by growers about the operation of furrow irrigation would not be relevant to the operation of mini-sprinkler irrigation. Hence, much of the component knowledge growers with furrow irrigation possess regarding irrigation layout, laser grading and the timing and duration of irrigations would be obsolescent. Consequently, the replacement of furrow irrigation with mini-sprinkler irrigation is competence destroying. Growers must acquire new skills in the operation, service and repair of pumps, valves, pipes and mini-sprinklers.

The changes in architectural principles may require growers to understand the consequences of differences in wetting patterns and flow rates and to learn new skills in the frequency and duration of irrigation. This may entail the acquisition of new skills in monitoring, evaluation and analysis in order to accurately assess the state of their soil and vines, draw appropriate conclusions about the need for management intervention and make appropriate decisions about irrigation scheduling. Furthermore, the process of replacing furrow irrigation with mini-sprinklers may involve some degree of problem solving and planning to fit the particular circumstances of growers. These changes may require new management procedures, the replacement of old equipment and the establishment of new relationships with suppliers (Abernathy and Clark 1985).

Table 7 Radical innovation – conversion from furrow irrigation to mini-sprinkler irrigation

Furrow irrigation		**Mini-sprinkler irrigation**	
Component	**Component Principles**	**Component**	**Component Principles**
Gate	Mechanism for releasing water into channel		
Furrow	Narrow channel in soil for directing water		
Siphon	Mechanism for directing water into furrows from channel		
		Pump	A mechanism for compressing water
		Valve	A mechanism to control the flow of water through a pipe
		Timer	A mechanism to open or close valves at a pre-set time
		Mini-sprinklers	Water outlet that emits water at relatively low volume
		Pipes	Round, sealed receptacle used to contain and transport water
		Filter	Mechanism for removing impurities from water
Spade	Mechanism for subjectively assessing water content of soil	Tensiometer	Mechanism for measuring water content of soil
Architecture	**Architectural Principles**	**Architecture**	**Architectural Principles**
Gravity irrigation	Irrigation system is a fixed structure	Pressurised irrigation	Irrigation system is a fixed structure
	Under the influence of gravity water moves through system from high to low elevation		Water moves through system from high to low pressure
	Irrigation scheduling based on satisfying physiological requirement of plants for water optimises plant growth and crop production		

In short, the conversion from furrow irrigation to mini-sprinkler irrigation is likely to entail considerable problem solving and experiential learning as well as learning new technical information (Nieuwenhuis 2002; Shields et al. 2003). Hence, the role for extension may be to include the provision of technical information on principles of mini-sprinkler irrigation, the provision of information on maintenance and management, guidelines on irrigation scheduling, support for acquisition of analytical, evaluative and monitoring skills, and support for experiential learning and experimentation (Rogers 1995; Czinkota et al. 2000; Nieuwenhuis 2002).

Assistance in planning and installation may also be required. This may involve growers in attending courses and demonstrations, visiting other growers and employing agronomic consultants. Hence, a mix of printed information and personally conveyed information using formal and informal, group and individual processes may be appropriate (Rogers 1995; Czinkota et al. 2000; Shields et al. 2003).

The conversion to mini-sprinklers may also have profound implications for the operation of other farm sub-systems. With furrow irrigation, a relatively high proportion of the vineyard floor is watered. This restricts the potential to carry out other activities in the vineyard during irrigation. Furthermore, furrow irrigation requires relatively constant monitoring to ensure appropriate rate of flow is achieved along the furrow. In contrast, with mini-sprinklers a relatively low proportion of the vineyard floor is watered. Also, relatively little time is required monitoring mini-sprinkler irrigation. Consequently, the conversion from furrow to mini-sprinkler means that other activities such as inter-row management, pest and disease management and harvesting can be undertaken while irrigating. Also, the labour effort involved in irrigating is substantially reduced.

In short, as an example of radical innovation, the conversion from furrow to mini-sprinkler irrigation can have profound implications for the operation of other farm-sub-systems. This suggests that substantial effort may need to be invested in anticipating and evaluating the benefits and costs of radical innovations, and planning their implementation. This reinforces the conclusion that the conversion from furrow irrigation to mini-sprinkler irrigation is likely to entail considerable problem solving and experiential learning as well as learning new technical information.

Discussion

The classification of agricultural innovations according to extent of innovation in the components and architecture of farm sub-systems seems consistent with concepts in diffusion theory like relative advantage, complexity, trialability and observability. ‘Complexity’ concerns the degree of effort needed to understand and use an innovation (Rogers 1995). The more complex an innovation is, the more difficult will be the tasks of understanding their underpinning principles, implementing them and anticipating the consequences of adopting them. Hence, more complex innovations place greater demands on the learning and implementation skills of decision-makers (Rogers 1995). Given this characterisation of complexity, it seems reasonable to propose that incremental, modular, architectural and radical innovations are progressively more complex kinds of innovations. This suggests that the rate of diffusion would tend to be fastest for incremental innovations, slower for modular and architectural innovation, and slowest for radical innovations.

‘Observability’ is the ease with which the results of the innovation can be seen and evaluated, while ‘trialability’ is the degree to which an innovation can be tested or sampled before being fully adopted (Rogers 1995; Pannell et al. 2006). Given these definitions, we expect that incremental and modular innovations to farm sub-systems are likely to be easier to trial and the results easier to observe, than would be the case with architectural and radical innovations to farm sub-systems. Hence, the classification of innovations to farm sub-systems presented here may assist investors in research and extension to make assessments about the likely rate of adoption of innovations, as well as the kinds of extension activities that would accelerate adoption.

These considerations suggest that the classification of innovations presented here complements diffusion theory and that this proposition could be empirically tested using appropriate measurement scales.

The approach taken here to classifying agricultural innovations also seems consistent with farming systems research. Farming systems research treats agricultural enterprises as managed systems that consist of hierarchical networks of complicated, interdependent sub-systems that are open to biophysical, economic and social influences (Norman 1980; Ruthenberg 1980; Byerlee et al. 1982; Norman 2002). The objective of farming systems research is to find solutions to critical constraints within farm sub-systems that limit the operation of farm systems as a whole (Ruthenberg 1980; Byerlee et al. 1982; Norman 2002). These solutions often take the form of innovations in technology or management practices. Hence, the approach taken here of interpreting agricultural innovations as a type of innovation in the sub-systems of farms is entirely consistent with farming systems research.

The innovations that emerge from farming systems research are expected to diffuse among the population of agricultural enterprises with the appropriate type of farm system because the innovations are designed to integrate precisely with that type of farm system (Byerlee et al. 1982; Dorward et al. 2003; Kobrich and Khan 2003). Consequently, the approach taken here complements farming systems research, in that it provides a framework for assessing the relative rate at which innovations that are the product of farming systems research may diffuse through the relevant population of farm enterprises. The framework also provides insights into the kinds of extension activities that may be necessary to support that diffusion.

The approach taken here to classifying agricultural innovations complements participatory approaches to agricultural research and extension. Participatory approaches to research and extension lack systematic methods for promoting the dissemination of innovations on a broad scale (Douthwaite et al. 2002; Dorward et al. 2003). Hence, the approach presented here to classifying innovations into different types complements participatory research and extension programs by providing a means for identifying the kinds of extension activities that may be necessary to promote the dissemination of innovations through the wider population of producers.

The approach taken here to classifying agricultural innovations also complements the concept of farm context proposed by Kaine (2004). Kaine (2004) and others (Rogers 1995; Roling 1996; Pannell et al. 2006) propose that agricultural innovations will only be adopted if they create net benefits for producers, that is, they will only be adopted if they offer a relative advantage (Rogers 1995). Kaine (2004) draws on faming systems theory to suggest a method for identifying those producers for whom an innovation has the potential to create a net benefit. These producers represent the market for an innovation and this market can be classified into segments based on differences in their farm systems that influence the kinds of benefits to be had from an innovation. The identification of benefit segments provides a basis for designing extension messages to communicate the benefits of an innovation to producers. These messages provide the basis for producers to self-select in seeking information on innovations and choosing to attend extension activities. Hence, the approach presented here to classifying innovations into different types, by providing a means for identifying the kinds of extension activities that may be necessary to support the adoption of agricultural innovations, complements the identification of benefit segments.

The distinction Henderson and Clark (1990) have made between changes in the components of a system and changes in the architecture of a system appears to provide a method for classifying innovations that discriminates between the critical qualitative differences in the learning that is required to adopt them. This raises the possibility that their approach to classifying innovations may be used by extension professionals and policy makers to make decisions more systematically about the incorporation of different extension methods into the design of extension programs.

For example, Henderson and Clark (1990) suggest that architectural and radical innovations have greater disruptive effects on organisational systems than incremental and modular innovations. The corollary here is that architectural and radical innovations have greater disruptive effects on other farm sub-systems than incremental and modular innovations. The results of the applications presented here support this proposition. This suggests that, even though architectural innovations can have profound impacts on the operation of farm systems, they can appear deceptively simple to disseminate. Consequently, investors in research and extension may find extension programs intended to promote architectural innovations may produce unexpectedly disappointing results. On the other hand, if similar results were produced by a program promoting the adoption of a radical innovation, that program may well be regarded as a model of success. Hence, distinguishing between different types of innovations is fundamental important to making accurate assessments of the performance of extension programs.

We have argued that different kinds of extension activities suit the promotion of different types of innovations. An important consequence of this argument is that similar programs should not be employed to promote different types of innovations. This suggests that great care should be taken in using apparently successful extension programs as models for the design of programs to promote the adoption of other innovations. Similarly, great care should be taken in designing a single extension program to promote a variety of innovations.

Finally, we have focussed on applying Henderson and Clark's (1990) approach to classifying innovations in agricultural technologies and practices. In principle this approach could be extended to any change in farm sub-systems. This raises the possibility that other interventions in farm systems, such as the regulation of farm activities by government policy and legislation, could be classified in a similar fashion thereby providing insights into the degree of disruption such changes may introduce into farm systems. Such insights could be used to guide the design of extension programs aimed at supporting compliance by producers.

Conclusion

Applying the framework developed by Henderson and Clark (1990) to the agricultural innovations appears to provide insights into the kinds of information and knowledge that producers may require to successfully incorporate different types of innovations into their farm systems. As a consequence, the framework offers the promise of a systematic method for identifying the kinds of extension activities that might be necessary to promote the adoption of different types of innovations. Such a method would assist investors in research and extension to formulate expectations about the rate of diffusion of innovations in a more methodical manner, and would allow them to make decisions about investing in extension programs and activities in a more logical manner.

We have argued the use of the framework developed by Henderson and Clark (1990) is consistent with current thinking in extension including farming systems theory and research, diffusion theory, benefit segmentation and participatory approaches. As a consequence this framework provides insights that complement those obtained from these theories and approaches.

In principle, the framework could be extended beyond the adoption of agricultural innovations to classify other interventions in farm systems, such as regulatory interventions. This would offer insights into the selection of extension activities to support compliance programs.

Future work will be directed towards testing the proposed relationships between the different type of innovation and the knowledge and skills required for their adoption. For example, a series of case studies may be used to explore how producers have acquired component and architectural knowledge when adopting innovations and to determine if different extension processes were required for each.

The proposed relationship between the different types of innovations and the complexity, observability and trialability of innovations may also be explored in future work. Differences in the rate of diffusion of each type of innovation could also be investigated.

Finally, the application of the framework to compliance issues in agriculture could be explored in the future.

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